# STUDIES ON FRACTURAL BEHAVIOUR OF GLASS FIBER REINFORCED CONCRETE WITH RECYCLED AGGREGATES

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

**DOCTOR OF PHILOSOPHY**

**in**

**Civil Engineering**


**By**

**Anshul Garg**

**41600329**

**Supervised By**

**Dr. Pushpendra Kumar Sharma**


**LOVELY PROFESSIONAL UNIVERSITY**

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# DECLARATION

"I, Anshul Garg, hereby state that the proposal of this research is submitted in accomplishment of the requirements for the award of Doctor of Philosophy, in the School of Civil Engineering, Lovely Professional University, Punjab, is entirely my own work excluding the part which is referenced or accredited".

**Anshul Garg**

**41600329**

**October 2021**

# CERTIFICATE

"I certify that **Mr. Anshul Garg** bearing Registration Number **41600329** has prepared his thesis entitled **"Studies on Fractural Behaviour of Glass Fiber Reinforced Concrete with Recycled Aggregates"** for the honour of Ph.D in Civil Engineering, doctoral degree of Lovely Professional University**,** under my supervision. He has conceded out the work at the School of Civil Engineering, Lovely Professional University. This thesis report has never ever been submitted earlier in any institution. So this is the first time work ever".

## Dr. Pushpendra Kumar Sharma

Professor,

School of Civil Engineering,

Lovely Professional University, Phagwara, Punjab, India

Date: 29/10/2021

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PHAGWARA ANSHUL GARG

REGISTRATION No.41600329

***Dedicated***

***To***

**Almighty GOD**

**&**

My Beloved Father

**Late Shri Rameshwar Prasad Garg**

# ABS-TRACT

Fiber reinforcement of glass material polymer has develop into an unconventional strengthening in existing structure owing to its admirable rust conflict, resulting it promising to come together amid concrete poised of salt water and marine sand. It had been found that practice of glass filament increase potency of concrete and resistivity of material towards acid and alkali.

Further, global investigations has revealed that there survive clear differences among properties ("porosity, water absorption, low surface density, higher crushing value") of "recycled coarse aggregates (RCA)" and "natural coarse aggregates (NCA)". "According to the definite routine necessities of concrete, choosing suitable unprocessed materials and then designing the most financial, high-class concrete based on the appropriate mix fraction methods, is the best way to conquer the shortcomings of the predictable design methods, and this puts forward new opinions and design method".

This study is therefore based on usage of glass fibers with fractional replacement of standard aggregates with recycled aggregates and finding out the optimum mix.

Dissimilar percentages of glass fibers and second hand aggregates had been used in design mix concrete. The compressive strength, flexural strength and split tensile strength had been checked by casting cubes, beams and cylinders. Fracture toughness study had been performed on parameters "stress intensity factor (Kic) and crack tip opening displacement (CTOD)" by varying the fibre content for different percentages of recycled aggregates. The research work included replacement of recycle aggregates with five different mixes of concrete as 40,60,70,80 & 100% and in each five mixes the addition of S2 glass fibre with 0.25%-1% by its weight with an augmentation of 0.25% had been done. 3 point bending test on notched beams were conducted for fortitude of fracture toughness. The tests were performed as per the guidelines of "Bureau of Indian Standards" and "International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM)". This study gives an idea about optimum percentage of recycle aggregates and S2 glass fibre that could be used in concrete for different structural applications. The compressive strength of mix CR80G0.75 found to be 0.15% more than the normal concrete. The flexural strength and split tensile strength of CR70G0.75 mix had been found to be 0.74% and 0.5% respectively less than normal concrete which was very much near to the normal concrete. The fracture study depicted the behaviour of mix CR60G0.75 to be having 31.44% and 31.03% increased in critical stress intensity and crack tip opening displacement respectively as compared to normal concrete. Cost optimization performed on mixes CR0G0, CR60G0.75, CR60G0.5 and CR80G0.75 showed that there was an increase of 19.95 % in cost on using CR60G0.75 where as on using CR60G0.5 the cost increment was 12.04 % only and hence mix CR60G0.5 could be used instead of CR60G0.75. On checking chloride penetration of concrete it was found that the chloride penetration increased on increase of recycled aggregates and glass fibre but comes in moderate range which was acceptable. The XRD, SEM, EDS and FTIR analysis performed on normal concrete and optimized mixes CR60G0.5 and CR80G0.75 showed higher strength, elasticity, composite behaviour and corrosion resistivity of optimum mix concretes. Verification of experimental behavior carried out by finite element simulation using ANSYS workbench software depicted the possibility of employment of the optimum mix CR60G0.5 for flexural members where as optimum mix CR80G0.75 could be use for compression members.

**Keywords:** Glass Fiber, Recycled Aggregates, Critical Stress Intensity, Crack Tip Opening Displacement, XRD, SEM, ANSYS.

# TERMINOLOGY

| | |
|---|---|
| % | Percentage |
| 2θ | Angle between incident beam and scattered beam of X-Ray |
| a | Original crack size (mm) |
| $a_0$ | Initial crack length ( mm) |
| AR | Alkali Resistant |
| ASTM | American Society for Testing and Materials |
| B | Specimen depth (mm) |
| BF | Basalt Fiber |
| CA | Coarse Aggregates |
| $Ca(CO_3)$ | Calcite |
| $CaMgV_2O_7$ | Calcium Magnesium Vanadium Oxide |
| CaO | Calcium Oxide |
| CC | Control Concrete |
| CFRC | Confined Fiber Reinforced Concrete |
| cm | Centimetre |
| CMOD | Crack Mouth Opening Displacement |
| C-S-H | Calcium Silicates |
| CT | Compact Tension |
| CTM | Compression Testing Machine |
| CTOA | Crack Tip opening Angle |
| CTOD | Crack Tip Opening Displacement |
| cum | Cubic Meter |
| d | Distance between atoms of crystals |
| d | Difference between ranks of CTOD and Kic in Spearman's Rank Correlation Coefficient Method |
| E | Young's modulus of elasticity (MPa) |
| $E_c$ | Modulus of Elasticity of concrete in compression |
| EDS | Energy Dispersive Spectroscopy |
| EPFM | Elastic Plastic Fracture Mechanics |
| FA | Fine Aggregates |

| | |
|---|---|
| $f_c$ | Compressive strength of concrete |
| $f_{ck}$ | Characteristic Strength of Concrete |
| FEM | Finite Element Method |
| FM | Fineness Modulus |
| FTIR | Fourier Transform Infrared |
| g/cc | Grams per cubic centimetre |
| GFRC | Glass Fiber Reinforced Concrete |
| GFRP | Glass fibre reinforced polymer |
| $gm/m^3$ | Gram per meter cube |
| HCl | Hydrochloric Acid |
| ICDD | International Center for Diffraction Data |
| JWES | Japan Welding Engineering Society |
| K | Stress Intensity |
| Kg | Kilogram |
| $Kg/m^3$ | Kilogram per cubic meter |
| Kic | Critical Stress Intensity |
| KN | Kilo Newton |
| KN/mm^2 | Kilo Newton per square millimetre |
| LEFM | Linear Elastic Fracture Mechanics |
| m | Meter |
| mA | Milli Ampere |
| mm | Millimetre |
| MPa | Mega Pascal |
| n | Number of samples for Correlation Coefficient Calculation |
| $N/mm^2$ | Newton per square millimetre |
| NA | Normal Aggregates |
| NaCl | Sodium Chloride |
| NaOH | Sodium Hydroxide |
| NCA | Natural Coarse Aggregate |
| OPC | Ordinary Portland Cement |
| P max | Peak load |
| PFRC | Polypropylene fibre reinforced concrete |

| | |
|---|---|
| Q | Length Parameter |
| r | Correlation Coefficient |
| RA | Recycled Aggregates |
| RAC | Recycled Aggregates Concrete |
| RC | Recycled Concrete |
| RCA | Recycled Coarse Aggregate |
| RCPT | Rapid Chloride Penetration Test |
| RHC | Recycled Hydrated Cement |
| RILEM | “International Union of Laboratories and Experts in Construction Materials, Systems and Structures” |
| Rs | Indian Rupees |
| Σ | Submission |
| $S_1$ | Stress corresponding to a longitudinal strain of 0.00005 |
| $S_2$ | Stress corresponding to 40% of ultimate load |
| SCC | Self Compacting Concrete |
| SEM | Scanned Electron Microscopy |
| SENB | Single Edge Notch Bend |
| $SiO_2$ | Silicon Oxide |
| SMA | Shape Memory Alloy |
| UPVT | Ultrasonic Pulse Velocity Test |
| UTM | Universal Testing Machine |
| V | Volt |
| W | Specimen width (mm) |
| $w_c$ | Unit weight of concrete |
| x | Variable 1 (CTOD) for Correlation Coefficient calculation |
| XRD | X-Ray Diffraction |
| y | Variable 2 (Kic) for Correlation Coefficient calculation |
| ʎ | Wave length of X-Ray |
| $ZnP_6N_{12}S$ | Zinc Phosphorus Nitride Sulphide |
| $\varepsilon_2$ | Longitudinal strain produced by stress $S_2$. |
| $\varepsilon_{t1}$ | Transverse strain at mid height of the specimen produced by stress $S_1$. |
| $\varepsilon_{t2}$ | Transverse strain at mid height of the specimen produced by stress $S_2$. |

| | |
|---|---|
| $\mu$ | Poisson Ratio |

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# CHAPTER 1 : INTRODUCTION

## 1.1 General

This chapter deals with introduction to the whole thesis emphasizing the problem addressed, need of research and challenges faced during research progress. The research work is dedicated on use of recycled aggregates in more amount which is basically a waste material and its more usage results in reduction of environmental depletion.

## 1.2 Thesis Background

Construction activities are increasing day by day as due to increasing population and need of more space to live, work and pray. The increasing need of construction has execrated the need of construction materials which are diminishing day by day. Reutilization of construction and demolition waste is one of the main objectives of many countries in recent years, which leads to the sustainable construction activities. "Alternative materials have been one of the main objectives of maximum researchers to be used in concrete as depicted from the detailed literature review which exhibits the existing condition of acquaintance and examples of flourishing uses of different materials in concrete technology, and a meticulous use of "Recycled Concrete (RC) aggregate" as a coarse aggregate in non-structural and structural concrete. Numerous researchers have dedicated their effort to depict the properties of these kinds of aggregate, the bare minimum requirements for their utilization in concrete and the properties of concretes made with recycle aggregates". It had been found that the use of recycled aggregates in concrete reduces the strength and workability and so the maximum percentage of use of recycled aggregates is concise to 50%. So there is an urgent need to find methods which can increase the use of recycled aggregates. Various materials have been compared that can increase the strength and are economical also. After a detailed research on behavior of various materials and their compatibility with concrete it had been found that Glass fibers are best suited combination. Earlier periodical studies depict that glass fibers are good component of concrete and convention of glass fibers increase in strength of concrete and other properties. Therefore, usage of glass fiber reinforced concrete with recycled aggregate could be a promising method to give optimum strength and economy. In this study mechanical strength like compressive strength, flexural strength, split tensile strength in addition to Fracture Behaviour Study have been compared of glass reinforced concrete with recycled aggregates. Microstructure studies have also been performed on optimum mixes along with software verification.

Fracture mechanics is an area of mechanics that addresses the need of crack propagation in materials. A crack might be nucleated in the machine components or structures which may begin to grow during its life span. For big, complicated structures such as bridges, boats, aircraft, the chance of cracking/flawing is greater [1]. When a current crack is present, fracture technicalities are used to determine the permissible stress which the substance can resist in order to avoid fracture on it. The need of fracture mechanics have became very essential in construction sector as it deals with design of elements. The hypothesis on fracture mechanics is that a crack exists in design elements. The crack like hole, notch, a slot, a corner can be manmade due to various deficiencies in work. "The conventions on the Linear Elastic Fracture Mechanics (LEFM) remain considered as the material to be isotropic plus linear elastic". If inelastic deformation occurs near the tip of the crack and the dimension of the plastic sector is exceptionally short compared to the dimension of the crack (tiny resilient), LEFM can also be implemented efficiently. "The stress turf nearby the crack tip is calculated by means of the theory of elasticity. If the stresses nearby the crack tip surpass the toughness of the material fracture, the crack increases. The toughness of fracture in LEFM is defined by factor of stress intensity (K)". The material has to be regard by "Elastic Plastic Fracture Mechanics (EPFM)" as isotropic and elastic-plastic deformation occurred during fatigue loading" [2]. "Elastic Plastic Fracture Mechanics (EPFM)" relates when big areas of the fabric are subjected to plastic deformation at almost the crack tip. The stress energy turfs or the opening displacement close the crack tip are calculated in EPFM and the shell is developed when the opening energy exceeds the critical value. "The fracture toughness in EPFM is characterized by J-integral suggested by Rice [92] or Crack Tip Opening Displacement (CTOD) recommended by Well" [93]. As one of the best important fields of science, fracture mechanics is used to evaluate material conduct in construction. The tension-softening curvature can be regarded as a basic concrete constraint. The curve reflects the material's post ultimate load ability [94]. The most important characteristics of concrete for evaluating fracture conduct are the tension-softening diagram shown in Figure **1**.**1**.

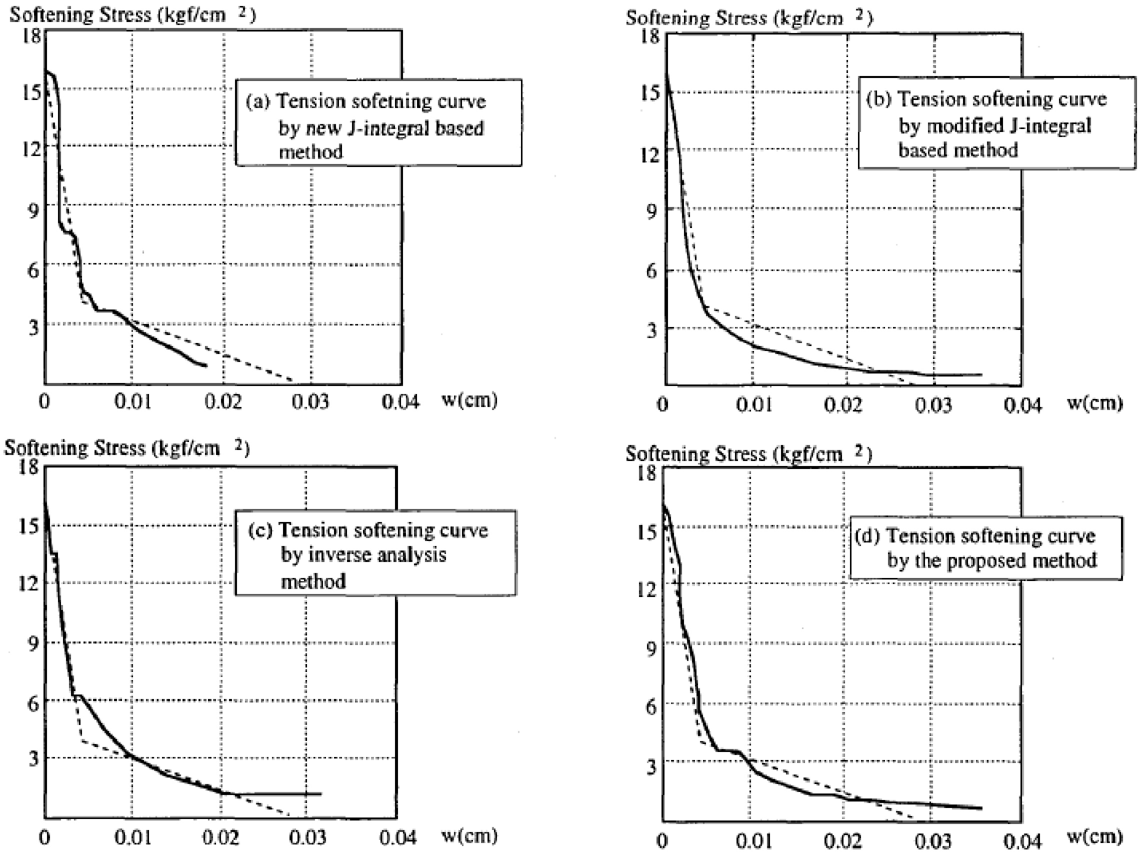



Figure 1.1 : Tension softening curve of normal concrete

(Source: Research paper reference [94])

Fracture energy is the factor of cohesive plant designs; it represents the cracking strength and the toughness of quasi-brittle plastics such as concrete. The models can capture the vital characteristics of a gradually fracturing apparent and its development up to the failure. The cohesive stress separation connection can fully characterize the energy dissipation for crack propagation. The selection of softening feature (or cohesive law) affects the structural reaction forecast and the behaviour of the local fracture. In the mathematical representations of multiple finite element programs for non-linear modelling, fracture energy had also been implemented [3].

Over current years, several countries are focusing on the recycling of construction and demolition waste as a latest building substance considering the use of it as one of the main goals over terms of sustainable building. Many researchers had committed their work to express the properties of recycled aggregates, the lowest amount requirements for their use in concrete [4]. Past studies also showed that glass fibers are strong concrete constituents and the use of glass fibers leads to an increase in concrete flexural strength. The S2 glass fiber is having maximum tensile strength among the other type of glass fibers. The use of S2 glass fiber in concrete with recycled aggregates could give better strength and efficiency.

### 1.3 Scope and Objective

Glass fiber and recycled aggregates are the two major constituents of this study. High-strength, alkali-resistance are some of the properties found in glass fibers which can be implanted in a concrete matrix. In this form, both fibers and matrix hang on to their physical and chemical identities, while offering a synergistic amalgamation of properties that cannot be achieved with either of the components acting alone.

One of the chief challenges of our current civilization is the fortification of environment. Some of the important attributes in this reverence are the reduction of the consumption of energy and natural raw materials resulting in utilization of waste materials. Recycled aggregates can be used as aggregates by partial replacement. The behaviour of these two materials are studied in the past but their combined effect on concrete has not been studied. Here an attempt have been made to check the strength, properties and fracture behaviour for combined use.

The objectives of this study are

1. To study the behaviour of fracture and cracks in beams under flexure on application of two point load using "critical stress intensity factor ($K_{ic}$) and critical crack tip opening displacement (CTOD)".
2. To verify the experimental results by modeling and analyzing using FEM simulations in ANSYS.

3. To analyze and design optimum mix based on results for different structural applications.

## 1.4 Chapter Outline

This thesis comprises of 6 (Six) Chapters, each has been written to fulfil the major objectives of research. The chapter contents are summarized in the paragraphs given below.

Chapter 2 consist a detailed study on the researches been done on the two main constituents glass fibre and recycled aggregates. The research has been listed in chronological order taking the latest findings first and a detailed summary has been prepared after analyzing the trends which are majorly visible.

Chapter 3 emphasises on the methodology being used in performing the detailed research setup and the various standards being used for performing the experiments under standard methodology with experimental investigation values obtained. It also comprises the software verification done on the optimum mixes obtained.

Chapter 4 consists of discussion of the results obtained in various experiments like mechanical strength, fracture behaviour study, cost analysis, Rapid Chloride penetration test and microstructure study.

Chapter 5 summarizes the whole study into certain points and concludes on the findings.

Chapter 6 includes future scope of study that means the further research that can be carried by other researchers.

# CHAPTER 2 : **LITERATURE REVIEW**

## 2.1 General

A detailed study on the previous researches done by various researchers all over the globe had been carried out. It had been found that using recycled aggregates result in decreasing the strength attributes and increasing the water absorption and carbonation. On the contrary better results like strength and credibility had been found on using "glass fibers" in concrete. Possibility of applicability of more "recycled aggregates in concrete" could be achieved by using "glass fibers" in concrete.

## 2.2 Literature review on mechanical properties of glass fiber reinforced concrete and recycled aggregate concrete

Glass fiber had been found as a material that exhibits benefits by increasing "flexural strength of concrete" where as recycled aggregate as a constituent could be used again in concrete and it had been verified by various researchers. Demolished concrete now-a-days is having great impact on environmental depletion which can be reduced by using recycled aggregates in concrete. The research works done by various researchers on "glass fiber reinforced concrete and recycled aggregate concrete" have been described in sequential ascending order like Junji Takagi et al., in 1974 did a remarkable job by investigating the effect of randomly oriented glass fibres on the "flexural strength, compressive strength, splitting tensile strength, and Young's modulus of concrete", and on the experimental data obtained concluded that on increasing the fiber content results beneficial to concrete as it gives more strength [5]. Thereafter in 1996 C. Vipulanandan et al., varied the polymer amount till 18% and checked the flexural behaviour of polyester polymer concrete where the fiber content was 6% by weight of Polymer Concrete. Generally on addition of fibers it has been found that there is an increase in the "flexural strength, failure strain (strain at peak stress), and fracture properties", but during the study done by C. Vipulanandan, flexural modulus of Polymer Concrete was found to be remained almost unchanged. It was found that on adding six percent by weight fiber content and doing saline treatment of aggregates and fibers increases the "flexural strength" of Polymer

Concrete to 41.6 MPa, which is almost double the strength of unreinforced 18% Polymer Concrete [6]. In year 2000, Limbachiya M. C checked the behaviour of recycled aggregates on concrete by partially replacing with natural coarse aggregates and found that on using 30% of recycled aggregates no change in concrete strength was found but on further increase in percentage of recycled aggregates the strength of concrete reduces [7]. In year 2001, a campaign was held at "Federal University of Rio Grande do Sul, Brazil by Leite" where "recycled aggregates" were used in the production of concrete. Coarse, fine ceramic and recycled concrete were used with several replacement percentages of RA was tested for various water-cement ratios 0.4, 0.45, 0.60, 0.75, and 0.80, and it had been found that a high percentage of fine RA reduces "compressive strength, splitting and flexural tensile strength and modulus of elasticity" [8]. Further in year 2001 S.H. Alsayed, et al., moved a step ahead by studying the exaggerated behaviour of "glass fiber reinforced plastic bars" using as reinforcing substance for concrete structures and found that GFRP bars are having low modulus of elasticity and may control deflection in long beams reinforced with GFRP bars [9]. In year 2002 Chini A. R. et at., tested use of recycled aggregates in pavement and found that using of 100% recycled aggregates gives fair compressive strength but less flexural and split tensile strength [10]. Then in 2002, F. Buyle-Bodin et al., studied water absorption, air permeability and carbonation of recycled aggregate concrete by using both "coarse and fine recycled aggregates" and found that "water absorption is more while using recycled aggregates. The carbonation rate of recycled aggregate concrete is also higher which leads to a weaker resistance of recycled aggregate concrete to environmental attacks" [11]. Further in year 2002 L. Azzouz et al., compared mechanical properties of concrete with 100% of natural aggregates where recycled concrete aggregates were partially replaced with 0, 25, 50, 75 and 100% of "natural aggregates". Results showed that "it is possible to manufacture a concrete with maximum of 50% recycled aggregates and the strength thereafter reduces" [12]. A research campaign was done at the "Israel Institute of Technology by Katz", in 2003, where "recycled aggregate" was researched in a new and innovative idea by producing it in the laboratory by devastating concrete specimens of 1, 3 and 28 days aged. Replacement of natural aggregate is done by recycled aggregates of various sizes. Fine RCA had been applied in smaller amount to improve workability. “The hardened concrete was tested for compressive strength, splitting and flexural tensile strength, modulus of elasticity, water absorption, carbonation penetration and shrinkage”. The properties of the RCA with nearly 100% of aggregate replacement, were tested. “Various particle size group showed significant differences between the properties of the recycled aggregates where as the crushing age had almost no effect. The properties of the concrete made with RA were inferior to those of concrete made with virgin aggregates. Concrete made with aggregates crushed at age 3 days exhibited better properties than those made with aggregates of the other crushing ages” [13]. K. Ramesh, et al., 2003, experimentally checked “the stress–strain behaviour of confined fiber reinforced concrete (CFRC) and tested nine prisms of size 150x150x300 mm under strain control rate of loading” and resulted increase in strength and strain of CFRC” [14]. The glass fiber was widely researched in further years like in 2004 J.M.L. Reis et al., discovered in their experiment an increase of 13 percent in fracture toughness of “glass fiber polymer concrete (GFPC)” in comparison of non-reinforced polymer concrete with epoxy [15]. In year 2004 Khatib J. M., researched on use of fine recycled aggregates of particle size less than 5 mm and used 25%, 50% and 100% instead of river sand and found reduction in strength of about 15% to 30% [16] as shown in Figure 2.1. The figure shows that on increasing the percentage of fine recycled aggregates in concrete the compressive strength reduces.

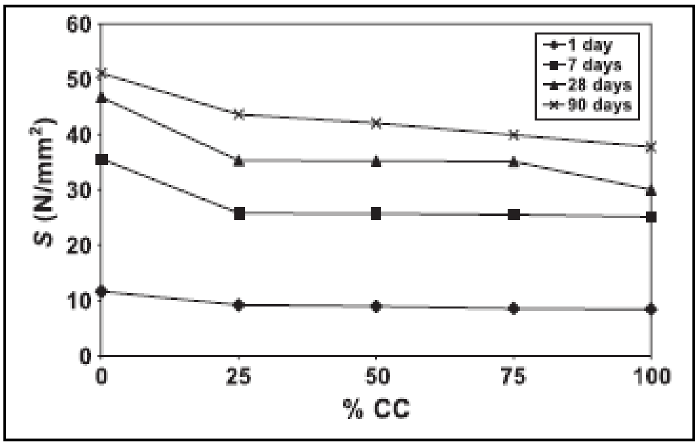



Figure 2.1 : Effect of fine recycled aggregate on compressive strength

“Steam curing method had been used for curing recycled aggregate concrete with fly ash using 0, 20%, 50% and 100% of recycled aggregates with 0.45 water-cement ratio and fly ash of 0%, 25% and 35% by weight replacements of cement" and was tested for "compressive strength, modulus of elasticity, chloride penetration and shrinkage" in Kou Shi C et al., research in 2004 and found decrease in strength of concrete on increase in content of recycled aggregate in concrete". It had been found that for incorporating higher percentages of recycled aggregate in concrete, fly ash between 25-35% can be used with steam curing [17]. Further research done by Poon C. S., in 2004 also exhibit the same scenario that the usage of recycled aggregates had been found optimum till 50% usage and workability reduces on using recycled aggregates in concrete [18]. Further Yeol Choi, et al., in 2005, found 20 percent to 50 percent increase in "split tensile strength" and 9 percent to 13 percent increase in "compressive strength" on using "glass fiber reinforced concrete (GFRC)" and "polypropylene fiber reinforced concrete (PFRC)" [19]. In year 2006, Saeed A. ant its team researched in detail on all major aspects of using recycled aggregates in concrete and pavement. The effect of environmental depletion had also been discussed in the report and had been summarized to use recycled aggregates but in limited amount in concrete [20]. Continuation to this in year 2007, G. Barluenga, et al., evaluated that on using around 600 $gm/m^3$ "Alkali Resistant (AR) glass fibers" in standard concrete and self compacting concrete (SCC) shows "the maximum crack control ability, but larger amounts then this did not increase the efficiency further" [21]. In the Cervantes et al., campaign, (2007) at the "University of Illinois, USA, the RCA families were defined in terms of the addition of synthetic fibers in the concrete production. Only the coarse fraction of natural aggregates was replaced with different ratios of recycled concrete (0, 50, and 100%) and with 0.2% of synthetic fibers. The effective w/c ratio remained constant at 0.51. The hardened concrete was tested for compressive strength, splitting tensile strength, modulus of elasticity and shrinkage". The test results reported that "use of 50% RCA with 0.2% synthetic fibers produced a pavement quality concrete with similar fracture and shrinkage properties to that of the virgin coarse aggregate concrete" [22]. M. Etxeberria in 2007 experimentally tested shear behaviour and strength of beams considering four concrete mixes with different percentages of recycled aggregates with partial replacement by 0 percent, 25 percent, 50 percent and 100 percent with different transverse reinforcement taking same "compressive strength" and found "a substitution of less than 25% of coarse aggregate, scarcely affects the shear capacity of RC beams" [23]. It was found out in year 2009 by Srinivasa Rao, et al., that "there was an increase in durability of concrete by testing "rapid chloride penetration test" on alkali resistant glass fiber reinforced concrete of M30, M40 and M50 grade and also compared with ordinary concrete. They also found reduction in bleeding and increase in acid resistance" [24]. During year 2009 A. Bordelon et al., studied "fracture behaviour of paving concrete made with recycled concrete as a coarse aggregate, virgin coarse aggregate, and a blend of recycled concrete and virgin coarse aggregate with Discrete structural fibres and observed that 50–50 blend of virgin and recycled concrete coarse aggregate produced similar fracture properties to VAC and both were 53% higher than the total fracture energy of the 100% RCA concrete" [25]. Experimental results were used to establish a relationship between some properties of hardened concrete ("compressive strength, splitting and flexural tensile strength, modulus of elasticity, abrasion resistance, shrinkage, water absorption, carbonation penetration and chloride penetration") and the "density and water absorption" of the aggregates by Jorge de Brito, et al., in 2010 and found "The use of concrete with recycled aggregates should always take into consideration that in most cases they perform worse than conventional concrete but that the variability of their properties are similar. Therefore, the decrease in the concrete with recycled aggregate performance in comparison to the conventional one can be anticipated with the knowledge of the substitution rate and of the aggregates properties" [26]. Kavita Kene, et al., in year 2012, conducted mechanical strength studies on "steel and glass Fiber Reinforced Concrete Composites. The steel fibers of 0% and 0.5% volume fraction were used and alkali resistant glass fibers were added to 0% and 0.25% by weight of cement using 12 mm cut length of glass fiber". It was found in this study that on adding "glass fibers results in increase of compressive strength, flexural strength and split tensile strength" [27]. Further year 2012 proved to be a major year on research of glass fibers in concrete and many researches were been done like Avinash Gornale, et al., reported that there is an increase in compressive strength, flexural strength, split tensile strength of glass fiber reinforced concrete for "M20, M30 and M40 grade of concrete" by 20% to 30%, 25% to 30% and 25% to 30% respectively [28]. Further in 2012 also researchers Muna M .Abdullah et al., reported that "mechanical properties of glass fiber reinforced concrete have more strength where they used fibrous glass of content 0, 600, 1000, and 1400 gm/m$^3$". They reported increase in the splitting tensile strength by approximately 1, 4.3, 12.5% respectively as shown in Figure 2.2 and increase in "compressive strength" of concrete by ratios 3.6, 7.1, 9.3% respectively and shown in Figure 2.3.

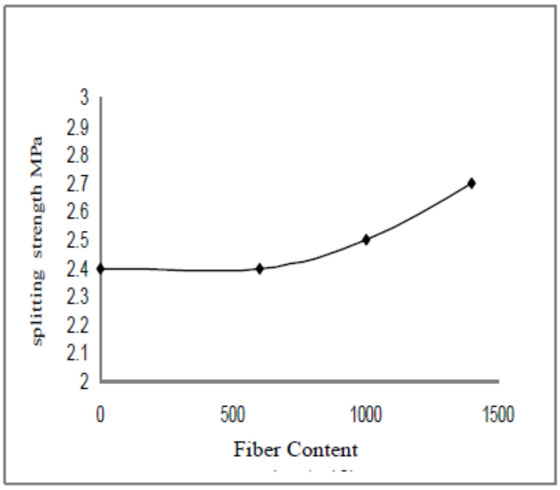



Figure 2.2 : Splitting tensile strength for concrete at different fiber content

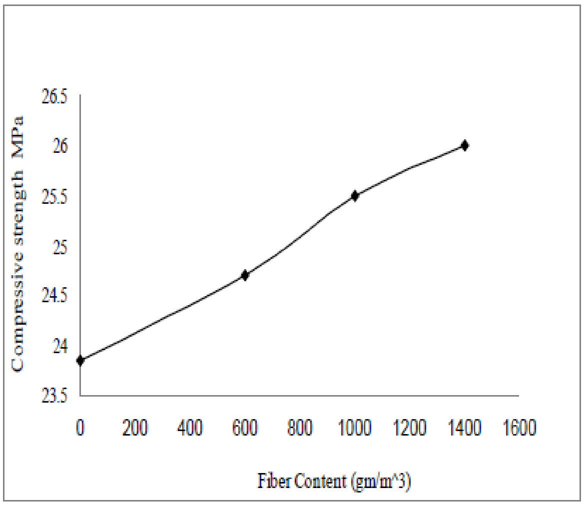



Figure 2.3 : Compressive strength for concrete at different fiber content

This study also focused on the increment of young's modulus by 9.7, 56.6, 84% respectively due to "use glass fibers in concrete" [29]. In the same year as well Yogesh Murthy, et al., when performed "flexural strength" test on "Glass fiber reinforced concrete beams" having 1.5% of glass fibers reported an increase of 30%

in “flexural strength” but found that slump got reduced on increment of fiber content [30]. Thereafter in year 2013, G. Jyothi Kumari, et al., instead of using “glass fiber” of small size, used polymer flats made up of “glass fiber” called “glass fiber reinforced polymer flats” which were silica coated which showed shear resistance and exhibit fairly better ductility [31]. It was further found by Tassew et al., in 2014, that a little effect on “compressive strength and modulus of elasticity” was found on using “glass fiber” between 0% and 2% by volume in ceramic concrete but discovered a significant increases in “flexural strength and direct shear strength”, regardless of the matrix type or fiber length, where as the “workability decreased with an increase in fiber content” [32]. The mechanical properties and fracture behaviour of glass reinforced concrete for different percentages of 0.25, 0.5, 0.75 and 1.0, found that fracture energy increased significantly after 0.25% dosage of glass reinforced concrete studied by Ahmet B. Kizilkanat et al., in 2015 [33]. In year 2015 Kutalmis Recep Akça et al., replaced normal aggregate with recycled aggregates and used polypropylene fiber 0%, 1% and 1.5% by volume and “Compressive strength, splitting tensile strength, flexural tensile strength, static and dynamic modulus of elasticity” experiments were conducted in order to determine mechanical performance of the concrete series. A remarkable increase in split tensile and flexural strength had been found on increment of fibre content [34]. In year 2016, Arslan M. E., studied the mechanical strength behaviour of concrete with glass fiber content of 0.5, 1, 2 and 3 Kg/m3 and reported no significant increase in compressive strength and young’s modulus of concrete but flexural strength and split tensile strength was found higher on usage of 1 Kg/m3 of glass fiber in concrete as shown in Figure 2.4 and Figure 2.5 which indicates on using of glass fiber on higher content to be not beneficial and a maximum limit of using glass fiber in concrete reported till 1% only [35].

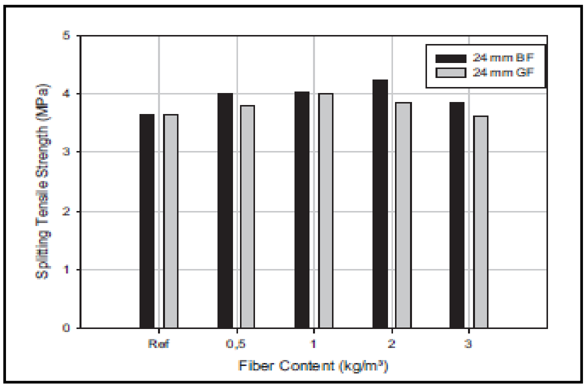



Figure 2.4 : Splitting tensile strength of the mixtures

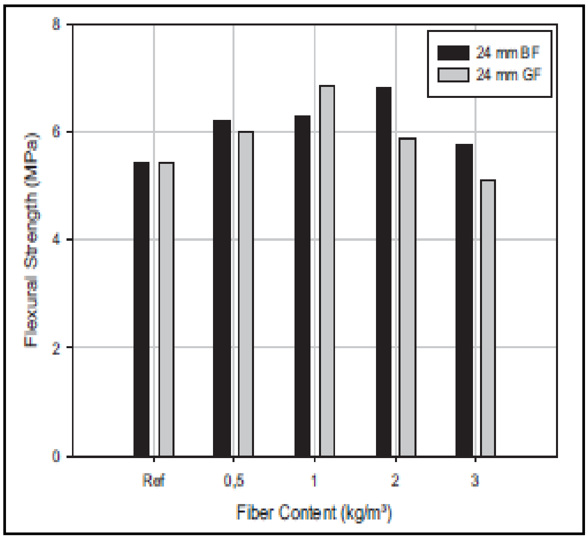



Figure 2.5 : Flexural strength of the mixtures

Rath B. et al., in 2017 researched by adding glass fibers with supplementary cementitious material coal ash to concrete where coal ash was used to reduce cement quantity. Scanned Electrode Microscope analysis (SEM) and Ultrasonic Pulse Velocity Test (UPVT) was performed and found that addition of glass fibres could be beneficial for concrete but can be expensive so use of fly ash can reduce the cost and help on obtaining a optimum mix [36]. There after Faisal Sheikh Khalid, et al., in 2017 studied on Mechanical Properties of Concrete Containing “Recycled Concrete Aggregate (RCA)” and “Ceramic Waste as Coarse Aggregate Replacement and used 25 percent, 35 percent, and 45 percent RCA and ceramic waste as coarse aggregate in producing concrete and reported that 35% RCA and 35% ceramic waste showed the best properties compared with the normal concrete” [37]. Mohsen Ahmadi, et al., also found the same by using waste tyres and recycled aggregates in concrete. Main results indicated that "by adding recycled fibers into the concrete with recycled aggregates lead to the production of structural concrete by 50% replacement of aggregates. Moreover on adding recycled fibers by 0.5 percent and 1 percent of concrete by volume reduces the thickness of concrete pavement for the amount of 8 percent and 16 percent, respectively" [38]. In year 2017 Ngoc Kien Bui researched on "properties of recycled aggregate concrete (RAC) by using sodium silicate and silica fume. The method proposed was applied to 100 percentage of coarse recycled concrete aggregate compared to untreated RAC had been able to improve compressive strength up to 33 - 50%, splitting tensile strength 33–41%, and elastic modulus 15.5–42.5%". From the experimental data, the compressive strength of the treated RAC could be estimated at any age [39] as shown in Figure 2.6.

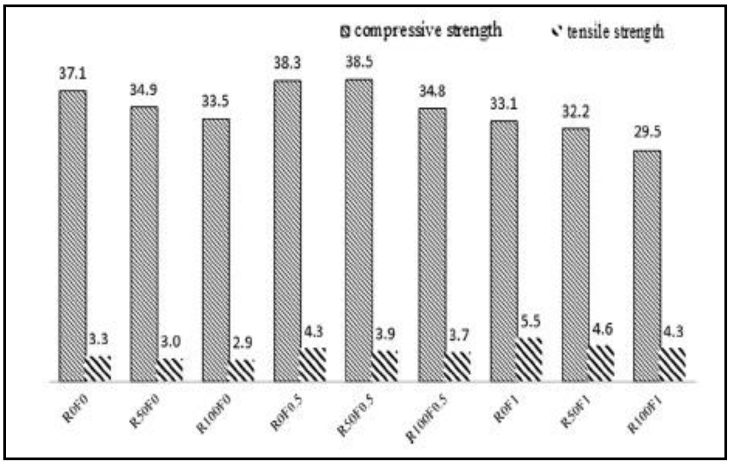



Figure 2.6 : Variation of compressive strength and tensile strength on addition of recycled aggregates and steel fibers to concrete

The paper by Hasan Katkhuda in 2017 presents the results of a study that investigated "the improvement of the mechanical properties of recycled concrete aggregate (RCA) produced by adding chopped basalt fibers (BF) with contents of 0.1%, 0.3%, 0.5%, 1%, and 1.5% by total volume of the mix to treated and untreated recycled aggregates". "The recycled aggregates were surface treated by pre-soaking them in a 0.1 M hydrochloric acid (HCl) solution for 24 hr. to remove the adhered mortars to improve the bond between the recycled aggregate and the cement. In addition, chopped BF was added to normal concrete (NA) mixes as a control for comparison. The results showed that using chopped BF minimally enhanced the compressive strength of the concrete mix but significantly improved its flexural and splitting tensile strength. Furthermore, the optimum BF content that produced the same splitting tensile and compressive strength as NA was 0.5% for untreated RCA and 0.3% for treated RCA, while the flexural strength was 0.3% for untreated RCA and 0.1% for treated RCA" [40]. A dynamic research done by Viviana Letelier et al., in 2017 focused on use of waste materials like recycled aggregates and recycled hydrated cement (RHC) shows an optimum mix by using 20% of RA and 5% of RHC [41]. Then in year 2018, Christiana Alexandridou et al., have conducted experimental study where concrete mixtures were prepared using partial replacement of natural aggregates with percentages of recycled aggregates ranging from 0 percent to 75 percent, results indicate that the "compressive strength of recycled concrete ranges from significantly lower (37% reduction) to equal, compared to conventional concrete, depending on the composition of recycled aggregate" [42]. Then in 2018 again G. Wardeh et al., studied experimental "behaviour of compressive strength and flexural strength on usage of recycled aggregate in concrete and found that compressive strength on introduction of recycled aggregates results in a decrease in elastic modulus and showed more cracks than conventional concrete members" [43]. As per article published in "IOP conference series by Kaiyun Wu et al.", stated the experimental study of "fracture behaviour of recycled aggregate concrete using 50%, 70% and 100% partially replacing normal aggregates and tested initial cracking load and fracture energy. In the experimental procedure and result prediction it was found that initial cracking load was high with normal aggregate concrete which is found less in case of recycled aggregate concrete. Further the same is depicted in fracture energy behaviour and was found a remarkable decrease of fracture energy using recycled aggregate concrete" [44]. In year 2018 Jianzhuang Xiao, Studied behaviour of Recycled Aggregate Concrete in comparison to partial replacement of Normal Aggregates, where 0, 30, 50, 70 and 100 percentage replacement of normal aggregates were done and checked compressive strength and found that compressive strength of recycled aggregate concrete (RAC) is lower than that of natural aggregate concrete (NAC) under the condition that water-cement ratios (w/c) are same [45]. As per the review paper written by Ali Akhtar et al., "collecting data from 40 countries it was found that till 2012 the construction and demolition waste generated per year is more than 3 billion and is increasing constantly. The various researchers studied in their review paper found that the use of 30% to 50% recycled aggregate was suggested to achieve the strength requirements which is not sufficient for developing countries India and China" [46]. Yijie Huang et al., compared mechanical properties of concrete with natural coarse aggregate, recycled coarse aggregate and coral coarse aggregate considering 50% and 100% recycled aggregate [47]. In the research done by B. Cantero, assessed "the performance of structural concretes containing 20%, 25%, 50%, 75% or 100% mixed recycled coarse aggregate, analysing fresh concrete workability, density and air content and hardened concrete compressive, flexural and splitting tensile strength. The decline in strength relative to conventional concrete was smaller at longer curing ages. Concretes bearing up to 50% recycled aggregate exhibited reduction in performance to 10% or under in most of the properties studied, even at late ages. In light of the present findings, the mixed recycled aggregates used in this research may be deemed apt for use in structural concrete with a characteristic strength of up to 30 MPa" [48]. George Dimitriou in year 2018 also stated that it is beneficial in using recycled aggregates to 50% [49]. F. Fiol in 2018 used "Recycled Aggregates (RA)" from structural precast elements substituting 20 percent, 50 percent and 100 percent of normal aggregates. "Three Control Concretes (CC-30, CC- 37.5, CC-45) manufactured with Natural Aggregates (NA), and their corresponding Recycled Aggregate Concretes (RAC-20, RAC-50, RAC-100) were evaluated in terms of physical and mechanical properties". The infresh properties results ("flowability, viscosity and passing ability") of the RAC were suitable for their use as SCC [50].

Furthermore, the tests of "compressive, splitting tensile and flexural strength, as well as density, porosity, water absorption, ultrasonic pulse velocity, stiffness, and both dynamic and static modulus" provided results close to those of the SCC with Fresh aggregates. R.V. Silva et al., in 2018 after reviewing 130 research papers majorly focusing on fresh properties of concrete, reported that "water absorption of recycled aggregates is much higher than normal aggregates and so use of admixtures can help to obtain workability" [51].

Further many researches had been done and all reported an increase in flexural and split tensile strength of concrete on using glass fibers [52]-[57].

To carry the literature review in detail review papers were written and published in various journals focusing on review of recycled aggregates, glass fibers, fracture study and flexural behaviour [58]-[61].

Therefore the studies done on glass fiber reinforced concrete had summarized that the use of glass fiber in concrete results in increase in flexural and split tensile strength and very less variation in “compressive strength of concrete” and so “glass fiber reinforced concrete” could be well functional in “flexural members”. As been already discussed in previous chapter that the major objective of this research focuses to use more amount of waste in concrete.

### 2.3 Literature review on Fracture Study Parameters

The major objective of the research in this thesis focused on fracture study of fiber reinforced concrete with recycled aggregates and so detailed research had been done on fracture study in concrete which has been listed in chronological order like in year 1981, Newman suggested the alternatives for a surface fracture in a finite plate subject to standardized strain by considering the stress-intensity factor. Different equations were developed for different ratios of crack length to plate thickness and crack depth to crack length were evaluated and found that for the ratios of crack depth to plate thickness less than 0.8, the equations obtained from finite element analysis were having results tolerance ±5% but for crack depth to plate thickness ratios of 0.8 and more the equations don’t give appropriate solutions which could be directly compared [62]. Thereafter in year 1984 Tanaka et al. researched fracture study and fatigue study on oxygen free high conductivity copper, very low carbon steel and stainless steel. “The relationship between crack propagation rate and J-integral range was obtained. The critical CTOD was defined as the opening of crack tip which was calculated at the original notch tip of the specimen utilizing the deliberated most extreme load and the critical, effective cracking length” [63]. In year 1991 S. P. Shah draft to RILEM on methodology to conduct three point bend test to determine fracture parameters Kic and CTOD [64] which was further published as RILEM-50 code [83]. Tracey in 2000, researched “the finite element operation of separating the cracked setup into triangular shaped singularity components around the crack tip with adjacent isoperimetric trapezoidal shaped components. Here the rigidity of the tip component was calculated by an accurate integration of the anticipated singular field, resulting in incompatibility on the boundary of the circular element by joining straight-edged triangular elements, stress intensity factors within 5 percentage of accepted values was obtained" [65]. Z. Jun in year 2003 researched on concrete beams with notch and applied three point bending test and found that fracture energy and tensile strength depends on higher amount and strength of coarse aggregates [66]. R. Ince in 2008 researched the two-parameter model fracture parameters that were evaluated using regression analysis. In the study different beams of various w/c ratios ranging 0.34-0.85 were tested under three-point bend test and was found that "fracture parameters of two-parameter model were inversely proportional to w/c ratios and the results agreed with Abram's Law" [67]. Thereafter in year 2012, X. K. Zhu et al. described "the foremost vital fracture constraints of the potential energy unharness rate G, the strain intensity factor K, the J-integral, the crack-tip displacement d and the crack-tip angle (CTOA) and conferred, primarily within the written account request, the important and progressive developments of those fracture parameter take a look at and analysis methods. This review paper functions as a brief technical manuscript for tracing the significant improvement of fracture robustness testing and investigation, for higher considerate and victimization correct fracture constraints and fracture strength that had been defined by various researchers" [68]. In 2012 Tagawa et al. explored silicone rubber reproduction of charged crack tips by opening shapes and crack tip displacement (CTOD) in single edge notch bend (SENB) samples. Their dimensions showed that CTOD in BS7448 overestimated the genuine CTOD for low yield-to-tensile steel and encouraged the investigation of a new method of CTOD calculation**,** consideration of variability in the reducing conduct of the crack tip owing to strain hardening. The silicone rubber repetition of charged crack tips in SENB samples for various YR steels was experimentally explored with crack opening profiles and CTOD. In BS 7448, CTOD settled with the real CTOD in YR=0.9 material. In YR=0.6 material, still an overestimation was obviously noted. These ways led from the location of the plastic strain influenced by the various hardening characteristics of the strain [69]. Shinde et al. addressed the impacts of precisely small weld beam and high resistance overmatching on the fracture strength of laser beam repaired parts with focus on the plastic restraint variance in fracture toughness specimens and structural elements with pop in repair metal. The equivalent CTOD ratio, β, was evaluated numerically to correct CTOD toughness for restrictive failure in structural elements [70]. Patil et al. noted that Al-alloy A384 acquired the mild fracture toughness value around 22.91 MPa. For Al- alloy A384 material, the fatigue pre cracking load is 1.97 KN which is required to produce sharp crack close to the crack tip. The peak load (Pmax) achieved prior to complete sample fracture is approximately 2.67 KN. The fracture load (PQ) acquired for Al-alloy A384 is approximately 2,068 KN. Al-alloy A384's temporary fracture toughness was noted around 18.53 MPa. Analytical calculation such as temporary fracture toughness and Al-alloy A384 fracture toughness was calculated to be 18.44 MPa and 23.78 MPa respectively. Comparative research is produced between the test and the analytical value of the toughness of the fracture and it is found that there is only 3% mistake between them [71]. Brandão et al. suggested a method for estimating CTOD as a driving force for elastic-plastic fracture and is used for assessing faults in welded constructions. A semi- empirical CTOD design curvature has been created by the Japan Welding Engineering Society (JWES) to calculate CTOD. Moreover, with a crack, there is individual sort of welded joint, namely a semi-welded corner boxing fillet. Additional investigations should be carried out for other welded joints and crack dimensions [72]. Khor calculated crack tip opening by means of the equations BS 7448-1/ISO 12135, ASTM E1820 and JWES were contrasted with the outcomes acquired by SRC and FE modeling experiments. The ASTM approach provides a technique for determining CTOD from J without necessarily measuring the displacement of the crack mouth, while confirming practical precision through a spectrum of strain-hardening materials [73]. Yasuhito et al. addressed the impacts of little weld bar and high opposition overmatching on the crack durability of laser bar fixed parts with an attention on the distinction in plastic requirement of break strength examples and auxiliary components with fix metal disfigurement [74]. Moural et al. demonstrated the reliance on the sample density and ligament length of the fracture toughness. For all samplings with different ligament lengths, a critical foundation radius was originated in which the fracture's strength is entirely independent of the core radius of the notch. The expected fracture toughness is in excellent agreement with the measured information using the established models [75].

### 2.4 Literature review on use of ANSYS on concrete beams

The research consist of verification of obtained results using software and so possibilities of various softwares were checked and found that software ANSYS can be used for analysis of beams. A detailed review had been done on use of ANSYS in modeling and analysis of concrete beams has been listed in chronological order. In year 2010, L. Dahmani et al., researched by using 3 meter long beam model of element SOLID65 in ANSYS 8.0 and found a correlation between fracture mechanics formulas and software results [76]. Kotresh M. in year 2018 predicted a numerical approach to the stress field behaviour of crack in “shape memory alloy (SMA)” particles reinforced composite known as the adaptive composite using Finite element modelling and using ANSYS to evaluate the results [77]. Furthermore researches were found on using ANSYS as a tool to evaluate the behaviour of materials on load applications [78]-[79] and so it had been summarized that this software could be used for verification of the optimum mixes and the results obtained by the software are fully correct and reliable.

### 2.5 Summary of Literature Review

After detailed Literature Review it was found that for using more recycled aggregates than 50% in concrete can reduce “flexural strength and split tensile strength of concrete” and so there is a need of a material that can compensate the reduction of strength and help in providing the optimum strength and economy. Looking on the various options that could be used to increase the “flexural strength and split tensile strength” glass fiber was found with better results in flexure and tension both. It was reviewed that S2 glass fiber is having maximum tensile strength than other types of glass fibers. The fracture behavior was also improved on using glass fibers in concrete and so the research finally focused on usage of more recycled aggregates with glass fibers and to find the optimum mix which would be good in strength, workability, Chlorine resistivity and economy. It has been also summarized that the optimum mixes obtained could be checked and verified by modeling and analysis using software ANSYS workbench.

## 2.6 Research Gap and Motivation of the Research

After broad and narrow literature review of existing research, research gap related to the domain and thrust area had been found to work on "Studies on Fractural Behaviour of Glass Fiber Reinforced Concrete with Recycled Aggregates". It had been found that maximum 50% of recycled aggregates could be used in concrete but on adding further recycled aggregates the strength reduces and so glass fibers can help in obtaining optimum strength with higher percentages of recycled aggregates. The fracture study on recycled aggregates with glass fiber had not been performed by prior researchers. The motivation of the research came from the book "Recycled Aggregates Concrete Structures" authored by Jianzhuang Xiao in year 2018 [95]. In chapter 4 of the book published it had been mentioned that fibers can be used to obtain better strength while using recycled aggregates. This intrinsically motivated to perform research on the above mentioned topic. The further motivation was on use of demolished waste which could help in reduction of depletion of environment.

## 2.7 Hypothesis of Research

This study is focused on mix design of M25 grade concrete as it is widely used for construction works. Therefore this research is limited to strength requirements and fracture study of M25 grade concrete. For checking strength of concrete specimens cured for 7 and 28 days as expected to use this concrete for structural use. Another important hypothesis was to collect the normal and recycled aggregates from local region like Jalandhar, Ludhiana and Amritsar.

# CHAPTER 3 : EXPERIMENTAL PROGRAM

## 3.1 General

In this study design mix of M25 grade concrete has been used. The materials have been tested for physical properties required to perform mix design. Glass Fibers of S2 class were used in proportions of 0.25%, 0.5%, 0.75% and 1.00% by weight of concrete. Recycled aggregates had been used as partial replacement of natural coarse aggregates in proportions of 40%, 60%, 70%, 80% and 100%.

As it had been found through literature review that using 100% recycled aggregates decreases strength of concrete, but on addition of glass fibers could give a passage of using recycled aggregate till higher percentages, (more than 50%). Test on materials like cement, sand, coarse aggregates, S2 glass fibers and recycled aggregates were performed as per the Indian Standards. Mix design for M25 grade concrete had been conducted as per IS:10262-2009 [80]. Concrete was tested for workability, Compressive strength, Flexural strength, Split tensile strength, Fracture Behaviour by checking crack length and crack tip opening for various mixes. To check chloride penetration of optimum mix "Rapid Chloride Penetration Test" had been performed on two optimum mixes and normal concrete for comparison. Microstructure study had been performed to verify the behavior exhibit by samples during mechanical strength test using XRD analysis, SEM, EDS and FTIR analysis. The optimum mixes obtained after cost analysis were verified using software ANSYS workbench.

## 3.2 Scientific Theory

The glass fibers exhibits elastic behaviors in their stress-strain characteristics which in compared with structural metal that is more brittle in nature. It imparts high energy absorption which strengthened the concrete in microscopic scale. The high energy absorption reduces the effect of external loads to microscopic level and thus reduces the chances of catastrophic failure. The glass fiber in concrete increases the corrosive resistance, increases damping capacities, has low thermal expansion and is having anti-bacterial properties [97].

The glass fibers behavior in concrete is represented in Figure 3.1 where on application of load, the load is transferred to the fibers on micro-structural level and so the deflection in beam reduces with increase in flexure and tensile strength. The glass fibers not only make the concrete ductile but act as shockers for impact loads coming from any direction because of their random distribution in the concrete.

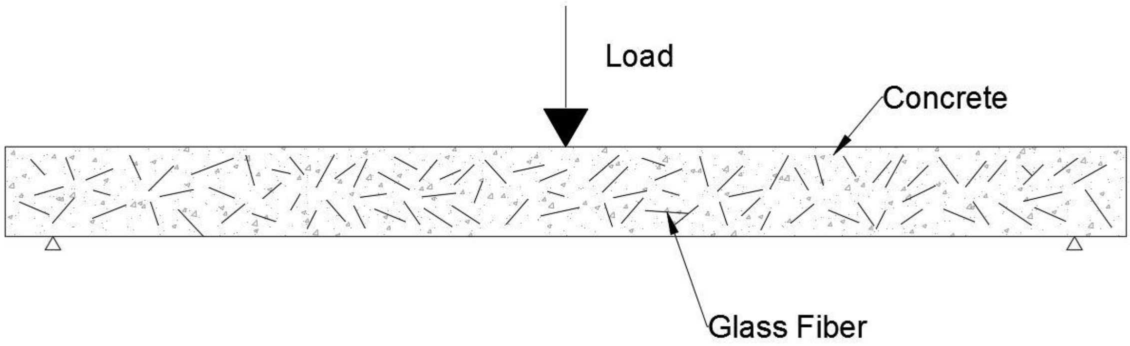



Figure 3.1: Concrete beam with glass fibers applied with load

### 3.3 Materials Used in Research Work

"Cement, fine aggregates, coarse aggregates, water" were used in mix design of M25 grade concrete. The properties and specifications of these materials are as under:

1. ***Cement:*** "Ordinary Portland cement" of 43grade was used for the present investigation. The cement was of uniform colour i.e. grey with a light greenish shade and free from any hard lumps. Summary of various tests conducted on cement are given in TABLE 3.1. All these tests were carried out in accordance with procedure laid down in IS:4031-1999 [84] and IS:8112-2013 [85].

2. ***Fine aggregates:*** The fine aggregates used for the experimental work had been locally procured and conformed to grading zone III .Sieve analysis of the fine aggregate was carried out in the laboratory as per IS:383-1970 [86]. The sand was first sieved through 4.75 mm sieve to remove any particle greater than 4.75 mm sieve and then washed to remove the dust. The physical properties and sieve analysis of fine aggregates are shown in TABLE 3.2 and TABLE 3.3.

TABLE 3.1: Physical properties of cement

| S. No. | Characteristics | Values obtained | Standard Values |
|---|---|---|---|
| 1 | Normal consistency | 33.3% | _ |
| 2 | Initial setting time | 48.5 min | >30 min |
| 3 | Final setting time | 240.5 min | <600 min |
| 4 | Fineness | 4.81 % | _ |
| 5 | Specific gravity | 3.12 | _ |
| 6 | Compressive strength | | |
| S. No. | Days | Compressive strength | |
| 1 | 3 | 24.81 MPa | |
| 2 | 7 | 37.52 MPa | |
| 3 | 28 | 47.64 MPa | |

TABLE 3.2: Physical properties of fine aggregates

| S. No | Characteristics | Value |
|---|---|---|
| 1 | Specific gravity | 2.585 |
| 2 | Bulk density | 1.333 g/cc |
| 3 | Fineness modulus | 2.628 |
| 4 | Water absorption | 0.889 |
| 5 | Grading zone | Zone III |

TABLE 3.3 : Sieve analysis of fine aggregates

| Sr.No. | IS-Sieve (mm) | Weight Retained (gm) | Percentage Retained | Percentage Passing | Cumulative % retained |
|---|---|---|---|---|---|
| 1 | 4.75 | 14.6 | 1.46 | 98.54 | 1.46 |
| 2 | 2.36 | 37.2 | 3.72 | 94.82 | 5.18 |
| 3 | 1.18 | 246.52 | 24.652 | 70.168 | 29.832 |
| 4 | 600 μ | 205.51 | 20.551 | 49.617 | 50.383 |
| 5 | 300 μ | 287.53 | 28.753 | 20.864 | 79.136 |
| 6 | 150 μ | 176.92 | 17.692 | 3.172 | 96.828 |
| 7 | Pan | 31.72 | 3.172 | | |
| | Total | 1000.000 | | SUM | 262.819 |
| | | | | *FM =* | *2.628* |

Total mass taken: 1000gm

Fineness modulus of fine aggregates = 2.628

3. ***Coarse aggregates:*** Trampled rock aggregates (locally available) of nominal size 20 mm were used in the research. The dirt and dust was removed by washing the aggregates and were desiccated to exterior dry conditions. The aggregates were tested as per IS:383-1970 [86].The various test required for mix design were performed and the values are given in TABLE 3.4 and TABLE 3.5 exhibits the values obtained in sieving of aggregates.

TABLE 3.4 : Physical properties of coarse aggregates

| S. No. | Characteristics | Value |
|---|---|---|
| 1 | Type | Crushed |
| 2 | Specific gravity | 2.692 |
| 3 | Water absorption | 0.557 % |
| 4 | Fineness Modulus | 6.912 |

TABLE 3.5 : Sieve Analysis of Coarse aggregates

| S. No. | Sieve size | Weight retained(gm) | Percentage retained (%) | Percent Passing (%) | Cumulative percentage retained |
|---|---|---|---|---|---|
| 1 | 80 | 0.00 | 0.00 | 100.00 | 0.00 |
| 2 | 40 | 0.00 | 0.00 | 100.00 | 0.00 |
| 3 | 20 | 68.51 | 2.283 | 97.717 | 2.283 |
| 4 | 10 | 2776.48 | 92.549 | 5.168 | 94.832 |
| 5 | 4.75 | 113.51 | 3.783 | 1.385 | 98.615 |
| 6 | Pan | 0.00 | 0.00 | 0.00 | |
| | Total | 3000.00 | | SUM | 195.73 + 500 = |
| | | | | *FM =* | *6.95* |

FM of 20 mm coarse aggregates= (195.73+500)/100 = 6.95

4. ***Water:*** Clean and Fresh tap water had been used in casting specimens of the current study. The water was comparatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standard.

5. ***Recycled aggregates:*** Are parts and bits of solid structures which are destroyed or remake. These were obtained by breaking big boulder obtained from demolished concrete as shown in Figure 3.2 and removing attached cement mortar using iron brushes were cleaned from soil and broken to littler pieces as shown in Figure 3.3 to produce aggregate which is named as recycled aggregates as shown in Figure 3.4. The recycled aggregates were being obtained from demolished waste from Jalandhar, Ludhiana and Amritsar. The physical properties required for mix design were tested and tabulated in TABLE 3.6. The sieve analysis of recycled coarse aggregate have been shown in TABLE 3.7.

Figure 3.2 : Concrete boulders obtained from demolished structures in Jalandhar, Ludhiana and Amritsar

Figure 3.3 : Demolished concrete broken and recycled aggregates obtained is processed for cleaning

TABLE 3.6 : Physical properties of recycled aggregates

| SN | Characteristics | Value |
|---|---|---|
| 1 | Water Absorption | 7.92% |
| 2 | Specific Gravity | 2.34 |

TABLE 3.7 : Sieve Analysis of recycled aggregates

| S.No. | IS-Sieve (mm) | Weight Retained (gm) | Percentage Retained | Percentage Passing | Cumulative % retained |
|---|---|---|---|---|---|
| 1 | 80 | 0 | 0 | 100 | 0 |
| 2 | 40 | 0 | 0 | 100 | 0 |
| 3 | 20 | 136 | 4.53 | 95.47 | 4.53 |
| 4 | 10 | 2801 | 93.36 | 2.11 | 97.89 |
| 5 | 4.75 | 43 | 1.43 | 0.68 | 99.32 |
| 6 | Pan | 20 | 0.67 | 0 | |
| | Total | 3000 | | SUM | 201.74+500= |
| | | | | FM | 7.017 |

Figure 3.4: Recycled Aggregates

6. ***S2 Glass Fiber:*** S2 Glass fibers are high quality glass fiber that gives the most significant level of tensile strength out of all glass filaments. Created with a more significant level of silica than standard glass fibers. The glass fibers used for research work were free from CaO and were of length 12-15 mm as shown in Figure 3.5. The properties of glass fiber used have been tabulated in TABLE 3.8. The S2 Glass fiber have been arranged from vendor AKS Build Systems, Ludhiana, Punjab, the details have been attached in APPENDIX 4: Vendor Detail for Glass Fiber. The S2 Glass Fiber should not be touched by bare hands and gloves should be used while handling this fiber.

Figure 3.5: S2 Glass Fiber to be not handled with bare hands

TABLE 3.8 : Properties of S2 glass fiber

| Property | Results |
|---|---|
| Type of material | Magnesium alumino silicate glass without CaO |
| Fiber length (mm) | 12-15 (mixed) |
| $SiO_2$ Content | 64-66% |
| Elastic Modulus(E) | 79-89 MPa |
| Aspect Ratio | 300-350 |

### 3.4 Mix Design of Concrete

The Mix design of M25 grade concrete was carried out as per according to IS:10262-2009 [80] as this is the most used grade in structural purposes where there is no specific requirement. The material test values obtained were used to perform mix design and target mean strength was used by calculating standard deviation. The water cement ratio used was 0.44 taken from IS code.

Characteristics strength =M25

Target men strength =25+1.65*4=31.6 N/mm$^2$

Maximum water cement ratio =0.44

Minimum cement content according to IS:456-2000 [87] =400 kg/ m$^3$

Nominal maximum size of aggregate =20mm

According to IS:10262-2009 [80] maximum water cement ratio =186 Lit.

For 50 * 75mm slump =186+3% of 186

=191.58 kg/m$^3$

Water cement ratio is 0.44 so; cement comes to be 435.409 kg/m$^3$

435.409 kg/m$^3$ > 400 kg/m$^3$

According to zone of site for fine aggregate

Volume of Coarse aggregate=0.64

As the concrete is to be used in pumps also therefore reduce 10% in volume of coarse aggregates

“Volume of Coarse aggregate = 0.64 * 0.9 = 0.576

Volume of Fine aggregate= 1- 0.576 = 0.424

Mixing calculation per unit the volume of concrete”

a. Volume of water -1m$^3$

=191.58*(1/1000)

=0.191 m$^3$

b. Volume of cement = 435.409/3.12*(1/1000) =0.1396

c. Volume of all in aggregate =a- (b + c)

=1-(0.1396+0.191)

=0.6694 m$^3$

“Mass of coarse aggregate = (e)*vol of coarse aggregate*specific gravity of coarse aggregate*1000”.

=0.6694 * 0.576 * 2.69 * 1000

=1037.19 kg

“Mass of fine aggregate =(e) * volume of fine aggregate * specific gravity of fine aggregate*1000”

=0.6694*0.424*2.59*1000

=735.108 kg

“The mix design proportions come to be in 1 cum of concrete”

| Cement | Fine Agg. | Coarse Agg. | Water | Units |
|---|---|---|---|---|
| 435.409 | 735.108 | 1037.19 | 191.58 | kg/$m^3$ |
| 1 | 1.688 | 2.38 | 0.44 | Ratio |

Using above mix design calculations cubes in 6 numbers were casted to check the compressive strength after 7 and 28 days of curing. The compressive strength of cubes after 7 days and 28 days have been tabulated in TABLE 3.9 and TABLE 3.10

TABLE 3.9 : Compressive strength after 7 days

| S. No. | Weight of Cube (Kg) | Peak Load (KN) | Compressive Strength (N/$mm^2$) | Average Compressive Strength (N/$mm^2$) |
|---|---|---|---|---|
| 1 | 7.787 | 454.8 | 20.21 | 23.19 |
| 2 | 8.172 | 571.4 | 25.39 | |
| 3 | 8.167 | 539.2 | 23.96 | |

TABLE 3.10 : Compressive strength after 28 days

| S. No. | Weight of Cube (Kg) | Peak Load (KN) | Compressive Strength (N/$mm^2$) | Average Compressive Strength (N/$mm^2$) |
|---|---|---|---|---|
| 1 | 7.93 | 798.6 | 35.49 | 33.39 |
| 2 | 7.91 | 723.4 | 32.15 | |
| 3 | 7.89 | 732.2 | 32.54 | |

### 3.5 Material compositions to be used in research work

It has been found in detailed literature review that recycled aggregates can be used in concrete but to a limited amount and that is till 50%. The major focus of this research is towards environment friendly concrete can be called as green concrete, evolution of a new kind of concrete using more percentage of recycled aggregates in it. Many countries are facing the problem of environmental depletion and which is creating serious issues like global warming. The demolished concrete waste if dumped untreated increase the carbonation emissions as shown in Figure 3.7. The main problem that was found in using higher percentages of recycled aggregates in concrete was strength and workability. The major strength reduction was found in flexural strength on using higher amount of recycled aggregates. On finding out other materials which could be added to increase flexural and split tensile strength of concrete, glass fiber was found out to be more promising in terms of strength and economy. Therefore, in this research higher percentages of recycled aggregates like 40%, 60%, 70%, 80% and 100% have been used as a partial replacement of natural coarse aggregates. The glass fibers used were S2 glass fibers; having maximum tensile strength as compared to other types of glass fibers. The percentages of glass fibers used in research work were literature reviewed and taken as 0.25%, 0.5%, 0.75% and 1.0% by weight of concrete. The material mix prepared has been shown in Figure 3.8. The materials that were used for various mix proportions have been listed in TABLE 3.11 where it states the materials required for casting 1 cubic meter of concrete. The designation of concrete specimens had been taken as CR__G__, where the meaning of the designation is shown in Figure 3.6.

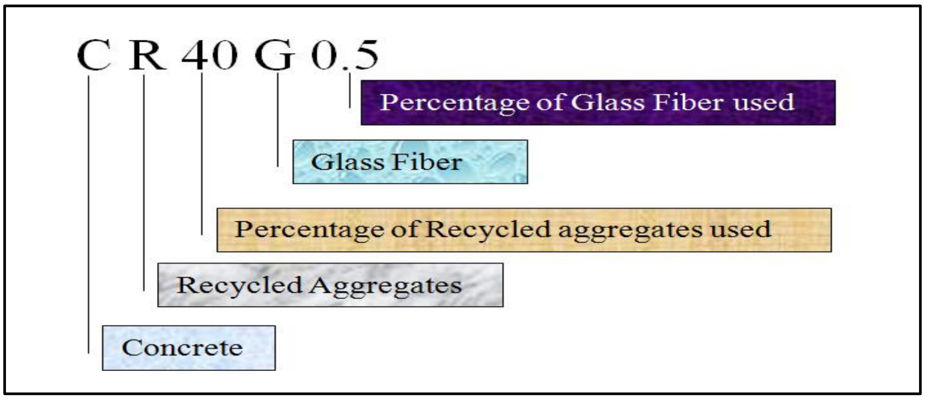



Figure 3.6 : Mix designation explanation in detail


Figure 3.7 : Demolished concrete dumped creating pollution

(Source: https://www.dreamstime.com/concrete-rubble-concrete-rubble-forest-image164137451)


Figure 3.8 :Concrete mix with RA & Glass fibre

TABLE 3.11 : Material composition of different mix designations for experimental study

| Material | CR0G0 | CR40G0.25 | CR40G0.5 | CR40G0.75 | CR40G1.0 |
|---|---|---|---|---|---|
| Cement | 435.41 | 435.41 | 435.41 | 435.41 | 435.41 |
| Coarse Aggregate | 1037.19 | 622.31 | 622.31 | 622.31 | 622.31 |
| Fine Aggregate | 735.11 | 735.11 | 735.11 | 735.11 | 735.11 |
| Recycled aggregate | 0.00 | 414.88 | 414.88 | 414.88 | 414.88 |
| Glass Fiber | 0.00 | 5.52 | 11.04 | 16.56 | 22.08 |
| Water | 191.58 | 191.58 | 191.58 | 191.58 | 191.58 |
| Material | CR60G0.25 | CR60G0.5 | CR60G0.75 | CR60G1.0 | |
| Cement | 435.41 | 435.41 | 435.41 | 435.41 | |
| Coarse Aggregate | 414.88 | 414.88 | 414.88 | 414.88 | |
| Fine Aggregate | 735.11 | 735.11 | 735.11 | 735.11 | |
| Recycled aggregate | 622.31 | 622.31 | 622.31 | 622.31 | |
| Glass Fiber | 5.52 | 11.04 | 16.56 | 22.08 | |
| Water | 191.58 | 191.58 | 191.58 | 191.58 | |
| Material | CR70G0.25 | CR70G0.5 | CR70G0.75 | CR70G1.0 | |
| Cement | 435.41 | 435.41 | 435.41 | 435.41 | |
| Coarse Aggregate | 311.16 | 311.16 | 311.16 | 311.16 | |
| Fine Aggregate | 735.11 | 735.11 | 735.11 | 735.11 | |
| Recycled aggregate | 726.03 | 726.03 | 726.03 | 726.03 | |
| Glass Fiber | 5.52 | 11.04 | 16.56 | 22.08 | |
| Water | 191.58 | 191.58 | 191.58 | 191.58 | |
| Material | CR80G0.25 | CR80G0.5 | CR80G0.75 | CR80G1.0 | |
| Cement | 435.41 | 435.41 | 435.41 | 435.41 | |
| Coarse Aggregate | 207.44 | 207.44 | 207.44 | 207.44 | |
| Fine Aggregate | 735.11 | 735.11 | 735.11 | 735.11 | |
| Recycled aggregate | 829.75 | 829.75 | 829.75 | 829.75 | |
| Glass Fiber | 5.52 | 11.04 | 16.56 | 22.08 | |
| Water | 191.58 | 191.58 | 191.58 | 191.58 | |
| Material | CR100G0.25 | CR100G0.5 | CR100G0.75 | CR100G1.0 | |
| Cement | 435.41 | 435.41 | 435.41 | 435.41 | |
| Coarse Aggregate | 0.00 | 0.00 | 0.00 | 0.00 | |
| Fine Aggregate | 735.11 | 735.11 | 735.11 | 735.11 | |
| Recycled aggregate | 1037.19 | 1037.19 | 1037.19 | 1037.19 | |
| Glass Fiber | 5.52 | 11.04 | 16.56 | 22.08 | |
| Water | 191.58 | 191.58 | 191.58 | 191.58 | |

Note:- All values are in $kg/m^3$

### 3.6 Compressive Strength Test

The cubes of specimens of size 150x150x150 mm had been casted as shown in Figure 3.9 and were tested under Compression load  as shown in Figure 3.10 was performed on compression testing machine of Make HEICO of 1000 KN, tested according to Indian standards IS:516-1959 [81]. Six specimens were tested of each designation three specimens after 7 days and three 28 days of curing and average value of results were considered. The results have been listed below in TABLE 3.12 and TABLE 3.13. The Average strength of various mix designations have been plotted on the bar chart given below in Graph 3.1.

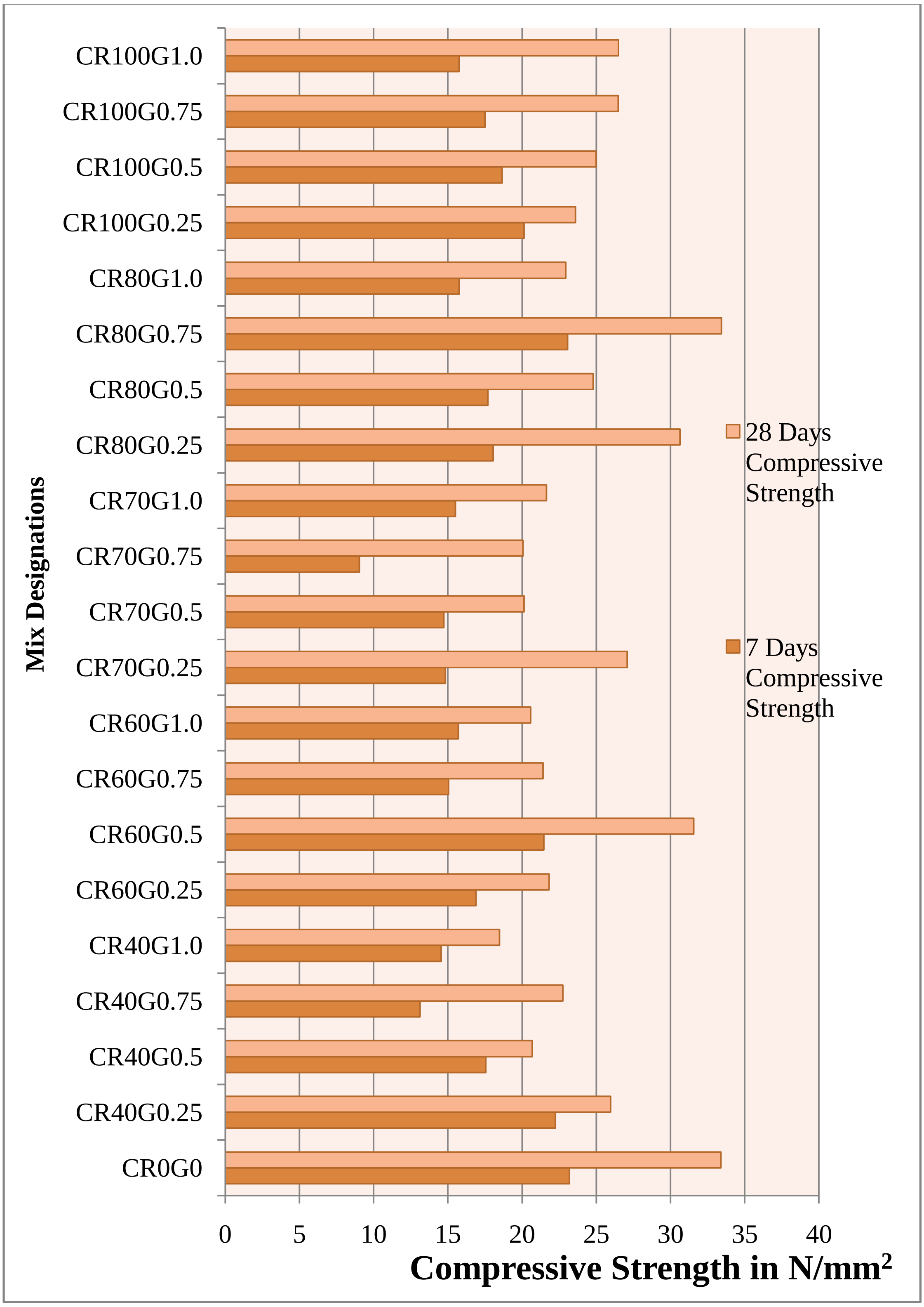
Figure 3.9 : Compression strength cube specimens

TABLE 3.12 : Compressive Strength of Cubes after 7 Days in N/mm$^2$

| Mix Designations | CR40G0.25 | CR40G0.5 | CR40G0.75 | CR40G1.0 |
|---|---|---|---|---|
| Sample 1 | 22.57 | 18.80 | 13.42 | 16.44 |
| Sample 2 | 21.87 | 16.89 | 12.75 | 13.56 |
| Sample 3 | 22.31 | 16.98 | 13.19 | 13.64 |
| Average | 22.25 | 17.56 | 13.12 | 14.55 |
| Mix Designations | CR60G0.25 | CR60G0.5 | CR60G0.75 | CR60G1.0 |
| Sample 1 | 16.06 | 20.76 | 13.51 | 15.56 |
| Sample 2 | 18.18 | 22.84 | 15.11 | 15.60 |
| Sample 3 | 16.44 | 20.80 | 16.49 | 15.96 |
| Average | 16.89 | 21.47 | 15.04 | 15.70 |
| Mix Designations | CR70G0.25 | CR70G0.5 | CR70G0.75 | CR70G1.0 |
| Sample 1 | 13.69 | 14.00 | 9.11 | 15.24 |
| Sample 2 | 15.96 | 16.09 | 8.97 | 15.16 |
| Sample 3 | 20.31 (discarded) | 14.09 | 12.36 (discarded) | 16.13 |
| Average | 14.825 | 14.73 | 9.04 | 15.51 |
| Mix Designations | CR80G0.25 | CR80G0.5 | CR80G0.75 | CR80G1.0 |
| Sample 1 | 18.00 | 18.27 | 23.33 | 15.67 |
| Sample 2 | 17.87 | 17.69 | 23.47 | 14.61 |
| Sample 3 | 18.31 | 17.16 | 22.37 | 16.96 |
| Average | 18.06 | 17.70 | 23.06 | 15.75 |
| Mix Designations | CR100G0.25 | CR100G0.5 | CR100G0.75 | CR100G1.0 |
| Sample 1 | 17.46 | 18.92 | 18.92 | 14.09 |
| Sample 2 | 18.71 | 16.89 | 16.89 | 17.29 |
| Sample 3 | 19.82 | 16.71 | 16.71 | 15.87 |
| Average | 18.66 | 17.51 | 17.51 | 15.75 |

TABLE 3.13 : Compressive Strength of Cubes after 28 Days in $N/mm^2$

| Mix Designations | CR40G0.25 | CR40G0.5 | CR40G0.75 | CR40G1.0 |
|---|---|---|---|---|
| Sample 1 | 23.51 | 20.00 | 19.11 | 18.49 |
| Sample 2 | 28.71 | 19.42 | 23.82 | 19.25 |
| Sample 3 | 25.64 | 22.62 | 25.29 | 17.70 |
| Average | 25.96 | 20.68 | 22.74 | 18.48 |
| Mix Designations | CR60G0.25 | CR60G0.5 | CR60G0.75 | CR60G1.0 |
| Sample 1 | 21.11 | 30.77 | 22.07 | 20.04 |
| Sample 2 | 21.58 | 31.36 | 20.22 | 22.46 |
| Sample 3 | 22.80 | 32.57 | 21.98 | 19.24 |
| Average | 21.83 | 31.57 | 21.42 | 20.58 |
| Mix Designations | CR70G0.25 | CR70G0.5 | CR70G0.75 | CR70G1.0 |
| Sample 1 | 27.87 | 21.88 | 21.07 | 21.33 |
| Sample 2 | 27.93 | 19.30 | 19.47 | 20.31 |
| Sample 3 | 25.47 | 19.24 | 19.64 | 23.29 |
| Average | 27.09 | 20.14 | 20.06 | 21.64 |
| Mix Designations | CR80G0.25 | CR80G0.5 | CR80G0.75 | CR80G1.0 |
| Sample 1 | 29.94 | 25.20 | 32.98 | 24.09 |
| Sample 2 | 31.97 | 23.64 | 34.80 | 21.91 |
| Sample 3 | 30.04 | 25.56 | 32.53 | 22.86 |
| Average | 30.65 | 24.80 | 33.44 | 22.95 |
| Mix Designations | CR100G0.25 | CR100G0.5 | CR100G0.75 | CR100G1.0 |
| Sample 1 | 22.53 | 26.31 | 27.56 | 25.51 |
| Sample 2 | 22.67 | 25.51 | 25.51 | 27.24 |
| Sample 3 | 25.60 | 23.11 | 26.40 | 26.76 |
| Average | 23.60 | 24.98 | 26.49 | 26.50 |




Graph 3.1: Variation of compressive strength of different mix designations with age of 7and 28 days


Figure 3.10 : Compressive testing machine 1000 KN capacity

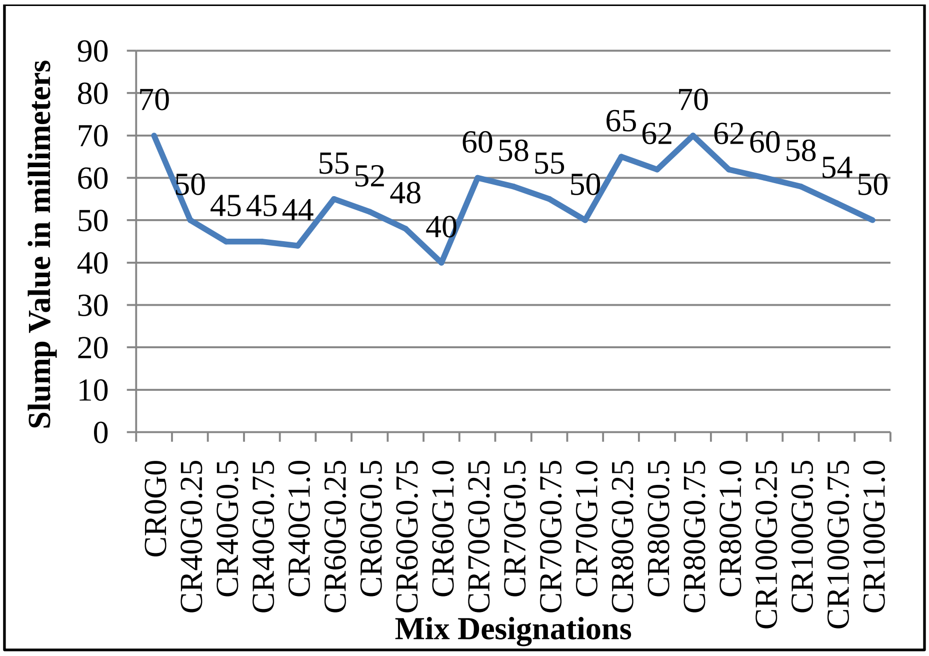
The Compressive strength results interpret the behaviour of concrete matrix under compressive load and an optimum value had been obtained on partial replacement of coarse aggregates with 80% of recycled aggregates with adding 0.75% of glass fibers. This optimum mix could be used for construction practice for casting compression members of structures.

### 3.7 Workability of Concrete

The workability was tested using slump cone method and the results have been listed in TABLE 3.14 which shows that on increasing quantity of recycled aggregates there is a decrease in workability and so a Super Plasticizer Master Glenium B233 was used to improve workability. The results of workability have been plotted in Graph 3.2.

TABLE 3.14 : Workability by Slump cone test (mm)

| Specimen | Slump | Specimen | Slump |
|---|---|---|---|
| CR0G0 | 70 | CR70G0.75 | 55 |
| CR40G0.25 | 50 | CR70G1.0 | 50 |
| CR40G0.5 | 45 | CR80G0.25 | 65 |
| CR40G0.75 | 45 | CR80G0.5 | 62 |
| CR40G1.0 | 44 | CR80G0.75 | 70 |
| CR60G0.25 | 55 | CR80G1.0 | 62 |
| CR60G0.5 | 52 | CR100G0.25 | 60 |
| CR60G0.75 | 48 | CR100G0.5 | 58 |
| CR60G1.0 | 40 | CR100G0.75 | 54 |
| CR70G0.25 | 60 | CR100G1.0 | 50 |
| CR70G0.5 | 58 | | |




Graph 3.2 : Workability by Slump Cone Test in millimeters

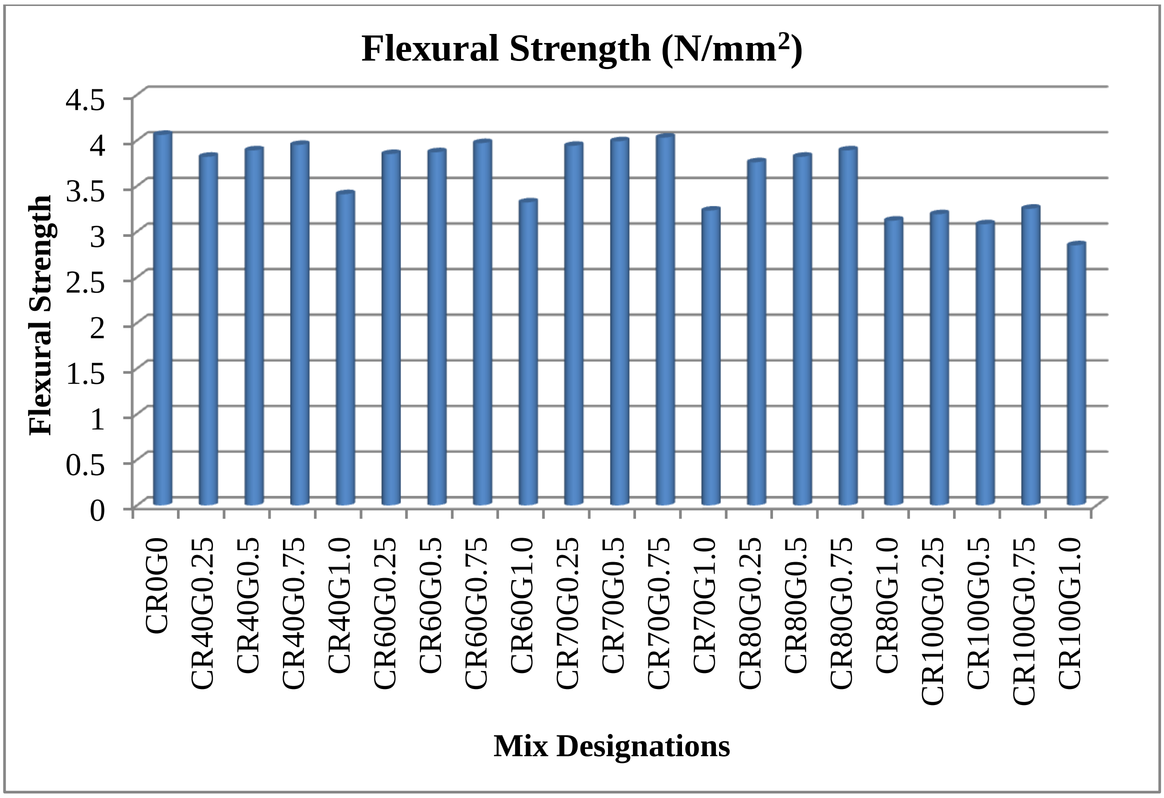
### 3.8 Flexural Strength Test

The beam samples of size 100x100x500 mm were casted three in numbers of each designation. The beams had been tested under four point flexural strength test on compression testing machine Make HEICO, Capacity 1000 kN with flexural Strength test setup as shown in Figure 3.11, tested according to Indian standards IS:516-1959 [81]. The average values of the flexural strength were considered for analysis shown in TABLE 3.15 and plotted on the bar chart given below in Graph 3.3.

Figure 3.11 : Testing of flexural strength sample using flexural strength setup on compressive strength testing machine

TABLE 3.15 : Flexural Strength of various Mix Designations

| Specimen | Flexural strength (N/mm$^2$) | Specimen | Flexural strength (N/mm$^2$) |
|---|---|---|---|
| CR0G0 | 4.06 | CR70G0.75 | 4.03 |
| CR40G0.25 | 3.82 | CR70G1.0 | 3.23 |
| CR40G0.5 | 3.89 | CR80G0.25 | 3.76 |
| CR40G0.75 | 3.95 | CR80G0.5 | 3.82 |
| CR40G1.0 | 3.41 | CR80G0.75 | 3.89 |
| CR60G0.25 | 3.85 | CR80G1.0 | 3.12 |
| CR60G0.5 | 3.87 | CR100G0.25 | 3.19 |
| CR60G0.75 | 3.97 | CR100G0.5 | 3.08 |
| CR60G1.0 | 3.32 | CR100G0.75 | 3.25 |
| CR70G0.25 | 3.94 | CR100G1.0 | 2.85 |
| CR70G0.5 | 3.99 | | |




Graph 3.3 : Flexural Strength of various mix designations

The flexural strength of specimens showed that the mix which contains 70% of recycled aggregates and 0.75% of S2 Glass Fibers is taking the maximum flexural load and so it could be used for flexural purposes like beams and slabs but fracture study also exhibit an important role in selecting the optimum mix proportion.

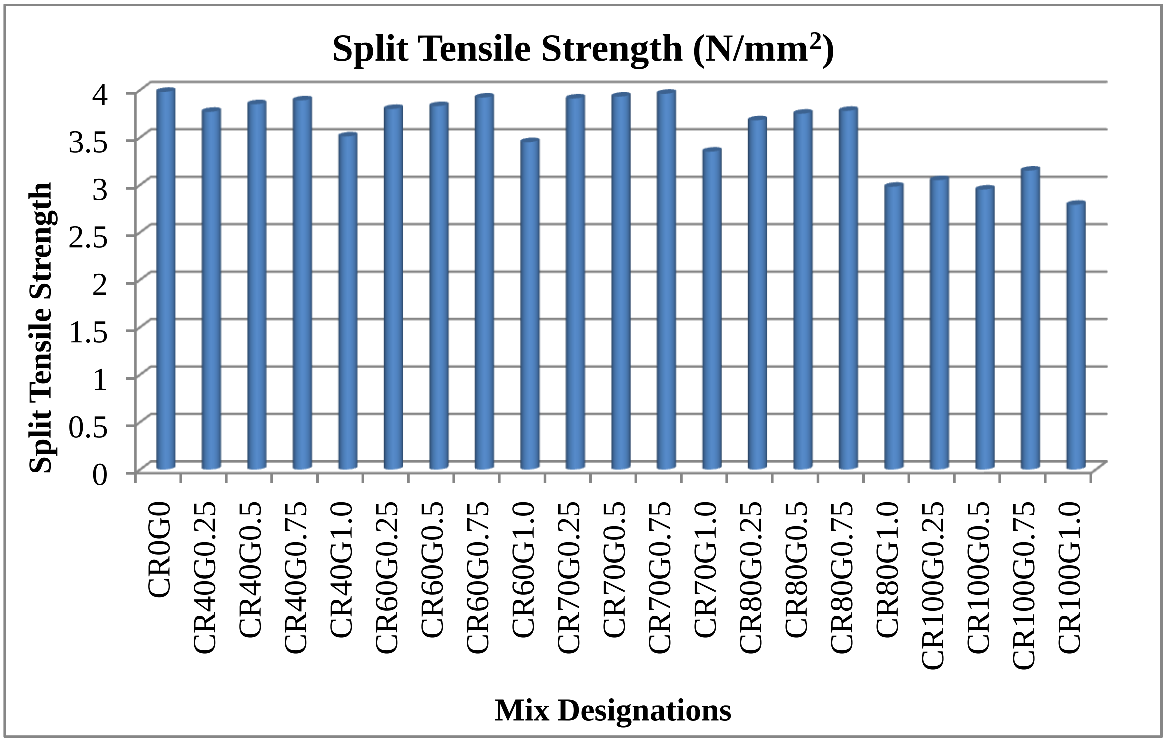
### 3.9 Split Tensile Strength Test

The cylindrical specimens of sizes 150 mm dia. and 300 mm long were casted three in numbers of each designation and tested for Split Tensile strength test on compressive strength testing machine of Make HEICO of capacity 1000 KN as shown in Figure 3.12, tested according to IS:5816-1999 [82]. The average values of the obtained strength were considered for analysis as shown in TABLE 3.16. and plotted on the bar chart given below in Graph 3.4.


Figure 3.12 : Testing of Split Tensile Strength sample using compressive strength testing machine

TABLE 3.16 : Split Tensile Strength of various Mix Designations

| Specimen | Split Tensile strength ($N/mm^2$) | Specimen | Split Tensile strength ($N/mm^2$) |
|---|---|---|---|
| CR0G0 | 3.98 | CR70G0.75 | 3.96 |
| CR40G0.25 | 3.77 | CR70G1.0 | 3.35 |
| CR40G0.5 | 3.85 | CR80G0.25 | 3.68 |
| CR40G0.75 | 3.89 | CR80G0.5 | 3.75 |
| CR40G1.0 | 3.51 | CR80G0.75 | 3.78 |
| CR60G0.25 | 3.80 | CR80G1.0 | 2.98 |
| CR60G0.5 | 3.83 | CR100G0.25 | 3.05 |
| CR60G0.75 | 3.92 | CR100G0.5 | 2.95 |
| CR60G1.0 | 3.45 | CR100G0.75 | 3.15 |
| CR70G0.25 | 3.91 | CR100G1.0 | 2.79 |
| CR70G0.5 | 3.93 | | |




Graph 3.4 : Split Tensile Strength of various mix designations

The behaviour of split tensile strength for CR70G0.75 showed maximum results, near to normal concrete and therefore, mix of concrete having 70% of recycled aggregates and 0.75% glass fibers could be proposed for applications in concrete structures having flexural behaviour like beams and slabs.

### 3.10 Fracture behaviour using Three-Point Bend Test

To perform fracture analysis beam specimens of size 500x100x100 mm were casted of each designation. The experimental system for fracture behaviour consists of a three-point bending test on notched beam samples with an initial 30 mm notch depth and 3 mm width was performed as per guidelines of RILEM 50-FMC [83]. The fracture test was performed in Akara Material Testing Laboratory Pvt. Ltd., Tinkunne, Subhidhanagar, Kathmandu Nepal. The test reports obtained from testing laboratory is attached in APPENDIX 5: Test Report obtained from Testing Laboratory. The details of the specimen for the fracture test have been shown in Figure 3.13. The crack length was measured by using Vernier Caliper and the CMOD was measured using Displacement Transducer. The casted beam sample have been shown in Figure 3.14.

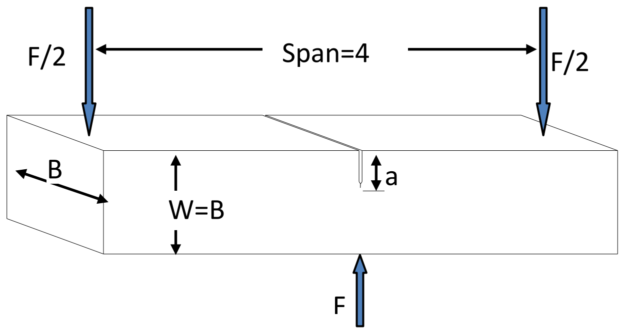



Figure 3.13 : Details of Fracture Test Specimens

According to the RILEM 50-FMC [83], the fracture toughness is determined using equation (1) as the critical stress intensity Kic.

$$\boldsymbol{Kic} = \frac{\boldsymbol{3FS\sqrt{\pi a}}}{\boldsymbol{2BW^2}}\boldsymbol{f(\alpha)} \qquad (1)$$

Where, Kic =critical stress intensity (MPa√m), F – max. load (N), S, B and W are the span, depth, and width in mm respectively of the testing beam.

f(α) is geometry factor, which depends on the ratio of the notch depth/crack length (a) to the depth (W) of the beam. In case S = 4W as applied in the current study, f(α) can be as shown in equation (2).

$$\boldsymbol{f(\alpha)} = \frac{[\mathbf{1.99}-\boldsymbol{\alpha}(\mathbf{1}-\boldsymbol{\alpha})(\mathbf{2.15}-\mathbf{3.93}\boldsymbol{\alpha}+\mathbf{2.7}\boldsymbol{\alpha}^{\mathbf{2}})]}{\sqrt{\boldsymbol{\pi}}(\mathbf{1}+\mathbf{2}\boldsymbol{\alpha})(\mathbf{1}-\boldsymbol{\alpha})^{\mathbf{1.5}}} \qquad (2)$$

The materials utilized for the investigation were Ordinary Portland Cement of Grade 43, locally presented river sand utilized as fine aggregates, reused aggregates of demolished structures, coarse aggregates of 20.0 mm and S2 glass fiber of 15 mm length and 0.1 mm width, Master Glenium B233 as super plasticizer and water of drinking quality. The crack length, peak load (Pmax) and CMOD was determined in experimental setup which was used to calculate Kic & CTOD through RILEM-50 FMC. The peak load observed from each specimen have been averaged and tabulated in TABLE 3.18. The number of specimen for beam casting for optimum value of fracture toughness was 42 where test is done after 28 days of curing. The test were performed on Universal Testing Machine of Make  DM Instruments of Capacity 1000 KN as shown in Figure 3.16 with three point test as shown in Figure 3.15. To measure Crack Mouth Opening Displacement, Displacement Transducer is used of Make SREEKA and to measure crack length Digital Vernier Caliper has been used of Make Generic. The cracked samples have been shown in Figure 3.17.


Figure 3.14 : Notched beam for fracture test


Figure 3.15 : Three- point test of beam for P max

Figure 3.16 : Universal testing machine of Make DM Instruments of capacity 1000 KN for Fracture toughness test

Figure 3.17 : Crack length of beam after P max

*3.10.1 Intrepretation of Experimental value of CTOD & Kic*

For length parameter (Q) by Jenq & Shah to assure brittleness number formula of Q as given below in equation (3),

$$\boldsymbol{Q} = \left[\frac{\boldsymbol{E*CTOD}}{\boldsymbol{Kic}}\right]^{2} \qquad (3)$$

This length parameter has been checked for concrete with optimum RA as 60% and 0.75% addition of S2 glass fibre.

Below listed TABLE 3.17 shows the experimental value to calculate brittleness number as given by Jenq & Shah, here the modulus of elasticity has been calculated through formula mentioned in Appendix (1) as per IS 456-2000 [87].

TABLE 3.17 : Brittleness Number Calculation

| Name | Modulus of elasticity (E) N/mm^2 | CTOD ( mm) | Kic ( Mpa√mm) | Length parameter ( Q) ( mm) |
|---|---|---|---|---|
| CR60G0.75 | 28653.09 | 0.038 | 2.09 * 31.62 | 271.45 |

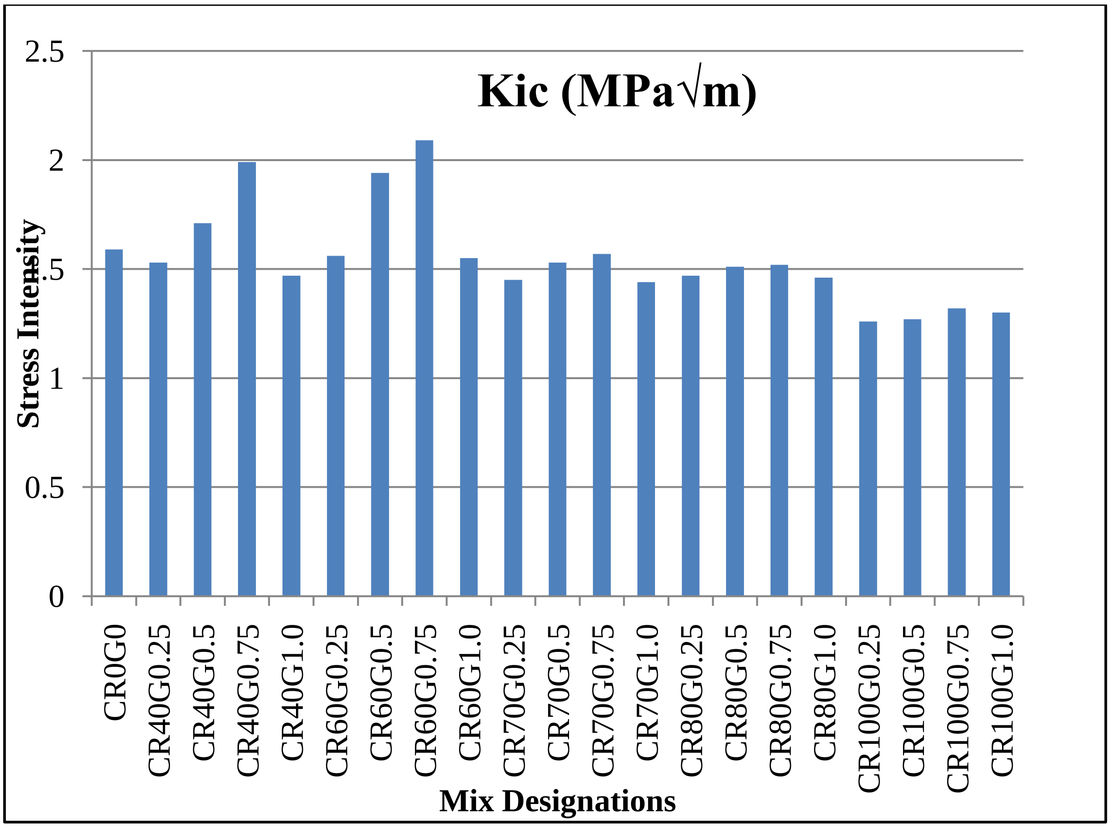
As per research the brittleness number of standard concrete should lie between 150-300 mm so above length parameter (Q) 271.45 mm which lies in the range and experimental value satisfies the brittleness number of concrete.

*3.10.2 Stress Intensity Factor (Kic)*

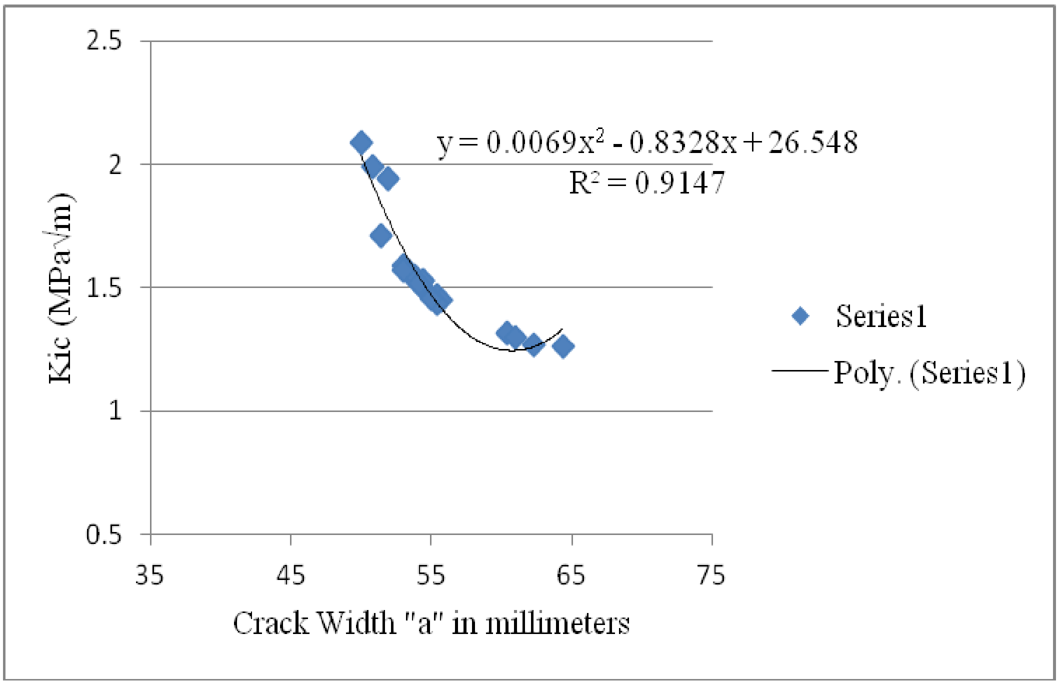
Fracture study was performed by using two parameters, Stress Intensity Factor (Kic) and Crack Tip Opening Displacement (CTOD). To perform fracture study notched beam specimens were subjected to 3-point bending in simply supported end condition. In order to determine the fracture strength, the 3-point bending tests were performed on beams with 100x100 mm cross section and an effective length of 400 mm. The results of peak load, Crack Length and critical stress intensity have been shown in TABLE 3.18. To represent the behaviour of concrete beams due to central load the acquired data is plotted in charts Graph 3.5, Graph 3.6 and Graph 3.7.

TABLE 3.18 : Results of Stress intensity (Kic) with Different S2 Glass Fiber and Recycle Aggregate on Concrete Beams

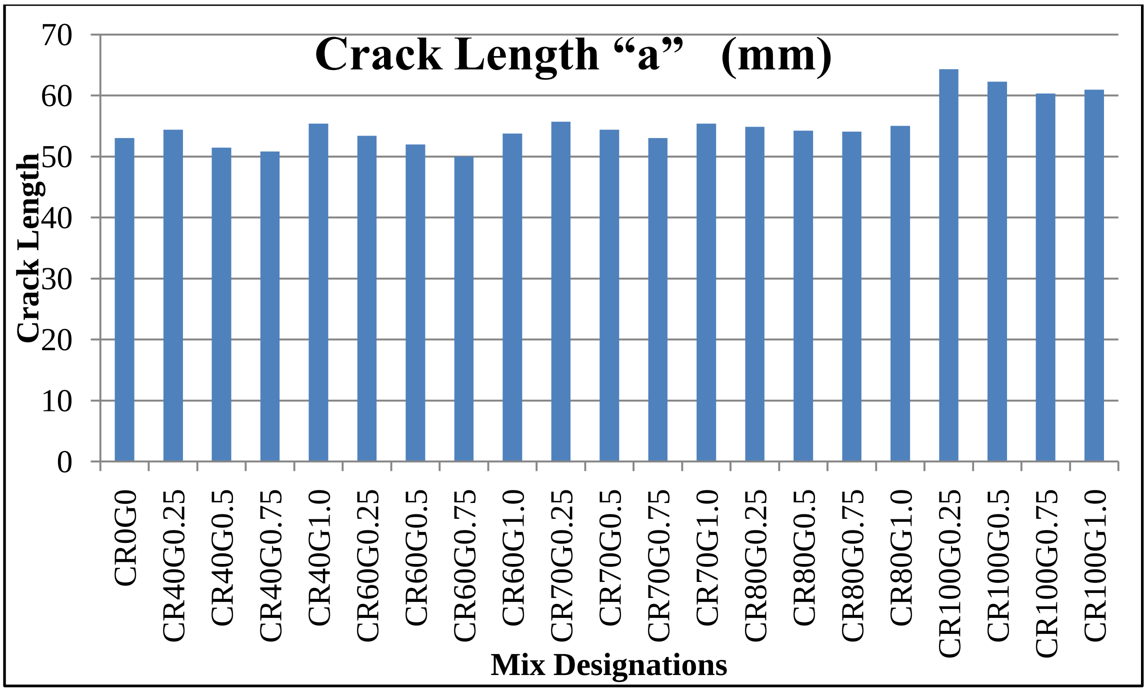
| SN | Name | Peak Load (N) | Crack Length "a" (mm) | Kic (MPa√m) |
|---|---|---|---|---|
| 1 | CR0G0 | 4550 | 53.03 | 1.59 |
| 2 | CR40G0.25 | 4370 | 54.41 | 1.53 |
| 3 | CR40G0.5 | 4895 | 51.45 | 1.71 |
| 4 | CR40G0.75 | 5715 | 50.85 | 1.99 |
| 5 | CR40G1.0 | 4200 | 55.4 | 1.47 |
| 6 | CR60G0.25 | 4450 | 53.42 | 1.56 |
| 7 | CR60G0.5 | 5575 | 51.97 | 1.94 |
| 8 | CR60G0.75 | 6015 | 50.01 | 2.09 |
| 9 | CR60G1.0 | 4425 | 53.78 | 1.55 |
| 10 | CR70G0.25 | 4150 | 55.73 | 1.45 |
| 11 | CR70G0.5 | 4360 | 54.41 | 1.53 |
| 12 | CR70G0.75 | 4505 | 53.05 | 1.57 |
| 13 | CR70G1.0 | 4100 | 55.39 | 1.44 |
| 14 | CR80G0.25 | 4205 | 54.9 | 1.47 |
| 15 | CR80G0.5 | 4325 | 54.24 | 1.51 |
| 16 | CR80G0.75 | 4350 | 54.08 | 1.52 |
| 17 | CR80G1.0 | 4165 | 55.06 | 1.46 |
| 18 | CR100G0.25 | 3575 | 64.35 | 1.26 |
| 19 | CR100G0.5 | 3600 | 62.28 | 1.27 |
| 20 | CR100G0.75 | 3750 | 60.36 | 1.32 |
| 21 | CR100G1.0 | 3700 | 60.96 | 1.30 |




Graph 3.5 : Stress Intensity (Kic) of all test specimens




Graph 3.6 : Kic vs crack width regression equation of all test specimens




Graph 3.7 : Crack length (mm) of all test specimens

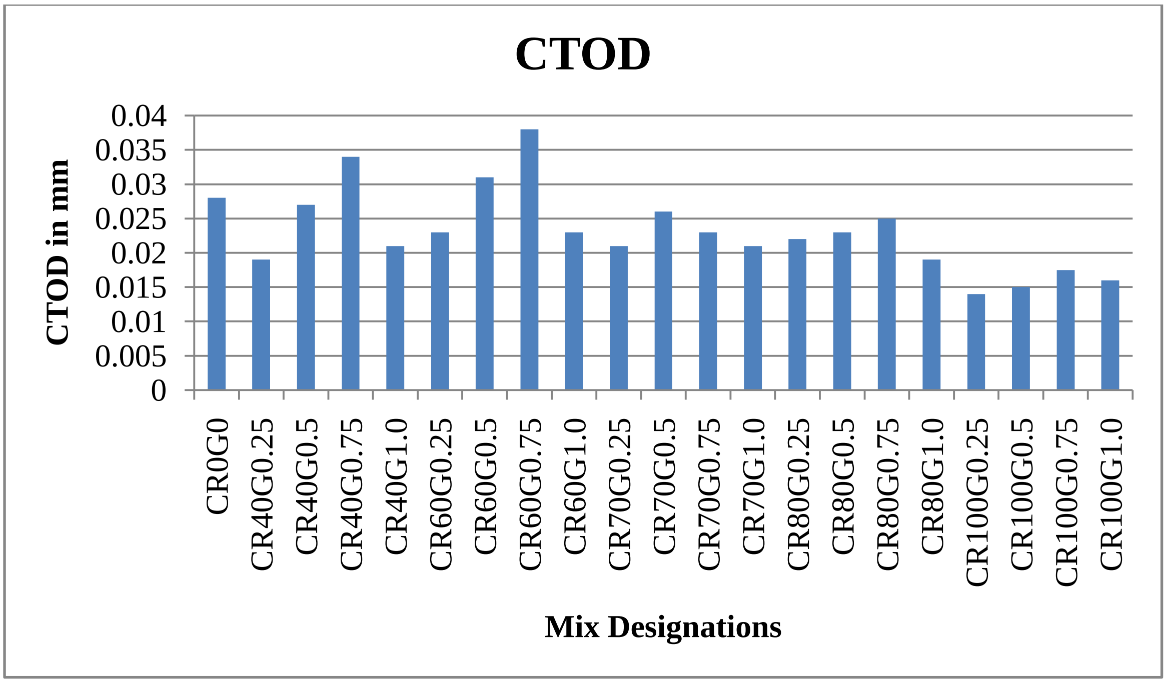
Fracture toughness increased with S2 glass fiber content with 60% recycled aggregate replacement and attained a maximum value for 0.75% fiber content and then decreased. With the introduction of S2 glass fibers, ductility was found to be improved and CR60G0.75 was found to be more ductile. The improvement in ductility was due to the active particle binding and containment. Flexural failure was the pattern of failure observed. Plain concrete beams failed by dividing into 2 halves, whereas GFRC beams only showed narrow cracks and no splitting. The results showed that the overall load and fracture capacity of GFRC beams were significantly increased relative to plain concrete beams.

*3.10.3 Crack Tip Opening Displacement (CTOD)*

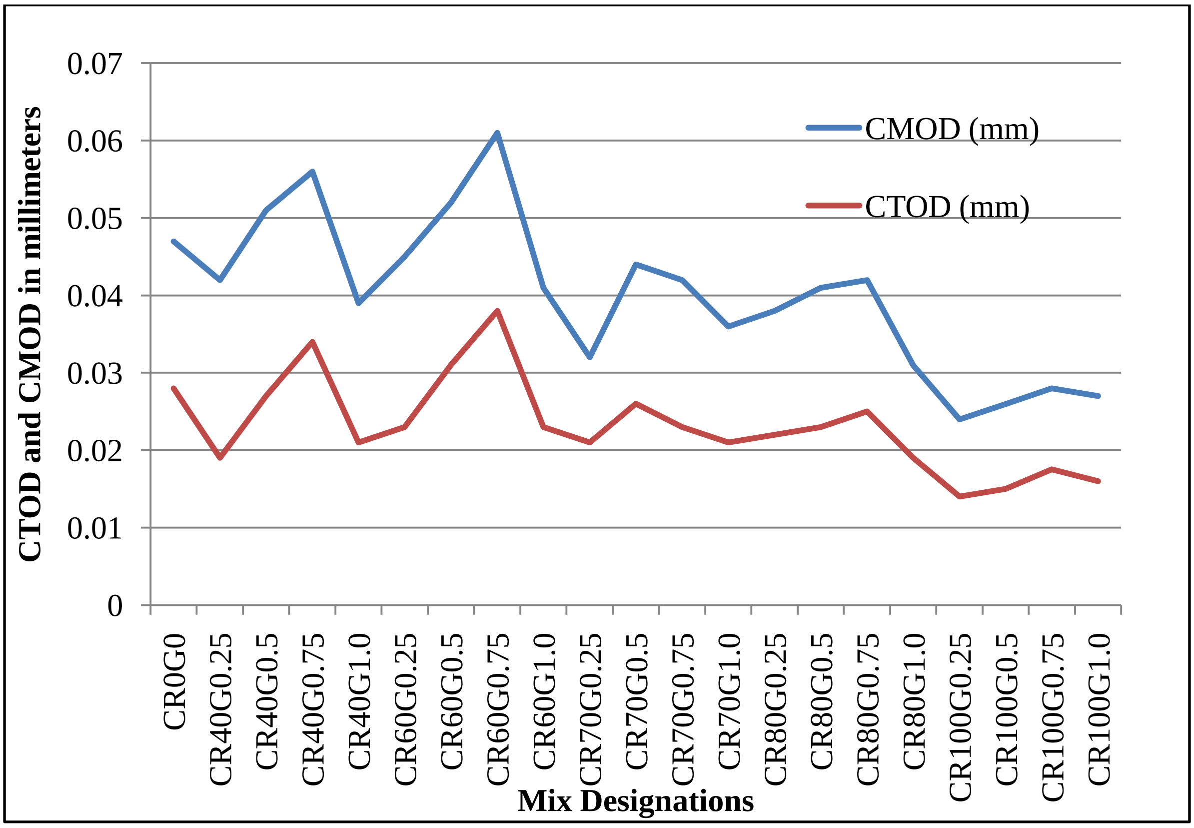
From RILEM-50 [83] after calculation of Kic and crack length experimentally, numerical value of CTOD were calculated from the formula as given in Appendix 1. Crack Mouth Opening Displacement (CMOD) was measured by Digital Vernier Calliper in mm at laboratory which is the initial opening and from the help of CMOD as given in Appendix 1 CTOD have been calculated. The results of CTOD and CMOD are listed in TABLE 3.19 and plotted in Graph 3.8 and Graph 3.9.

TABLE 3.19: Results of CTOD with Different S2 Glass Fiber and Recycle Aggregate on Concrete Beams

| SN | Name | CMOD (mm) | CTOD (mm) | Kic (MPa√m) |
|---|---|---|---|---|
| 1 | CR0G0 | 0.047 | 0.028 | 1.59 |
| 2 | CR40G0.25 | 0.042 | 0.019 | 1.53 |
| 3 | CR40G0.5 | 0.051 | 0.027 | 1.71 |
| 4 | CR40G0.75 | 0.056 | 0.034 | 1.99 |
| 5 | CR40G1.0 | 0.039 | 0.021 | 1.47 |
| 6 | CR60G0.25 | 0.045 | 0.023 | 1.56 |
| 7 | CR60G0.5 | 0.052 | 0.031 | 1.94 |
| 8 | CR60G0.75 | 0.061 | 0.038 | 2.09 |
| 9 | CR60G1.0 | 0.041 | 0.023 | 1.55 |
| 10 | CR70G0.25 | 0.032 | 0.021 | 1.45 |
| 11 | CR70G0.5 | 0.044 | 0.026 | 1.53 |
| 12 | CR70G0.75 | 0.042 | 0.023 | 1.57 |
| 13 | CR70G1.0 | 0.036 | 0.021 | 1.44 |
| 14 | CR80G0.25 | 0.038 | 0.022 | 1.47 |
| 15 | CR80G0.5 | 0.041 | 0.023 | 1.51 |
| 16 | CR80G0.75 | 0.042 | 0.025 | 1.52 |
| 17 | CR80G1.0 | 0.031 | 0.019 | 1.46 |
| 18 | CR100G0.25 | 0.024 | 0.014 | 1.26 |
| 19 | CR100G0.5 | 0.026 | 0.015 | 1.27 |
| 20 | CR100G0.75 | 0.028 | 0.0175 | 1.32 |
| 21 | CR100G1.0 | 0.027 | 0.016 | 1.30 |




Graph 3.8 : CTOD of all test specimens




Graph 3.9 : Line graph of CTOD & CMOD

### 3.11 Correlation between CTOD and Kic

The correlation is the statistical method to find degree of relationship between two variables. This method was been used for finding correlation between "Crack Tip Opening Displacement (CTOD) and Stress Intensity (Kic) for the two mix designation sets one having 60% of "recycled aggregates" and another having 80% of "recycled aggregates". The two well known methods used for finding correlation between the two variables are:

1. Karl Pearson's Coefficient of correlation
2. Spearman's Rank Method.

The correlation coefficient was calculated by both the methods and average value of correlation was considered for final analysis. The values obtained were compared with the Correlation Coefficient scale as shown in TABLE 3.20. The calculations of correlation coefficient as per the two methods have been given below.

TABLE 3.20 : Correlation Coefficient Scale

<table>
<tr><td rowspan="3">Perfectly Correlation (-1)</td><td colspan="4">Negative</td><td rowspan="3">No Correlation 0</td><td colspan="4">Positive</td><td rowspan="3">Perfectly Correlation (+1)</td></tr>
<tr><td>Strong</td><td>Moderate</td><td colspan="2">Weak</td><td colspan="2">Weak</td><td>Moderate</td><td>Strong</td></tr>
<tr><td>-0.9</td><td>-0.7</td><td>-0.5</td><td>-0.1</td><td>0.1</td><td>0.5</td><td>0.7</td><td>0.9</td></tr>
</table>

#### *3.11.1 Karl Pearson's Coefficient of Correlation*

The Karl Pearson gave a method to find the coefficient correlation by equation (5)

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \qquad (5)$$

Where x is CTOD, y is Kic and n is number of samples

The calculation of correlation coefficient of Mix designations with 60% recycled aggregates have been given in TABLE 3.21 and for Mix designations with 80% recycled aggregates has been shown in TABLE 3.22.

TABLE 3.21 : Karl Pearson's calculation for Mix Designations with 60% Recycled aggregates

| SN | Name | CTOD (mm) (x) | Kic (MPa√m) (y) | $x^2$ | $y^2$ | xy |
|---|---|---|---|---|---|---|
| 1 | CR60G0.25 | 0.023 | 1.56 | 0.000529 | 2.4336 | 0.03588 |
| 2 | CR60G0.5 | 0.031 | 1.94 | 0.000961 | 3.7636 | 0.06014 |
| 3 | CR60G0.75 | 0.038 | 2.09 | 0.001444 | 4.3681 | 0.07942 |
| 4 | CR60G1.0 | 0.023 | 1.55 | 0.000529 | 2.4025 | 0.03565 |
| Total | | 0.115 | 7.14 | 0.003463 | 12.9678 | 0.21109 |

The value of correlation coefficient was calculated as per equation (5)

Correlation Coefficient = $r = \frac{4*(0.21109)-0.115*7.14}{\sqrt{[4*0.003463-(0.115)^2][4*12.9678-(7.14)^2]}} = 0.983764$

TABLE 3.22 : Karl Pearson's calculation for Mix Designations with 80% Recycled aggregates

| SN | Name | CTOD (mm) (x) | Kic (MPa√m) (y) | $x^2$ | $y^2$ | xy |
|---|---|---|---|---|---|---|
| 1 | CR80G0.25 | 0.022 | 1.47 | 0.000484 | 2.1609 | 0.03234 |
| 2 | CR80G0.5 | 0.023 | 1.51 | 0.000529 | 2.2801 | 0.03473 |
| 3 | CR80G0.75 | 0.025 | 1.52 | 0.000625 | 2.3104 | 0.038 |
| 4 | CR80G1.0 | 0.019 | 1.46 | 0.000361 | 2.1316 | 0.02774 |
| Total | | 0.089 | 5.96 | 0.001999 | 8.883 | 0.13281 |

The value of correlation coefficient was calculated as per equation (5)

Correlation Coefficient = $r = \frac{4*(0.13281)-0.089*5.96}{\sqrt{[4*0.001999-(0.089)^2][4*8.883-(5.96)^2]}} = 0.905822$

*3.11.2 Spearman's Rank Coefficient of Correlation*

The Spearman's gave a method to find the coefficient correlation by using rank method and used equation (6)

$$\boldsymbol{r = 1 - \frac{6\sum d^2}{n(n^2-1)}} \qquad (6)$$

Where d is difference between ranks of CTOD and Kic and n is number of samples

The calculation of correlation coefficient of Mix designations with 60% recycled aggregates have been given in TABLE 3.23 and for Mix designations with 80% recycled aggregates have been shown in TABLE 3.24.

TABLE 3.23 : Spearman's Rank Correlation Coefficient calculation for Mix Designations with 60% Recycled aggregates

| SN | Name | CTOD (mm) | Kic (MPa√m) | Rank of CTOD | Rank of Kic | Difference in Ranks 'd' | '$d^2$' |
|---|---|---|---|---|---|---|---|
| 1 | CR60G0.25 | 0.023 | 1.56 | 3 | 3 | 0 | 0 |
| 2 | CR60G0.5 | 0.031 | 1.94 | 2 | 2 | 0 | 0 |
| 3 | CR60G0.75 | 0.038 | 2.09 | 1 | 1 | 0 | 0 |
| 4 | CR60G1.0 | 0.023 | 1.55 | 3 | 4 | -1 | 1 |
| | | | | | | Total | 1 |

The value of correlation coefficient was calculated as per equation (6)

Correlation Coefficient = $r = 1 - \frac{6*1}{4(4^2-1)} = 0.9$

TABLE 3.24 : Spearman's Rank Correlation Coefficient calculation for Mix Designations with 80% Recycled aggregates

| SN | Name | CTOD (mm) | Kic (MPa√m) | Rank of CTOD | Rank of Kic | Difference in Ranks 'd' | '$d^2$' |
|---|---|---|---|---|---|---|---|
| 1 | CR80G0.25 | 0.022 | 1.47 | 3 | 3 | 0 | 0 |
| 2 | CR80G0.5 | 0.023 | 1.51 | 2 | 2 | 0 | 0 |
| 3 | CR80G0.75 | 0.025 | 1.52 | 1 | 1 | 0 | 0 |
| 4 | CR80G1.0 | 0.019 | 1.46 | 4 | 4 | 0 | 0 |
| | | | | | | Total | 0 |

The value of correlation coefficient was calculated as per equation (6)

Correlation Coefficient = $r = 1 - \frac{6*0}{4(4^2-1)} = 1.0$

The average values of Correlation Coefficients obtained by two methods for Mixes having 60% and 80% recycled aggregates have been given in TABLE 3.25.

TABLE 3.25 : Average Correlation Coefficient for Mix Designations with 60% and 80% Recycled aggregates

| Recycled aggregate percentages | Karl Pearson's Correlation Coefficient | Spearman's Rank Correlation Coefficient | Average Correlation Coefficient |
|---|---|---|---|
| 60% | 0.983764 | 0.9 | 0.941882 |
| 80% | 0.905822 | 1.0 | 0.952911 |

The results obtained showed that there is a strong positive correlation between CTOD and Kic as per TABLE 3.20.

### 3.12 Cost Analysis

The design mix proportion of M25 is 1:1.688:2.38. The dry weight of material has been calculated as per the bulkage of dry weight to wet weight and as per the experimental investigation it had been found that 152% of dry weight will count to

100% of compacted weight of concrete. The cost of the materials like cement, coarse aggregates, fine aggregates, recycled aggregates and S2 glass fiber have been taken as per the cost from local market that is Jalandhar, Phagwara and Ludhiana from where the materials were purchased. The labour cost have been taken as per the current rate of labour and mason. The cost of concrete have been calculated for 10 cubic meter for concrete and the reference have been taken from book "Estimating and costing in Civil Engineering" by author B.N. Dutta [96]. The cost of cement was Rs 400 per Bag, the cost of sand was Rs 40/ cubic feet, the cost of coarse aggregate was Rs 25/ cubic feet, the cost of recycle aggregate was Rs 12/ Cubic feet, the cost of admixture was Rs 278 / Kg and the cost of S2 glass fibre was Rs 100/Kg. The cost required to cast 10 cubic meter concrete of mix designations CR0G0, CR60G0.75, CR60G0.5 and CR80G0.75 have been shown in TABLE 3.26, TABLE **3.27**, TABLE **3.28** and TABLE **3.29**

TABLE 3.26 : Cost Analysis of control mix of M25 Grade for 10 cubic meter

| Description | Quantity | Market Rate | Rate per cubic meter | Total Amount Customer cost | Total Amount Product cost |
|---|---|---|---|---|---|
| Cement | 2.999 cum | Rs 400 / bag | Rs 11520 | 34548.48/- | 34548.48/- |
| Sand | 5.062 cum | Rs 40 / cubic feet | Rs 1412.6 | 7150.58/- | 7150.58/- |
| Coarse Aggregates | 7.138 cum | Rs 25 / cubic feet | Rs 882.9 | 6302.14/- | 6302.14/- |
| Admixture | 66.18 Kg | Rs 5560 / 20 Kg | Rs 1839.8 | 18398/- | 18398/- |
| Mason | 3 Nos. | Rs 500 / person | Rs 150 | 1500/- | - |
| Labour | 12 Nos. | Rs. 400 / person | Rs 480 | 4800/- | - |
| Sundries | Lump Sum | - | Rs 45 | 450/- | 450/- |
| Total of Materials and Labour | | | | 73149.2/- | 66849.20/- |
| Add 1.5% water charges | | | | 1097.24/- | 1002.74/- |
| Total cost for 10 cubic meter concrete | | | | 74246.44/- | 67851.94/- |
| Total cost for 1 cubic meter concrete | | | | Rs 7424.644/- | Rs 6785.19/- |

TABLE 3.27 : Cost Analysis of Mix Designation CR60G0.75 for 10 cubic meter

| Description | Quantity | Market Rate | Rate per cubic meter | Total Amount Customer cost | Total Amount Product cost |
|---|---|---|---|---|---|
| Cement | 2.999 cum | Rs 400 / bag | Rs 11520 | 34548.48/- | 34548.48/- |
| Sand | 5.062 cum | Rs 40 / cubic feet | Rs 1412.6 | 7150.58/- | 7150.58/- |
| Coarse Aggregates | 2.855 cum | Rs 25 / cubic feet | Rs 882.9 | 2520.68/- | 2520.68/- |
| Recycled Aggregates | 4.283 cum | Rs 12 / cubic feet | Rs 423.77 | 1815/- | 1815/- |
| Glass Fibers | 165.6 Kg | Rs 100 / Kg | Rs 1656 | 16560/- | 16560/- |
| Admixture | 66.18 Kg | Rs 5560 / 20 Kg | Rs 1839.8 | 18398/- | 18398/- |
| Mason | 3 Nos. | Rs 500 / person | Rs 150 | 1500/- | - |
| Labour | 12 Nos. | Rs. 400 / person | Rs 480 | 4800/- | - |
| Sundries | Lump Sum | - | Rs 45 | 450/- | 450/- |
| Total of Materials and Labour | | | | 87742.74/- | 81442.74/- |
| Add 1.5% water charges | | | | 1316.14/- | 1221.64/- |
| Total cost for 10 cubic meter concrete | | | | 89058.88/- | 82664.38/- |
| Total cost for 1 cubic meter concrete | | | | Rs 8905.9/- | Rs 8266.44/- |

TABLE 3.28 : Cost Analysis of Mix Designation CR60G0.5 for 10 cubic meter

| Description | Quantity | Market Rate | Rate per cubic meter | Total Amount Customer cost | Total Amount Product cost |
|---|---|---|---|---|---|
| Cement | 2.999 cum | Rs 400 / bag | Rs 11520 | 34548.48/- | 34548.48/- |
| Sand | 5.062 cum | Rs 40 / cubic feet | Rs 1412.6 | 7150.58/- | 7150.58/- |
| Coarse Aggregates | 2.855 cum | Rs 25 / cubic feet | Rs 882.9 | 2520.68/- | 2520.68/- |
| Recycled Aggregates | 4.283 cum | Rs 12 / cubic feet | Rs 423.77 | 1815/- | 1815/- |
| Glass Fibers | 110.4 Kg | Rs 100 / Kg | Rs 1104 | 11040/- | 11040/- |
| Admixture | 66.18 Kg | Rs 5560 / 20 Kg | Rs 1839.8 | 18398/- | 18398/- |
| Mason | 3 Nos. | Rs 500 / person | Rs 150 | 1500/- | - |

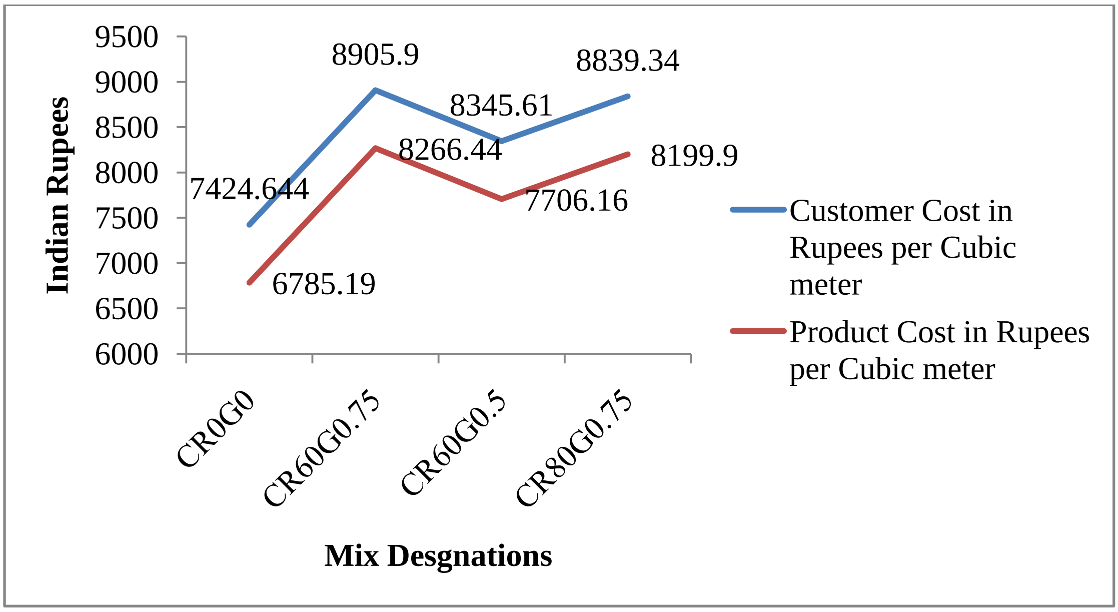
| | | | | | |
|---|---|---|---|---|---|
| Labour | 12 Nos. | Rs. 400 / person | Rs 480 | 4800/- | - |
| Sundries | Lump Sum | - | Rs 45 | 450/- | 450/- |
| Total of Materials and Labour | | | | 82222.74/- | 75922.74/- |
| Add 1.5% water charges | | | | 1233.34/- | 1138.84/- |
| Total cost for 10 cubic meter concrete | | | | 83456.08/- | 77061.58/- |
| Total cost for 1 cubic meter concrete | | | | Rs 8345.61/- | Rs 7706.16/- |

TABLE 3.29 : Cost Analysis of Mix Designation CR80G0.75 for 10 cubic meter

| Description | Quantity | Market Rate | Rate per cubic meter | Total Amount Customer cost | Total Amount Product cost |
|---|---|---|---|---|---|
| Cement | 2.999 cum | Rs 400 / bag | Rs 11520 | 34548.48/- | 34548.48/- |
| Sand | 5.062 cum | Rs 40 / cubic feet | Rs 1412.6 | 7150.58/- | 7150.58/- |
| Coarse Aggregates | 1.427 cum | Rs 25 / cubic feet | Rs 882.9 | 1259.9/- | 1259.9/- |
| Recycled Aggregates | 5.711 cum | Rs 12 / cubic feet | Rs 423.77 | 2420.15/- | 2420.15/- |
| Glass Fibers | 165.6 Kg | Rs 100 / Kg | Rs 1656 | 16560/- | 16560/- |
| Admixture | 66.18 Kg | Rs 5560 / 20 Kg | Rs 1839.8 | 18398/- | 18398/- |
| Mason | 3 Nos. | Rs 500 / person | Rs 150 | 1500/- | - |
| Labour | 12 Nos. | Rs. 400 / person | Rs 480 | 4800/- | - |
| Sundries | Lump Sum | - | Rs 45 | 450/- | 450/- |
| Total of Materials and Labour | | | | 87087.11/- | 80787.11/- |
| Add 1.5% water charges | | | | 1306.31/- | 1211.81/- |
| Total cost for 10 cubic meter concrete | | | | 88393.42/- | 81998.92/- |
| Total cost for 1 cubic meter concrete | | | | Rs 8839.34/- | Rs 8199.9/- |

Hence for CR60G0.5 the rate of the concrete was calculated Rs 8345.61/- per $m^3$ which is slightly higher than control mix but having more fracture toughness than normal concrete so 60 % replacement of coarse aggregates by recycled aggregates, the addition of 0.5 % S2 Glass fiber shows economical as well as optimum results.

Mix designation CR80G0.75 is having cost of nearly Rs. 8839.34/- per cubic meter which have cost slightly higher than cost of normal concrete that is Rs. 7424.644/- per cubic meter but use of 80 percentage of recycled aggregates increases the use of waste recycled aggregates to a very high content which is good for environment and natural resource management. The test results have been shown in Graph 3.10.




Graph 3.10 : Cost of Concrete mix designations in Indian Rupees

### 3.13 Rapid Chloride Penetration Test (RCPT)

Chloride Penetration of optimum mixes of concrete was checked using Rapid Chloride Penetration Test which had been performed in accordance to standard ASTM C1202 [88]. The specimens of CR0G0, CR60G0.5 and CR80G0.75 were prepared as cylinders of 100 mm diameter and 200 mm depth which were further spliced in samples of depth 50 mm. The obtained samples were then placed in vacuum saturator and the air voids were replaced with water particles as shown in Figure 3.18. The vacuum saturated samples were placed in mould of RCPT apparatus and sealed with silicone sealant as shown in Figure 3.19. The moulds were filled with NAOH solution of 0.3 molarity strength provided in positive diode, NACL solution with 3% strength provided in negative diode and tested by passing a current of 60 V DC. The current passed in sample was obtained in milli-amperes and the current passed had been noted after 30 minutes duration till 6 hours. The results have been tabulated in TABLE 3.30 and average charge passed have been calculated in Columbs. The results obtained have been compared with the standards of ASTM C1202 [88] given in TABLE 3.31.

Figure 3.18 : Vacuum saturator for replacing air voids with water

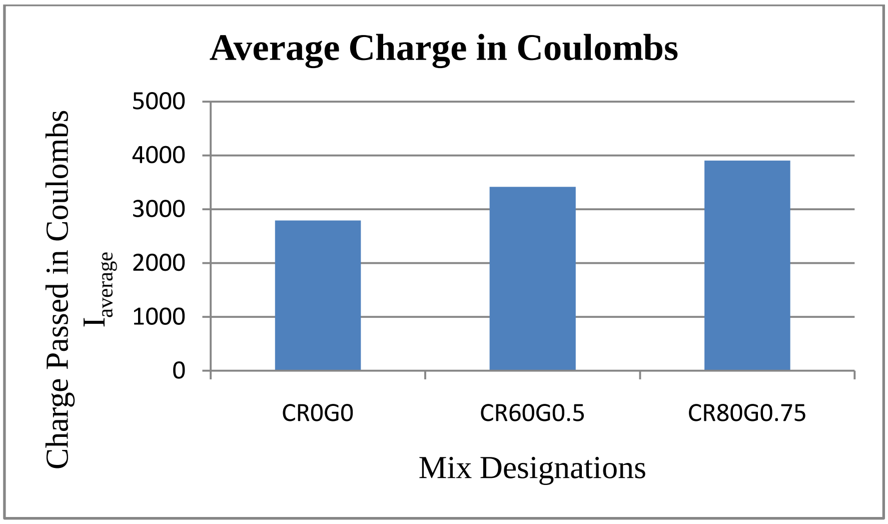

Figure 3.19 : Sealing of samples with Silicone Sealant

TABLE 3.30 : Rapid Chloride Penetration Test

| Designation | Time | CR0G0 (mA) | CR60G0.5 (mA) | CR80G0.75 (mA) |
|---|---|---|---|---|
| $I_0$ | 09:53 AM | 95 | 102 | 157 |
| $I_{30}$ | 10:23 AM | 108 | 107 | 226 |
| $I_{60}$ | 10:53 AM | 127 | 131 | 228 |
| $I_{90}$ | 11:23 AM | 132 | 149 | 179 |
| $I_{120}$ | 11:53 AM | 157 | 163 | 197 |
| $I_{150}$ | 12:23 PM | 148 | 178 | 166 |
| $I_{180}$ | 12:53 PM | 152 | 187 | 117 |
| $I_{210}$ | 01:23 PM | 155 | 192 | 69 |
| $I_{240}$ | 01:53 PM | 132 | 178 | 124 |
| $I_{270}$ | 02:23 PM | 123 | 168 | 179 |
| $I_{300}$ | 02:53 PM | 118 | 162 | 236 |
| $I_{330}$ | 03:23 PM | 107 | 158 | 247 |
| $I_{360}$ | 03:53 PM | 107 | 147 | 245 |
| $I_{Cumulative}$ (mA) | | 3105 | 3795 | 4338 |
| $I_{Average}$ (Coulombs) | | 2794.5 | 3415.5 | 3904.2 |

$I_{Cumulative} = I_0 + I_{360} + (2x\ (I_{30} + I_{60} + I_{90} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330}))$

$I_{Average} = I_{Cumulative} * 900/1000$




Graph 3.11 : Average Charge passed in Coulombs ($I_{Average}$)

TABLE 3.31 : Chloride Permeability based on charge passed

| Charge Passed in Coulombs | Chloride ION Penetrability |
|---|---|
| >4000 | High |
| 2000-4000 | Moderate |
| 1000-2000 | Low |
| 100-1000 | Very Low |
| <100 | Negligible |

The results obtained for the samples plotted in Graph 3.11 represent that the chloride penetration increases on increase of recycled aggregates but the results were coming in the range shown in TABLE 3.31 of moderate chloride ION penetration which is acceptable for practical applications.

### 3.14 X-Ray Diffraction Analysis (XRD)

X-Ray diffraction is a technique to determine the atomic and molecular structure of a crystal. The powdered sample is placed in the center of instrument as shown in the Figure 3.21 and illuminated with beam of X-Rays. The X-Ray tube and detector move in synchronized motion to receive the signal coming and is recorded in the graph between intensity and angle 2θ. The peaks observed are related to atomic structure of sample.

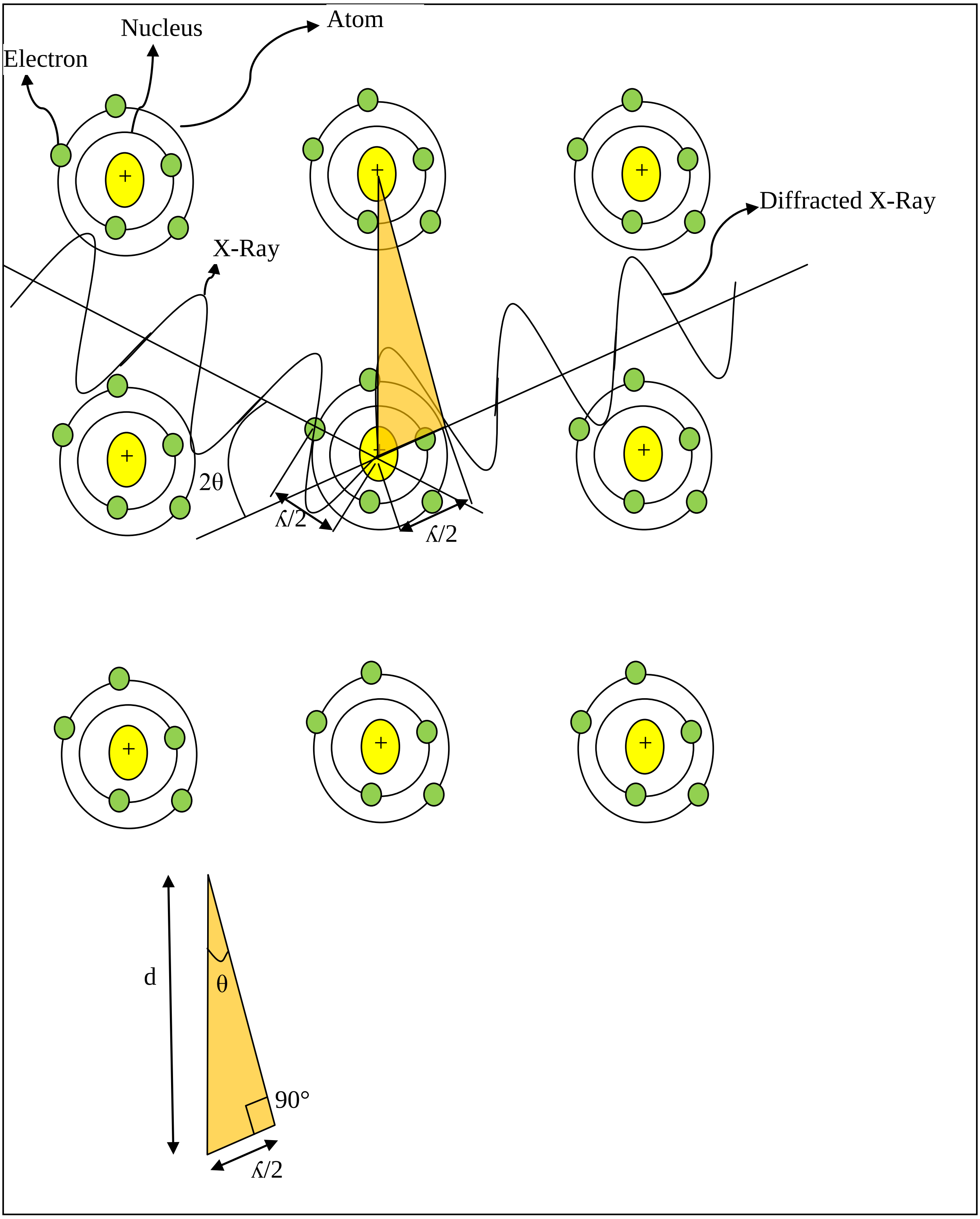



Figure 3.20 : Crystal structure with Atom arrangement showing X-Ray diffraction

The crystal is a form of regular arrangement of atoms and each atom consists of a nucleus surrounded by electrons. X-Rays are high energy light with repeated period called wavelength. When the wavelength is same as distance between atoms in a crystal the method is called diffraction as shown in Figure 3.20.

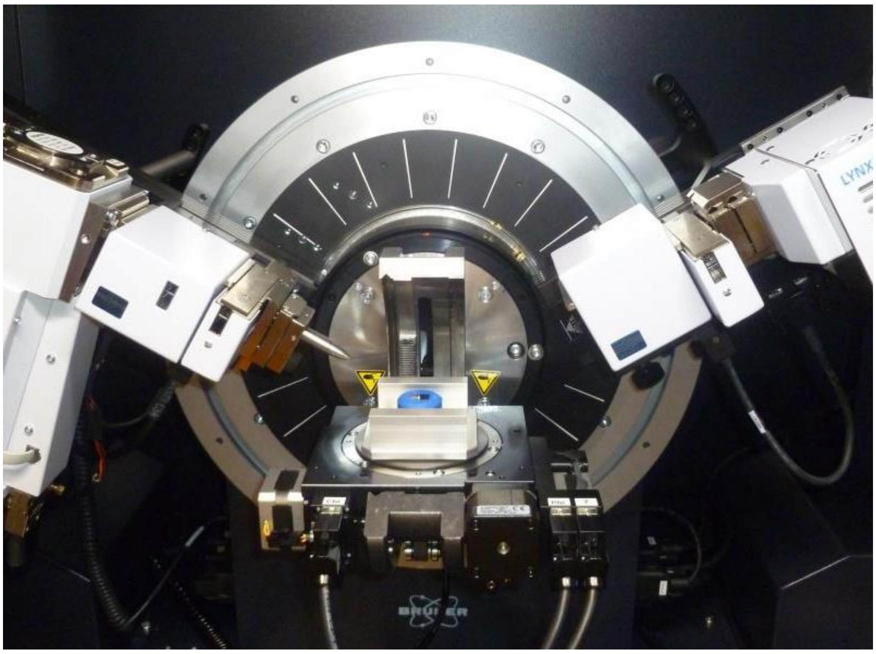


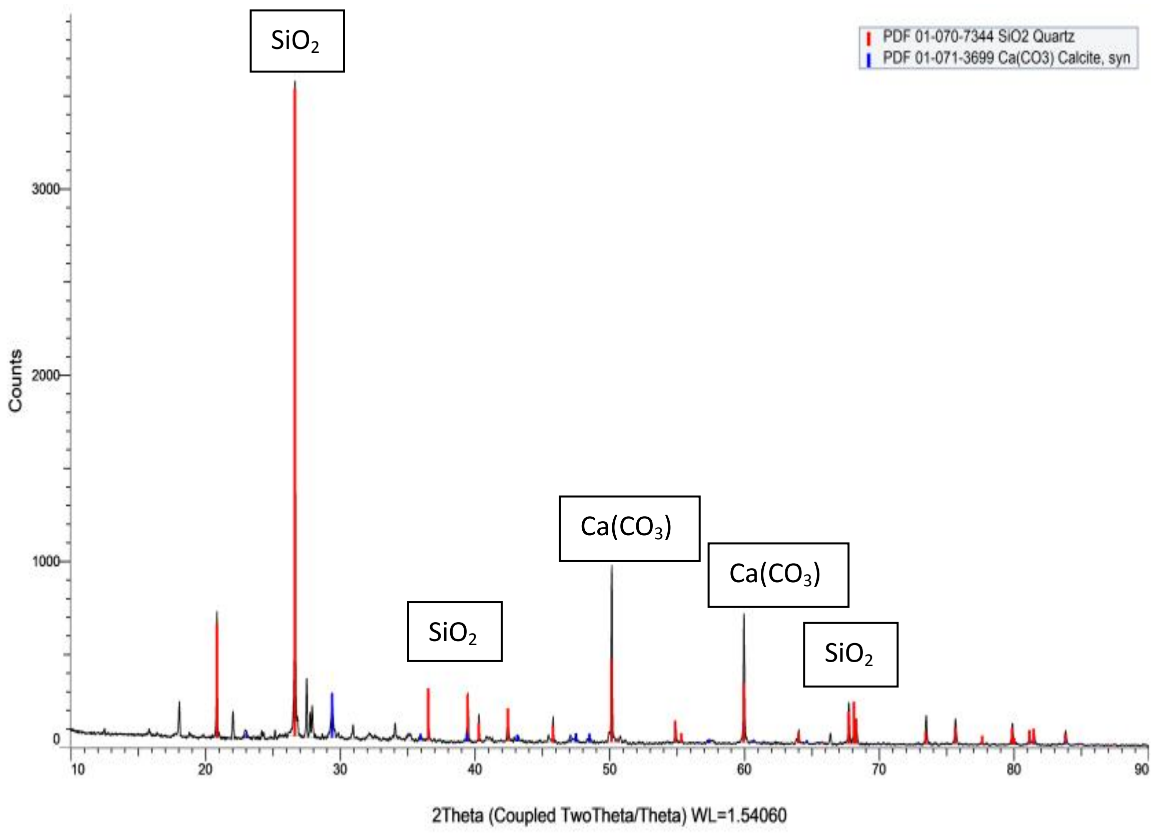

Figure 3.21 : The Bruker equipment for X-Ray Diffraction

When X-Ray impounds an atom its energy is absorbed by electrons and the electrons emit the energy in the form of X-Ray with same energy as the origin and this process is called elastic scattering. The angle between incident and scattered beam is called 2θ. The right angle triangle shown in Figure 3.20 is then used to find distance between atoms given by Bragg's Law as shown in equation (4)

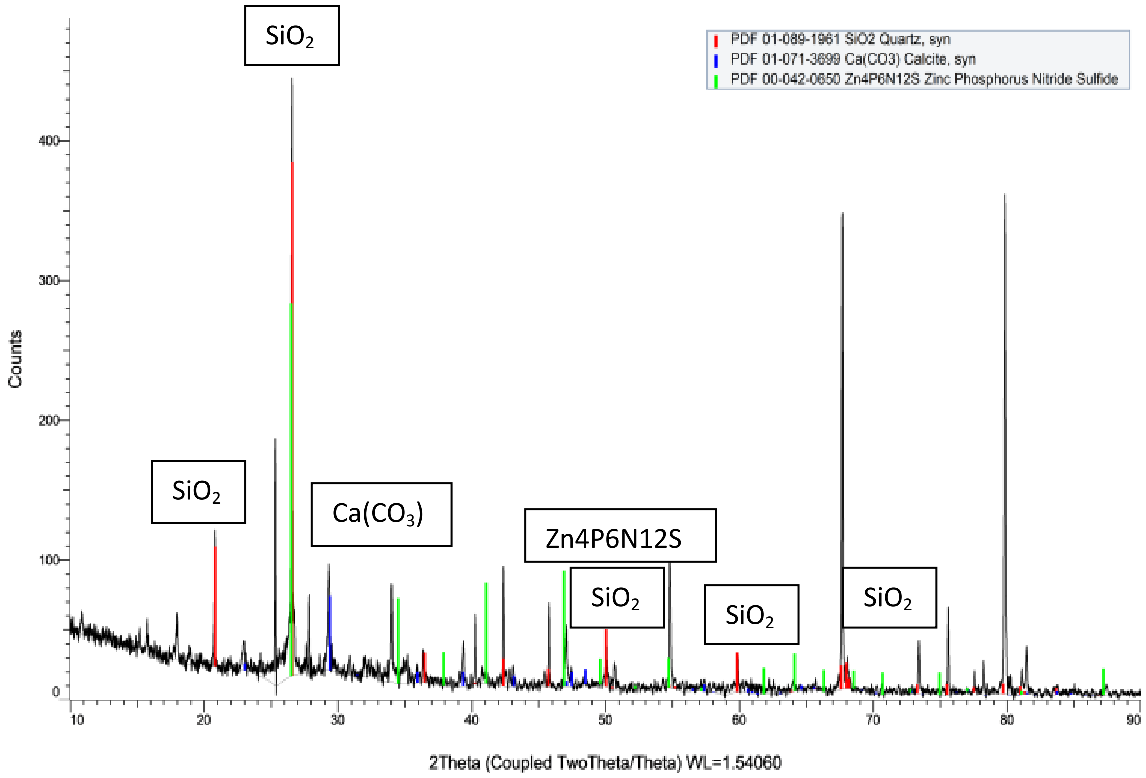
$$\boldsymbol{2d \sin \theta = n\Lambda} \quad (4)$$

The graph obtained are compared with International Center for Diffraction Data (ICDD) and the mapped with already available X-Ray diffraction data. The material peaks obtained have been shown in Graph 3.12, Graph 3.13 and Graph 3.14.

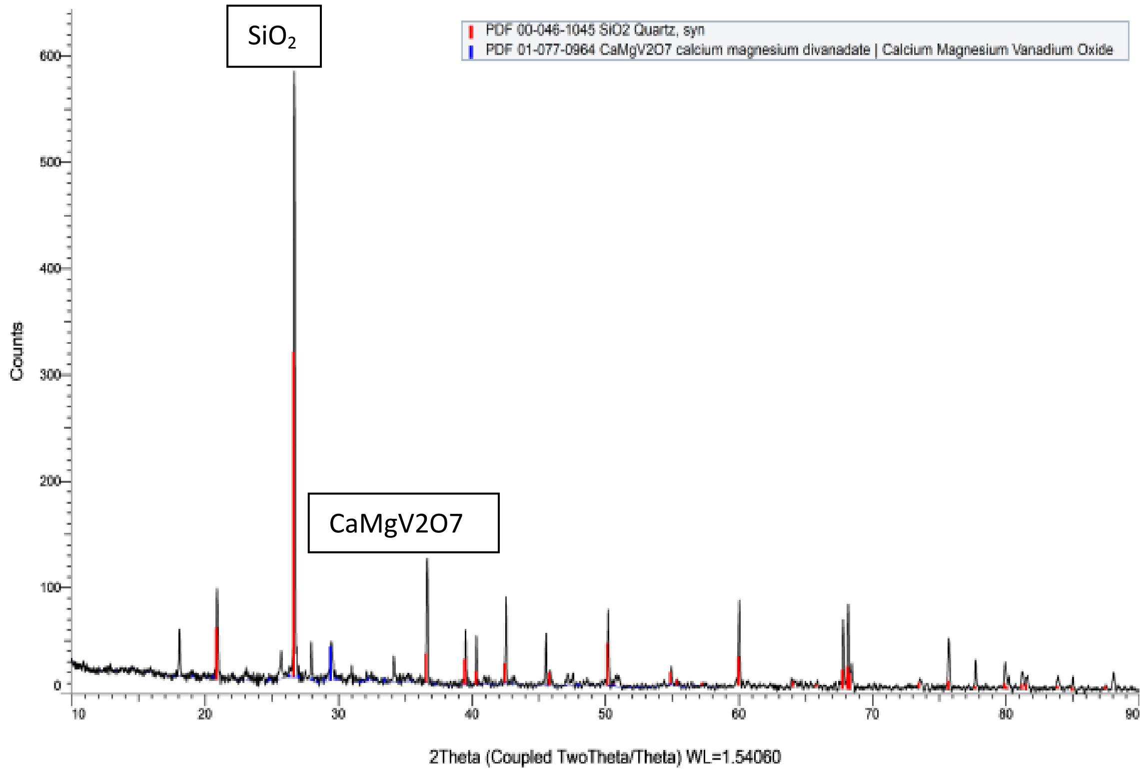
X-Ray Diffraction analysis was performed on the samples giving optimum results (CR60G0.5, CR80G0.75) and controlled sample (CR0G0). In this technique X-rays were passed through the powdered sample and graph was obtained between 2θ (angle between transmitted X-ray beam and reflected beam) and intensity counts which helps to identify intensity and structure of crystalline material as shown in Graph 3.12, Graph 3.13 and Graph 3.14. For normal concrete CR0G0 peak of $SiO_2$ was obtained at 3600, in CR60G0.5 the peak of $SiO_2$ was obtained at 450 and in CR80G0.75 the peak of $SiO_2$ was obtained at 580. The numbers of peak in CR60G0.5 of $SiO_2$ were found more. The specimens with recycled aggregates and glass fibers CR60G0.5 and CR80G0.75 were having less peaks of $Ca(CO_3)$ as compared to normal concrete. Presence of zinc phosphates was found in specimen CR60G0.5. In specimen CR80G0.75 presence of Calcium Magnesium vanadates were found.




Graph 3.12: Intensity vs 2θ graph of specimen CR0G0




Graph 3.13: Intensity vs 2θ graph of specimen CR60G0.5




Graph 3.14: Intensity vs 2θ graph of specimen CR80G0.75

### 3.15 Scanned Electronic Microscopy Analysis (SEM) and Energy Dispersive Spectroscopy Analysis (EDS)

The scanned electron microscope is an instrument used to check the microstructure of the materials by taking zoomed images. The powdered samples of crushed mix designations were coated with gold and scanned under electron microscope to a zoom level of 15000 times. The instrument was of Make JEOL shown in Figure 3.22 which consists of electron gun with anode and magnetic lenses in 2 numbers. The electrons emitted by electron gun were focused on the specimen using magnetic lenses as shown in Figure 3.23. The electrons bombarding on the specimen excite the electrons of specimen and emit X-Rays which were detected by the detector gives EDS values of material compositions and the scanned zoom image was analyzed for the material crystalline behaviour.

Figure 3.22 : Scanned Electron Microscope by JEOL

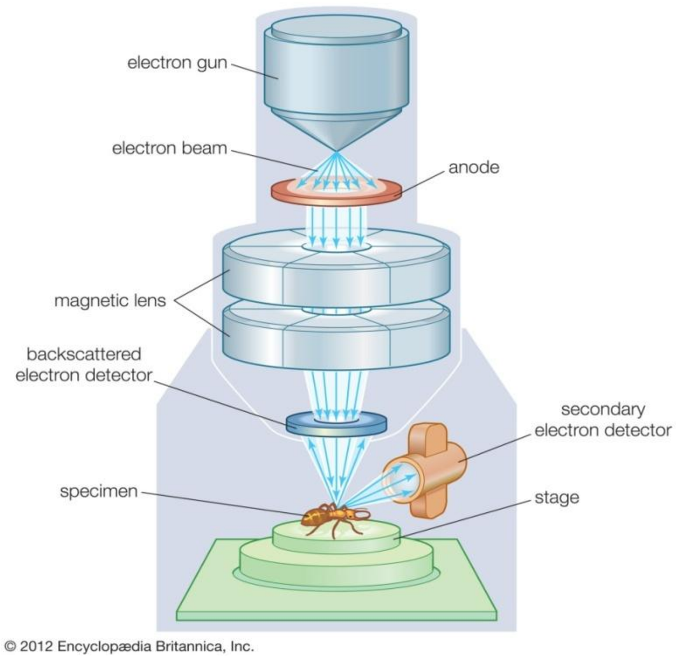



Figure 3.23 : Scanned Electron Microscope details

(Source: https://www.britannica.com/technology/scanning-electron-microscope)

The microstructure of the concrete specimens had been studied by using scanning electron microscopy analysis (SEM). This analysis provides topographical as well as compositional analysis of the material. The powdered samples had been tested for 15000 times zoom images shown in Figure 3.24, Figure 3.25 and Figure 3.26. The images obtained were analyzed and found that pores in normal concrete CR0G0 were more but less in CR60G0.5 and further less in CR80G0.75. The structure of CR80G0.75 was found to be more composite than CR0G0 and CR60G0.5.

The energy dispersive spectroscopy analysis (EDS) was performed on specimens CR0G0, CR60G0.5 and CR80G0.75 shown in Figure 3.27, Figure 3.28, Figure 3.29 and Graph 3.15, Graph 3.16, Graph 3.17. The atomic percentages of calcium silicates and silicon dioxides have been tabulated in TABLE 3.32 and expressed in graphical representation in Graph 3.18. The percentage of calcium silicates for specimen CR60G0.5 were found less than specimens CR0G0 and CR80G0.75. The percentage of calcium silicates was found maximum in specimen CR80G0.75 which represents the reason of more strength than CR60G0.5. Presence of more Silicon dioxide in CR60G0.5 represents more elastic behavior of mix and so verifies experimental behavior of specimen CR60G0.5 to have more fracture stress intensity and less crack width.

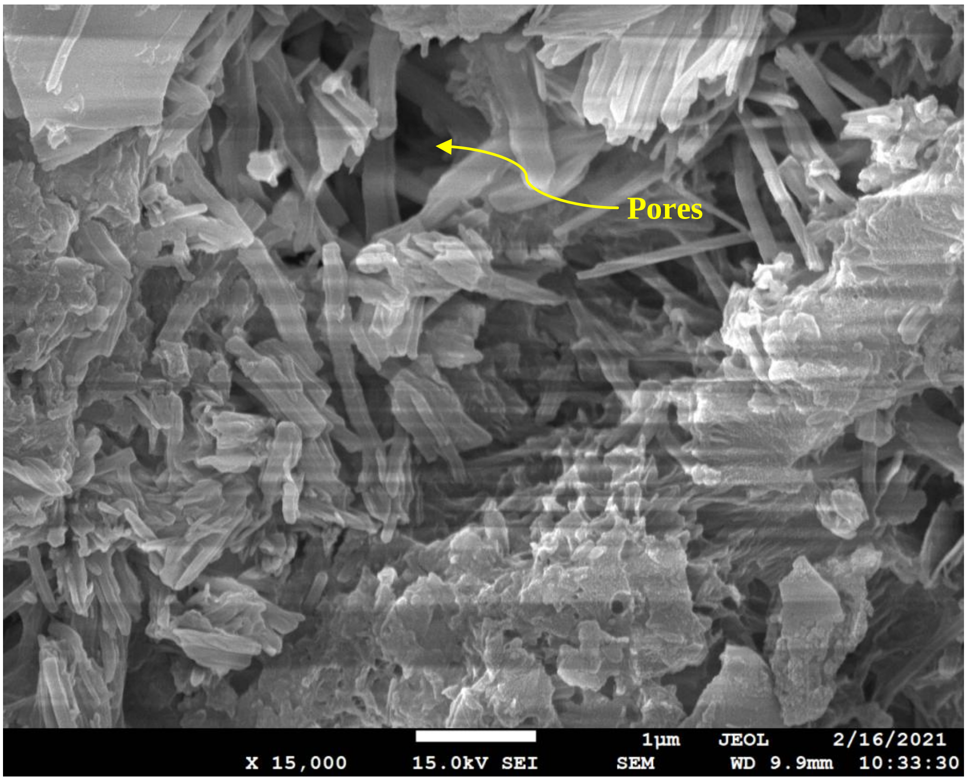



Figure 3.24: SEM image of CR0G0

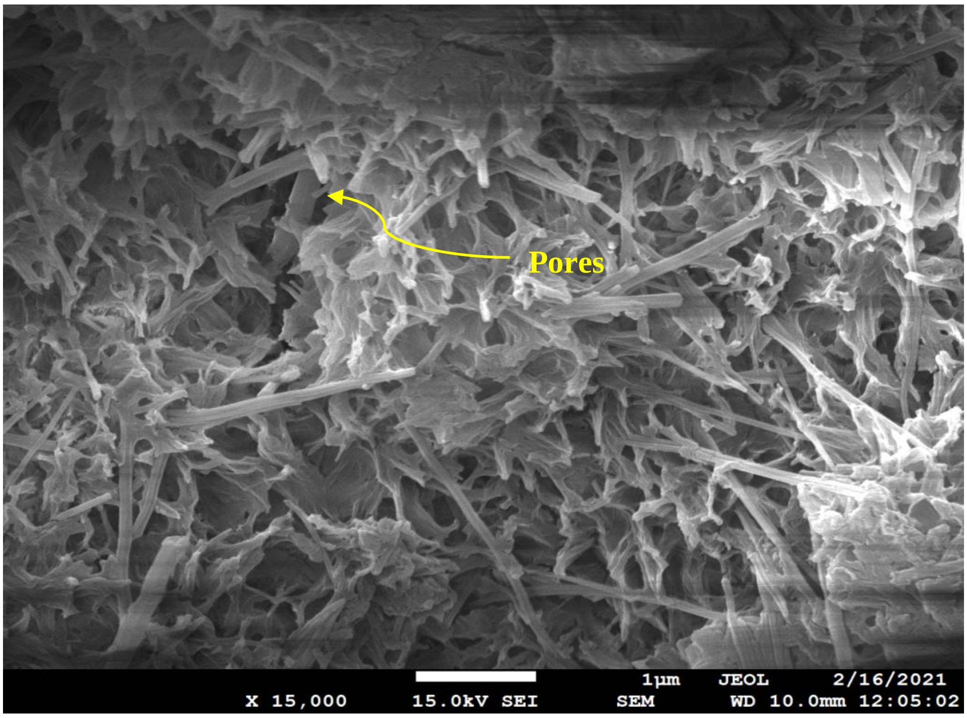



Figure 3.25: SEM image of CR60G0.5

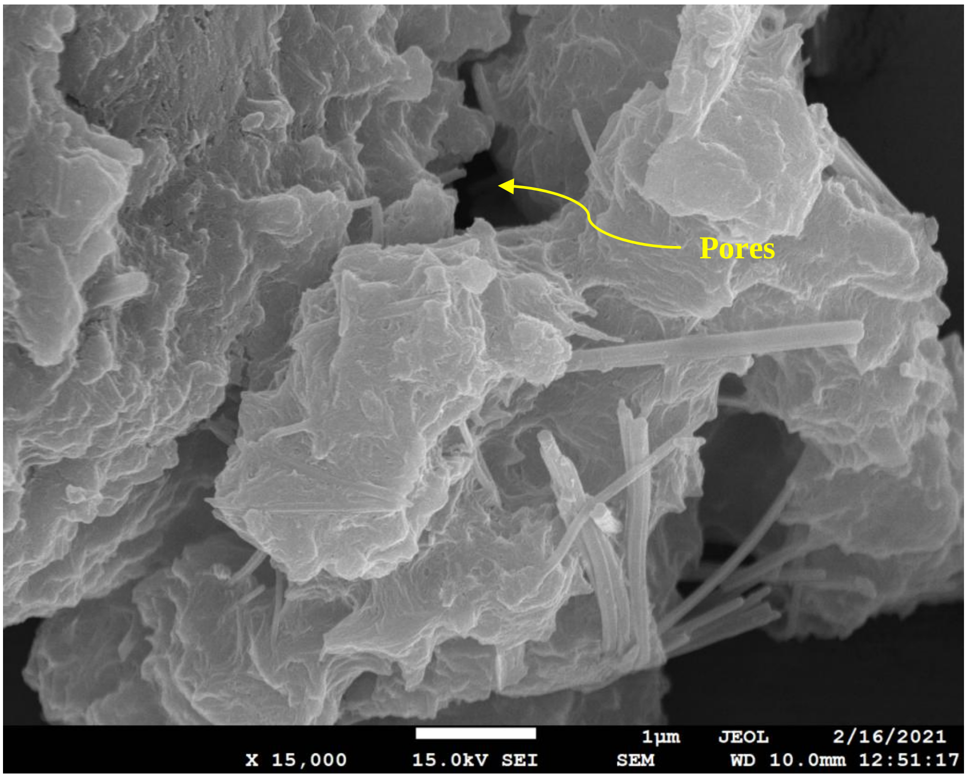



Figure 3.26: SEM image of CR80G0.75

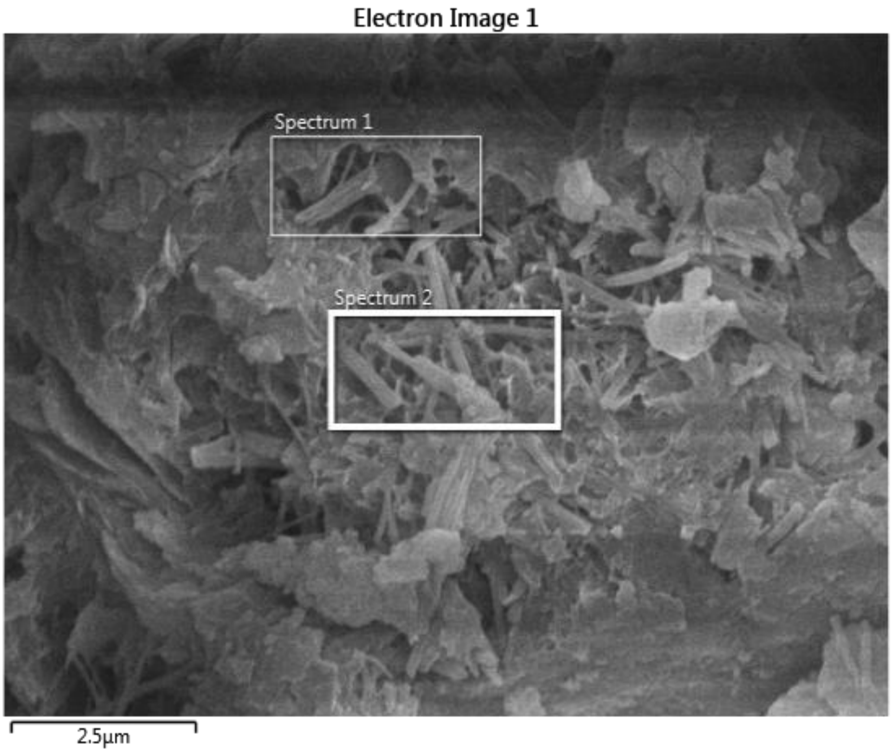
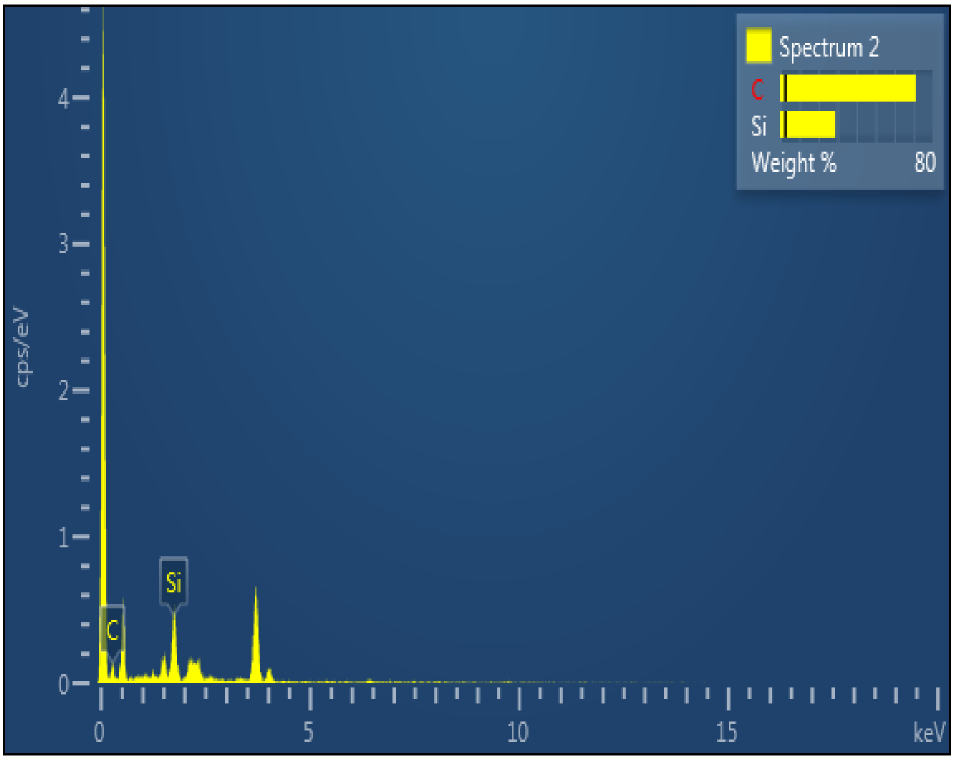



Figure 3.27: Position of spectrum selected for EDS analysis in CR0G0




Graph 3.15: Graphical representation of percentages of calcium silicates and silicon dioxide for specimen CR0G0

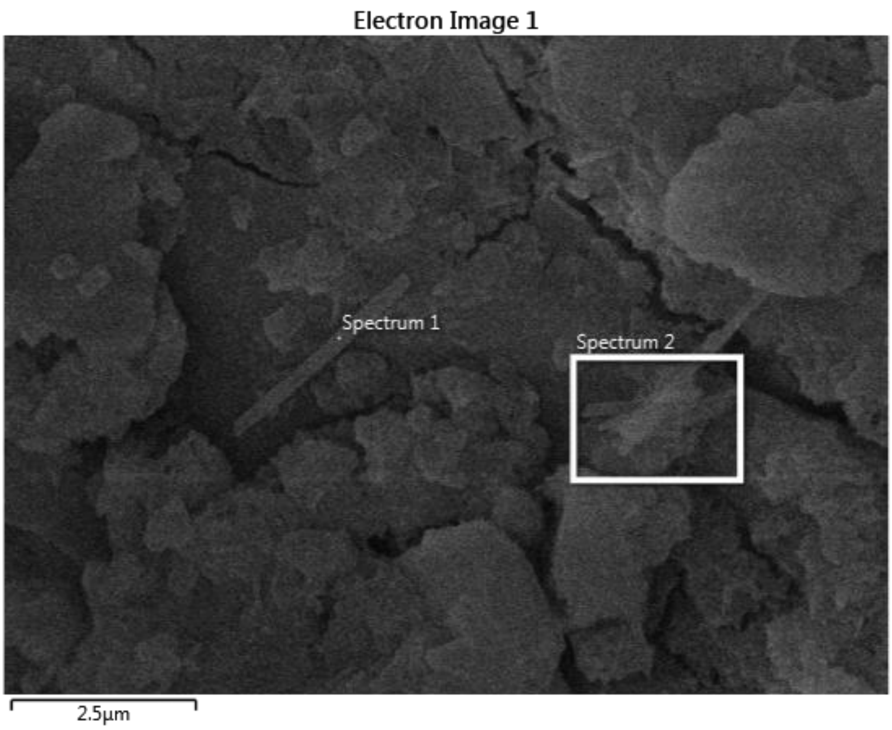
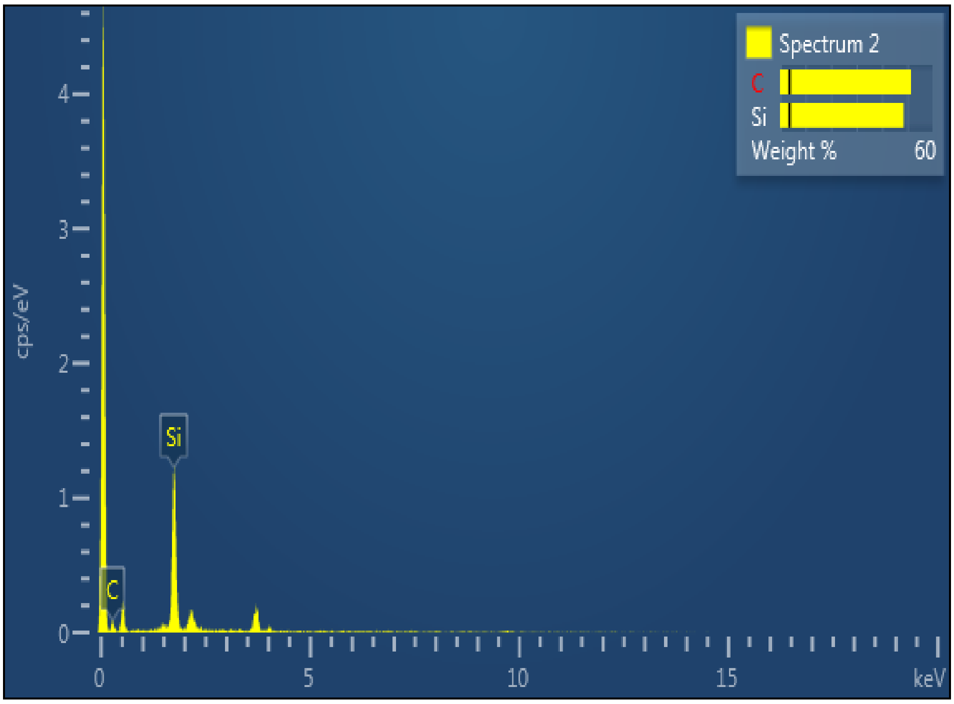



Figure 3.28: Position of spectrum selected for EDS analysis in CR60G0.5




Graph 3.16: Graphical representation of percentages of calcium silicates and silicon dioxide for specimen CR60G0.5

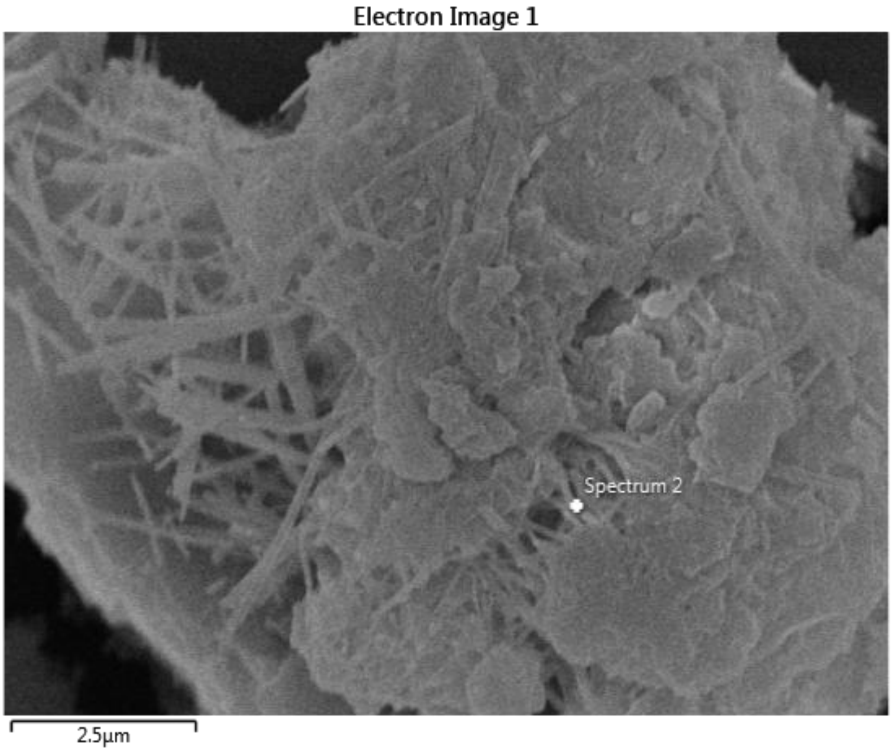
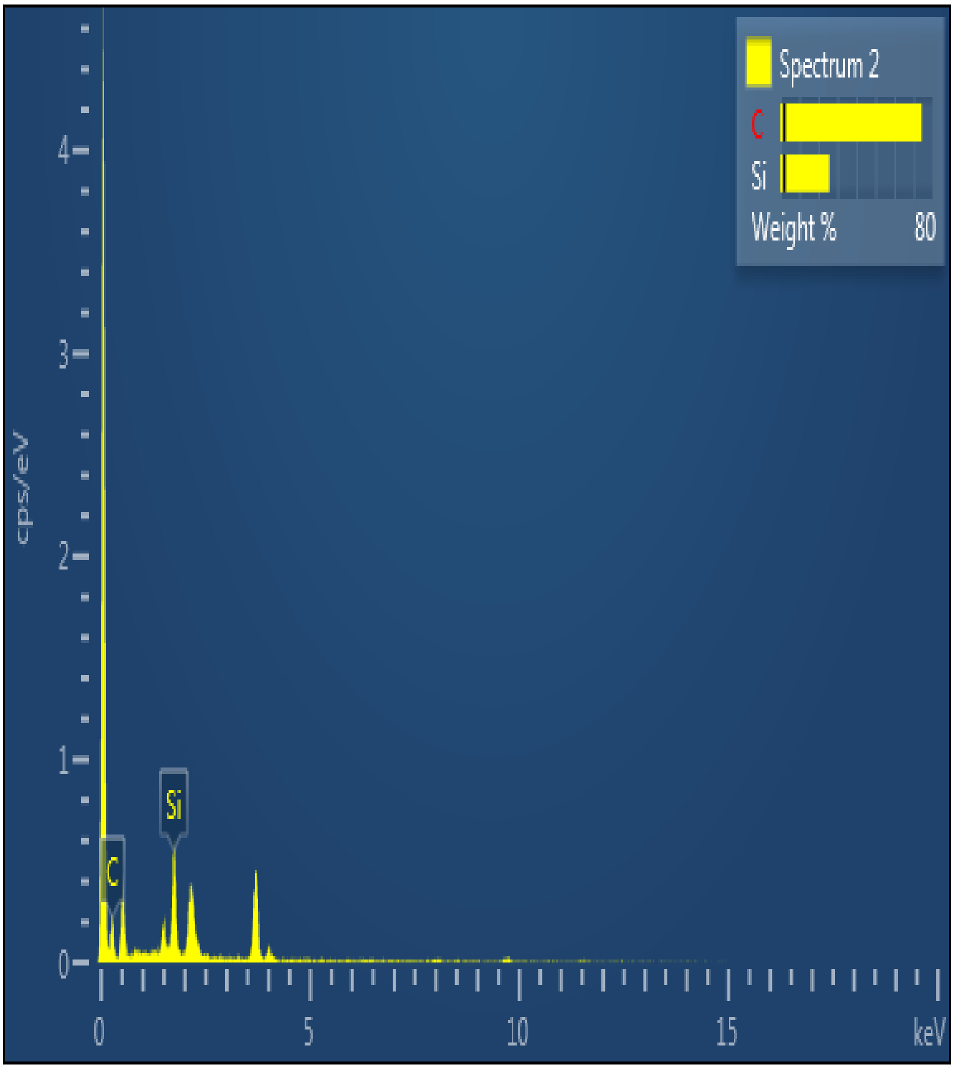


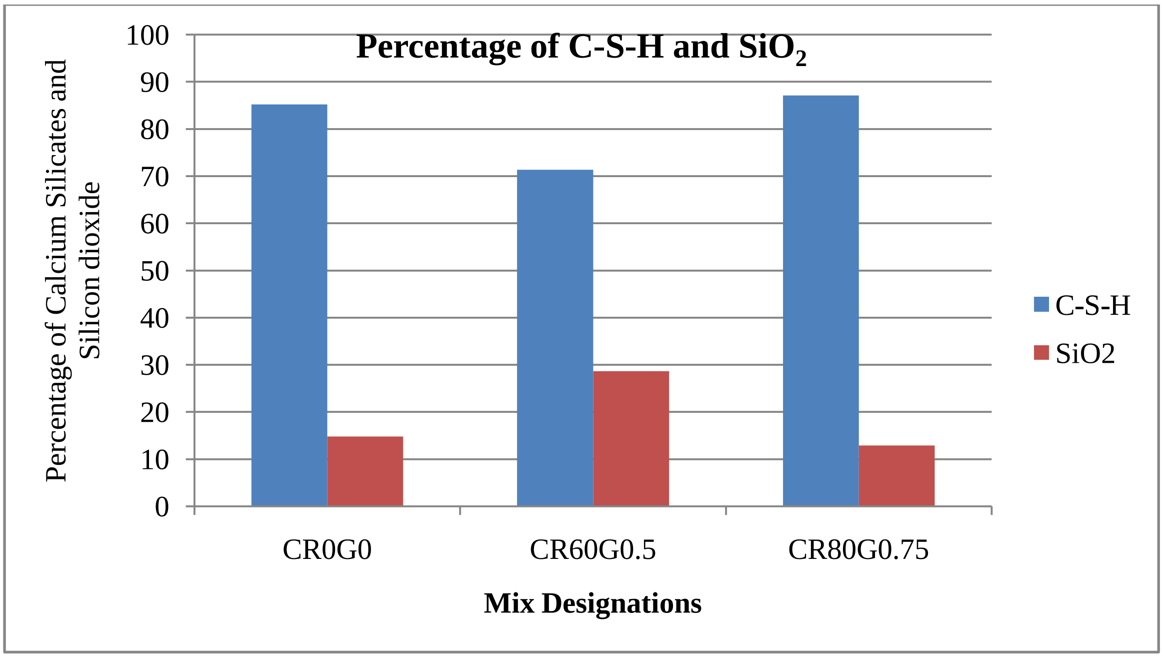

Figure 3.29: Position of spectrum selected for EDS analysis in CR80G0.75




Graph 3.17: Graphical representation of percentages of calcium silicates and silicon dioxide for specimen CR80G0.75

TABLE 3.32: Percentage of calcium silicates and silicon dioxide in different specimens

| Material | CR0G0 | CR60G0.5 | CR80G0.75 |
|---|---|---|---|
| C-S-H | 85.21 | 71.32 | 87.09 |
| SiO2 | 14.79 | 28.68 | 12.91 |




Graph 3.18 : Percentage of calcium silicates and silicon dioxide in different specimens

### 3.16 Software verification using ANSYS workbench

The software verification was one of the objectives of research and was performed by using software ANSYS workbench. To model the material in the software its young's Modulus and Poisson ratio had been experimentally calculated and verified by the theoretical formulas given by various standards. Using the values of Young's Modulus and Poisson ratio obtained from experimental setup, modelling of beam had been done in software ANSYS. The verification was done by applying four point loads on beam of size 100x100x500 mm and was loaded by two loads of 100 Newton each on two points as shown in Figure 3.31. The Maximum stress and maximum deflection were the parameters used to perform software verification.

The software verification had been done using ANSYS-workbench [91] and the stresses and deflection due to load were compared to verify the results obtained in experimental investigations were correlating with the actual behavior of the material.

To perform software analysis Young's Modulus of specimens and Poisson ratio were required and were checked by applying compressive load on cylindrical specimens of CR0G0, CR60G0.5 and CR80G0.75 as shown in Figure 3.30. The data obtained had been analyzed and plotted in the Graph 3.19. The data was implemented in the formula obtained from ASTM C469 [89] and Young's Modulus was calculated. The Young's Modulus was also calculated on the basis of Indian Standards IS:456-2000 [87] and American standard ACI 363 [90] for error analysis. The results were tabulated in TABLE 3.33. The formula used for calculation of Young's Modulus as per ASTM C469 [89] is given in equation (7)

$$\boldsymbol{E = \frac{(S_2 - S_1)}{(\varepsilon_2 - 0.00005)}} \qquad (7)$$

Where

$S_2$ –" Stress corresponding to 40% of ultimate load"

$S_1$ – "Stress corresponding to a longitudinal strain of 0.00005"

$\varepsilon_2$ – "Longitudinal strain produced by stress $S_2$"

The formula used for calculation of Poisson ratio as per ASTM C469 [89] is given in equation (8)

$$\mu = \frac{(\varepsilon_{t2} - \varepsilon_{t1})}{(\varepsilon_2 - 0.00005)} \qquad (8)$$

Where

$\varepsilon_{t1}$ = Transverse strain at mid height of the specimen produced by stress $S_1$.

$\varepsilon_{t2}$ = Transverse strain at mid height of the specimen produced by stress $S_2$.

The formula used to calculate Young's Modulus as per Indian Standard code IS:456-2000 [87] is given in equation (9)

$$\boldsymbol{E_C = 5000\sqrt{f_{ck}}} \qquad (9)$$

Where

$f_{ck}$ is characteristic strength of concrete

The formula used to calculate Young's Modulus as per American Standard code ACI 363 [90] is given in equation (10)

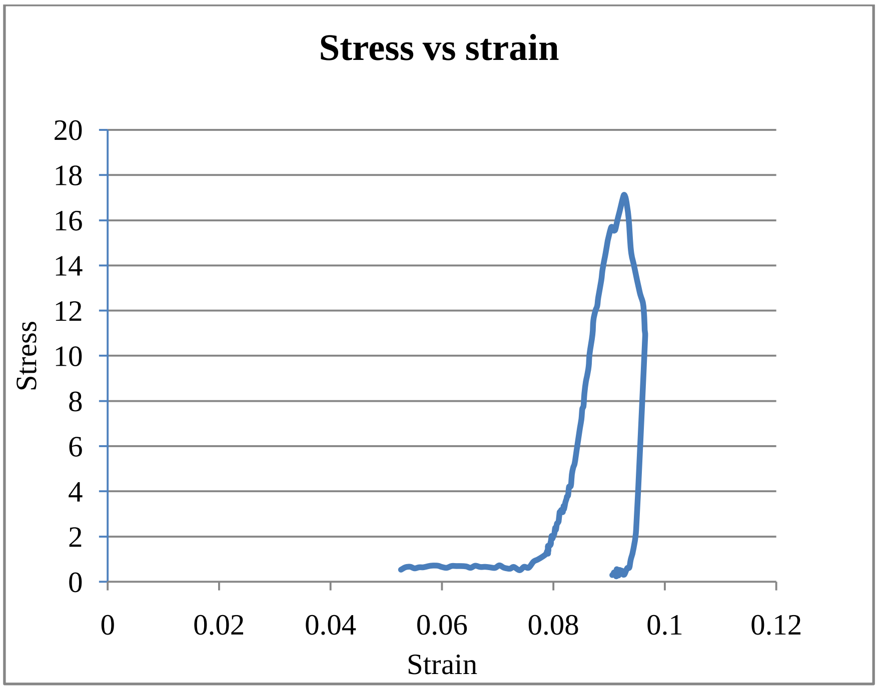
$$\boldsymbol{E_C = \left(\frac{w_c}{2300}\right)^{1.5}\left(3320\sqrt{f_c} + 6900\right)} \qquad (10)$$

Where

$f_c$ is compressive strength of concrete

$w_c$ is unit weight of concrete in $kg/m^3$

Figure 3.30: Testing of cylindrical specimens for Young's Modulus and Poisson ratio

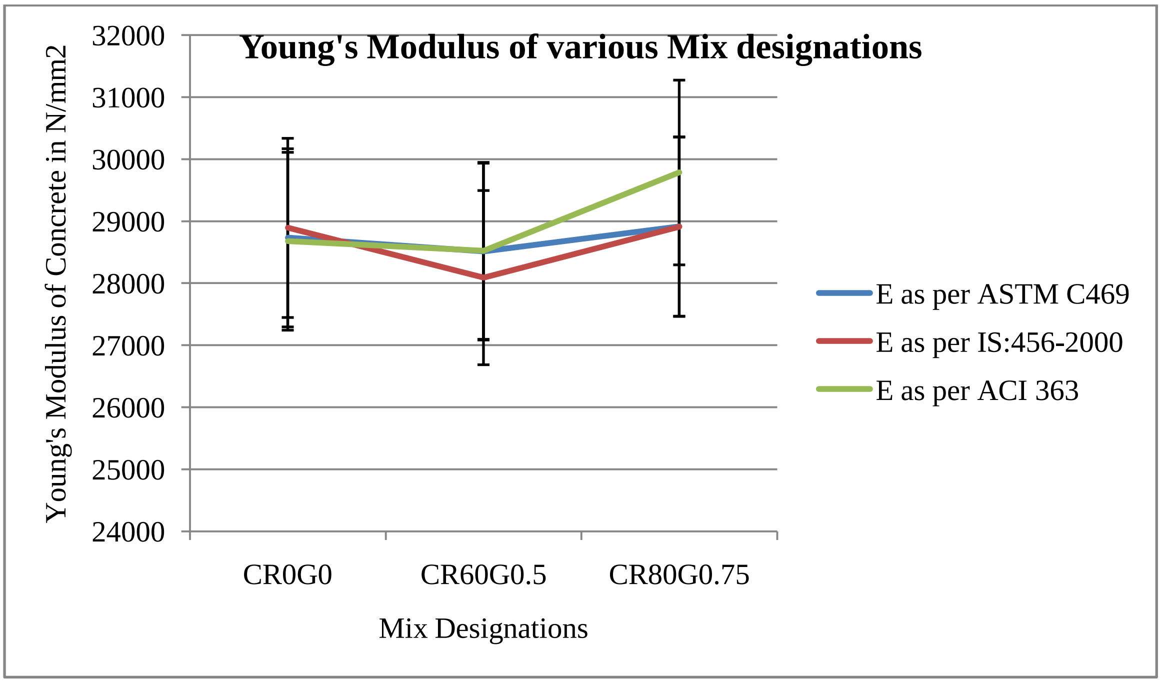


Graph 3.19: Stress strain graph obtained from testing cylindrical specimen under compressive load

TABLE 3.33: Value of Young's Modulus and Poisson ratio

| Specimen | E as per ASTM C469 | E as per IS:456-2000 | E as per ACI 363 | Poisson ratio | Percentage error with respect to IS:456-2000 | Percentage error with respect to ACI 363 |
|---|---|---|---|---|---|---|
| CR0G0 | 28734.56 | 28894.44 | 28678.96 | 0.17 | -0.553 | 0.194 |
| CR60G0.5 | 28512.38 | 28092.44 | 28524.59 | 0.164 | 1.495 | -0.043 |
| CR80G0.75 | 28917.32 | 28912.38 | 29788.04 | 0.16 | 0.017 | -2.923 |

The percentage error was coming less than 5% which is acceptable.




Graph 3.20 : Young's Modulus of various mix designations of concrete with respect to various Standards

*3.16.1 Modelling and analysis of beam specimen on ANSYS workbench*

The value of Young's Modulus and Poisson ratio had been used to model and analyze the beam model of size 500x100x100 mm under 4 point loading where loads of 100 N each were applied at two points as shown in Figure 3.31 and the results of stresses and deflections had been analyzed. The software ANSYS workbench pictures of analysis taking Maximum Stress as a parameter has been shown in Figure 3.32, Figure 3.34 and Figure 3.36 for mix designation CR0G0, CR60G0.5 and CR80G0.75 respectively and pictures of analysis taking Maximum Deflection as a parameter has been shown in Figure 3.33, Figure 3.35 and Figure 3.37 for mix designation CR0G0, CR60G0.5 and CR80G0.75 respectively. The analysis by software has been tabulated in TABLE 3.34. The results of young's modulus were plotted in Graph 3.20 and the results of analysis obtained from ANSYS workbench has been plotted in Graph 3.21.

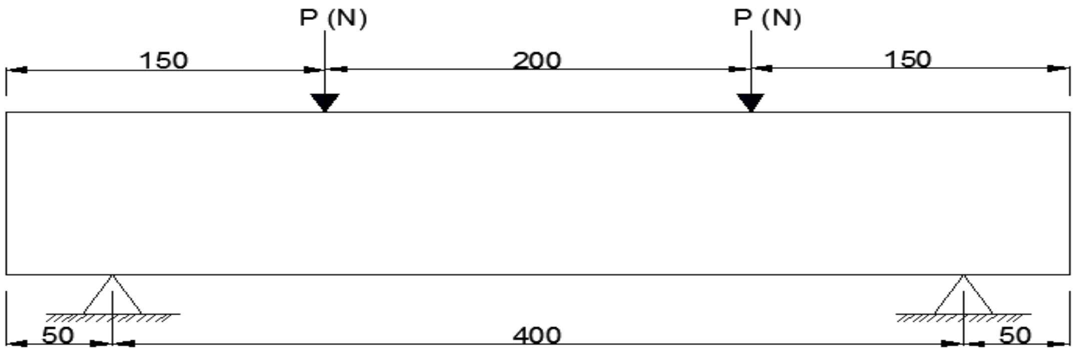



Figure 3.31: Loading pattern on beam model for analysis on ANSYS workbench

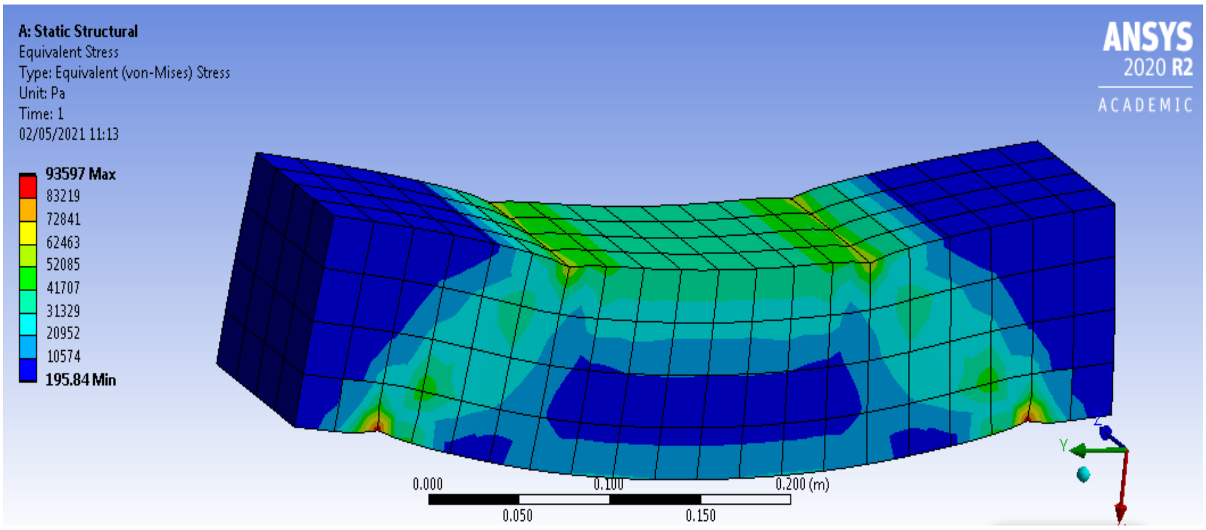



Figure 3.32: Maximum equivalent stress (Von Misses Stress) on beam of specimen CR0G0

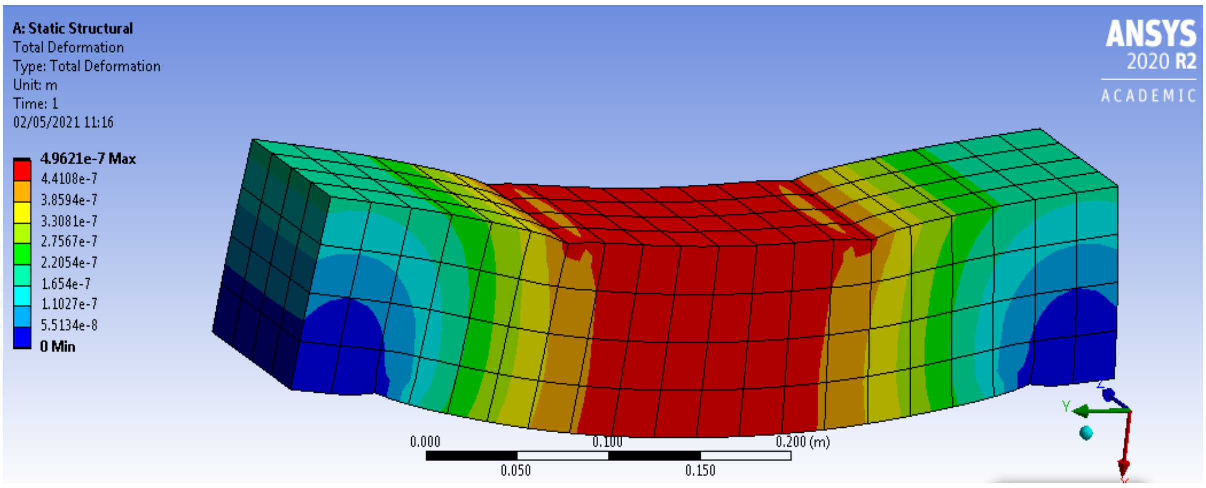



Figure 3.33: Maximum deformation on beam of specimen CR0G0

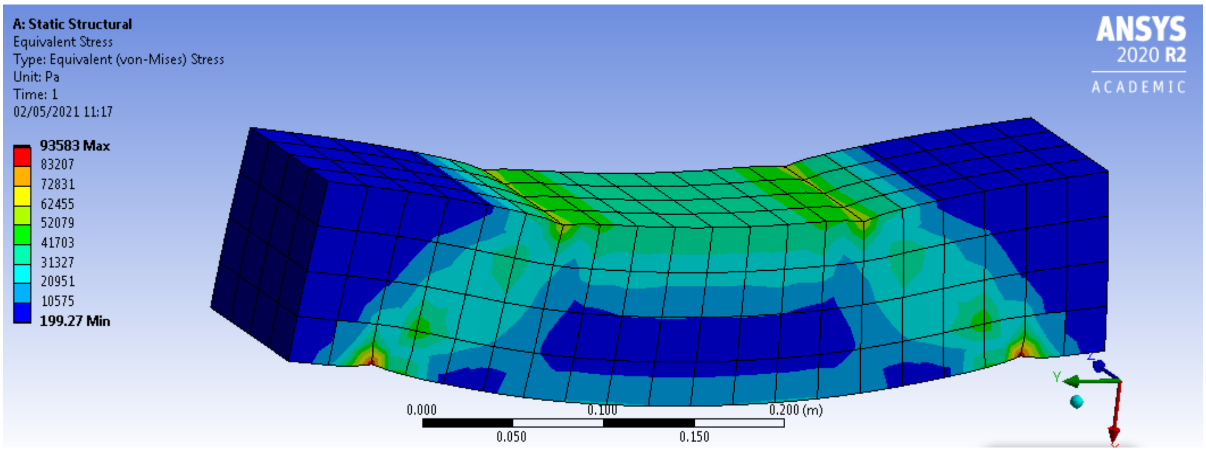



Figure 3.34: Maximum equivalent stress (Von Misses Stress) on beam of specimen CR60G0.5

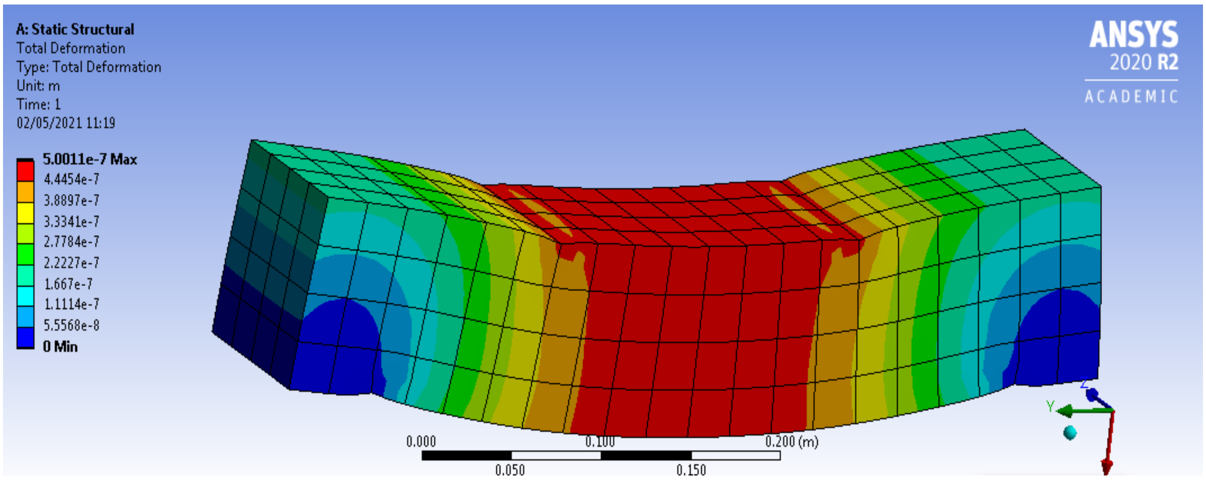



Figure 3.35: Maximum deformation on beam of specimen CR60G0.5

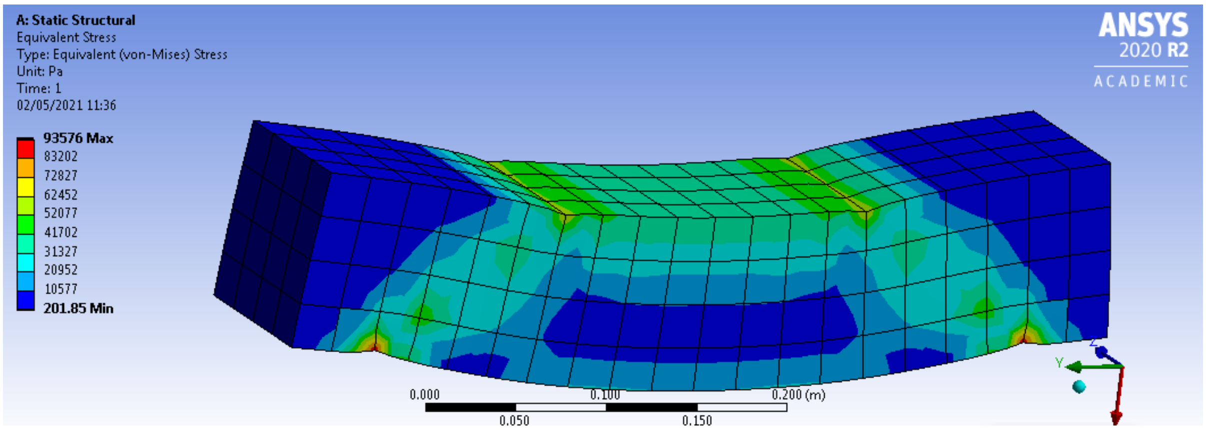



Figure 3.36: Maximum equivalent stress (Von Misses Stress) on beam of specimen CR80G0.75

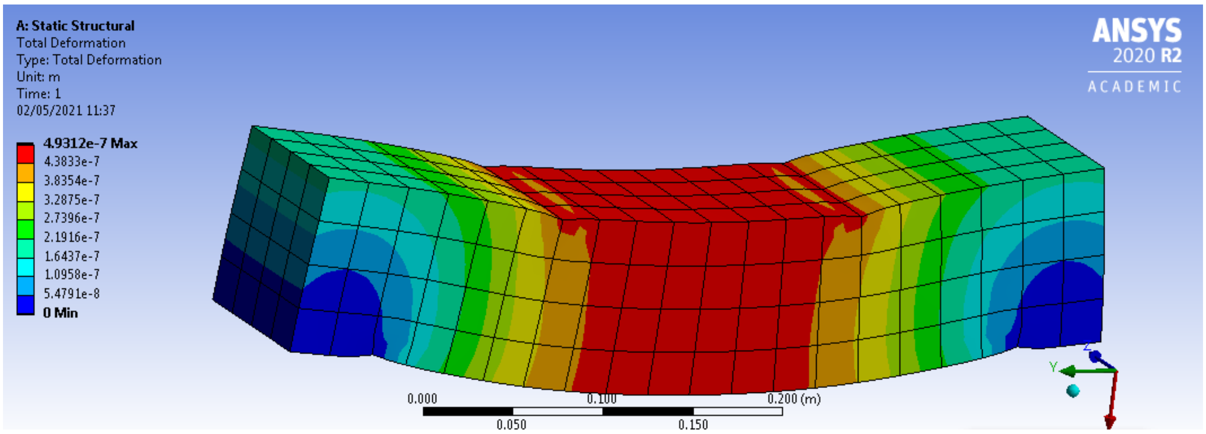
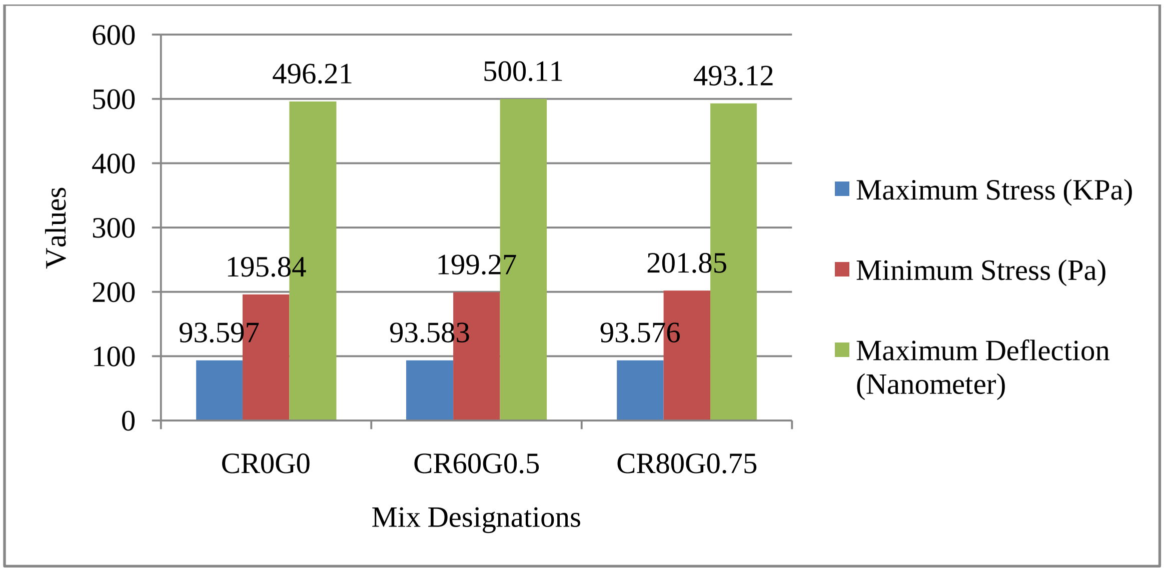



Figure 3.37: Maximum deformation on beam of specimen CR80G0.75

TABLE 3.34: Maximum stress, Minimum stress and Maximum deflection of beam specimen analyzed on ANSYS workbench

| Specimen | Maximum Stress (Pa) | Minimum Stress (Pa) | Maximum Deflection (mm) |
|---|---|---|---|
| CR0G0 | 93597 | 195.84 | $4.9621x10^{-04}$ |
| CR60G0.5 | 93583 | 199.27 | $5.0011x10^{-04}$ |
| CR80G0.75 | 93576 | 201.85 | $4.9312x10^{-04}$ |




Graph 3.21 : Maximum stress, Minimum stress and Maximum deflection of beam specimen of different mix designations

**3.17 Fourier transform infrared spectroscopy (FTIR)**

Fourier transform infrared spectroscopy is a technique of finding material composites by using infrared radiation and mathematical conversion. In this mathematical conversion time domain is converted to frequency domain. The basic principle of FTIR is that each molecular bond vibrates on a specific frequency depending on the type of element and type of bond. The instrument used to perform the analysis is of make PERKIN ELMER shown in Figure 3.38 consists of Infrared Source, Interferometer, beam splitter, stationary mirror, moving mirror and detector. In the process of analysis the infrared source emits infrared radiations which reaches the beam splitter and got splitter splits the beam into two equal intensity beams. Out of which one beam reaches stationary mirror and another reaches moving mirror. These mirrors reflects back the infrared beam to beam splitter again where both the beams combine together and create constructive interference as shown in Figure 3.39. The light transmits in form of wave and these waves coming from stationary mirror and moving mirror adds together to create a wave of high amplitude as shown in Figure 3.40. The combined light falls on sample and the frequency of wave when matches the frequency of composites then the energy is absorbed by the composite and less %

transmittance is obtained. Each component vibrates at a particular wave number. The vibration is in two forms which are stretching or bending where in stretching the bond between atoms of the component stretch and in bending the angle of the bonds between atoms changes. For example composite $SiO_2$ vibrates between 960 to 1000 $cm^{-1}$ wave number and therefore in this range the peaks are developed showing less % Transmittance which means that the energy is absorbed at this particular wave number. The light which is not absorbed by sample is transmitted to the detector which then plot a graph between energy verses time called Interferogram. A mathematical formula is then applied to the interferogram called Fourier Transformation equations (12) and (13). These equations finally gives relationship between wave number and % Transmittance.

$$I(x) = \int_0^\infty S(v) \cos 2\pi v x \, dv \qquad (12)$$

$$S(v) = \int_0^\infty I(x) \cos 2\pi v x \, dx \qquad (13)$$

where *I(x)* represents intensity of infrared lights

*S(v)* represents infrared light intensity at wave number *v*

*x* represents the optical path difference (Refer APPENDIX 1)

Figure 3.38: Fourier transform infrared spectroscopy instrument

(Source: https://www.lpu.in/cif/ftir.php)

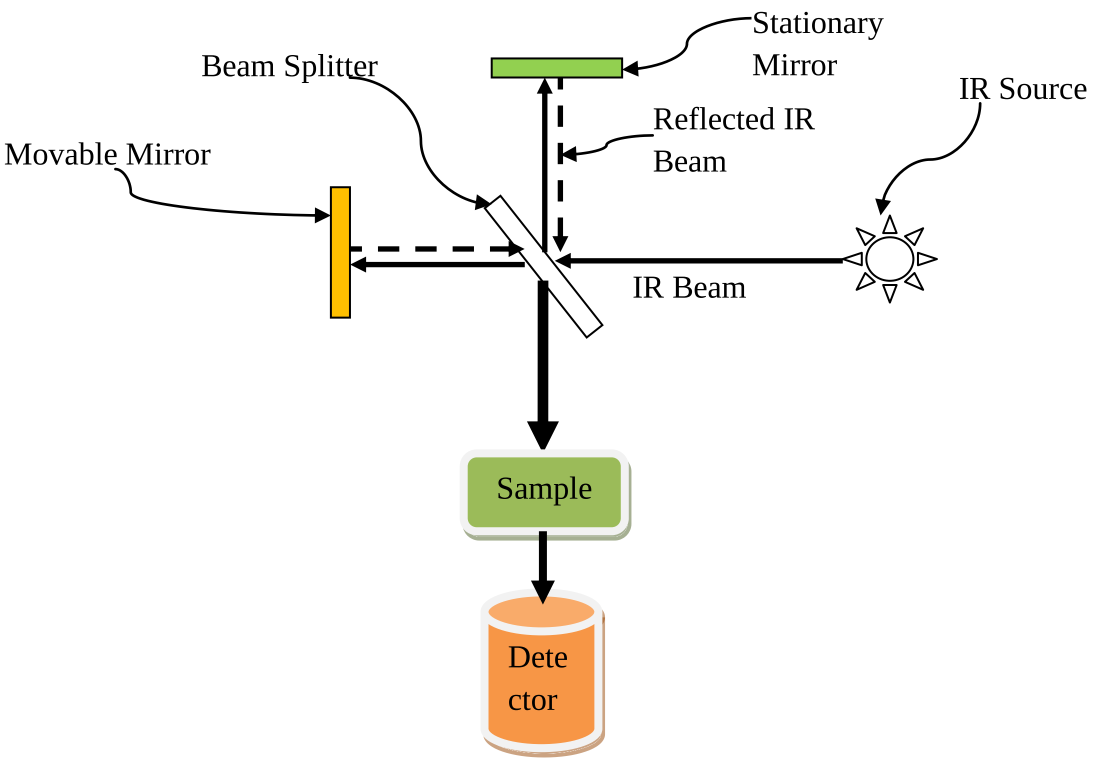



Figure 3.39: Components of Fourier transform infrared spectroscopy

The optimum samples CR60G0.5 and CR80G0.75 obtained in the study of mechanical strength, fracture, cost analysis, XRD, SEM, EDS and software analysis have been analyzed and compared with normal concrete CR0G0 under Fourier Transform Infrared Spectroscopy by taking samples of 1 cm size and the % transmittance is plotted against various wave numbers $cm^{-1}$. The results obtained have been shown in Graph 3.22 where the samples have been tested under wave numbers of 400 to 4000 $cm^{-1}$ and the components and wave numbers which have been considered [98] for analysis have been tabulated in TABLE 3.35.

TABLE 3.35: Compounds/ Bonds and wave numbers range

| S. No. | Components / Bonds | Wave number Range |
|---|---|---|
| 1. | $Ca(CO_3)$ / $CO_3$ | 820-880 $cm^{-1}$ |
| 2 | C-S-H / Si-O | 960-1000 $cm^{-1}$ |
| 3. | Monosulphates / $SO_4$ | 1100 $cm^{-1}$ |
| 4. | $Ca(CO_3)$ / $CO_3$ | 1200-1400 $cm^{-1}$ |
| 5. | $Ca(OH)_2$ / O-H | 3500-3700 $cm^{-1}$ |

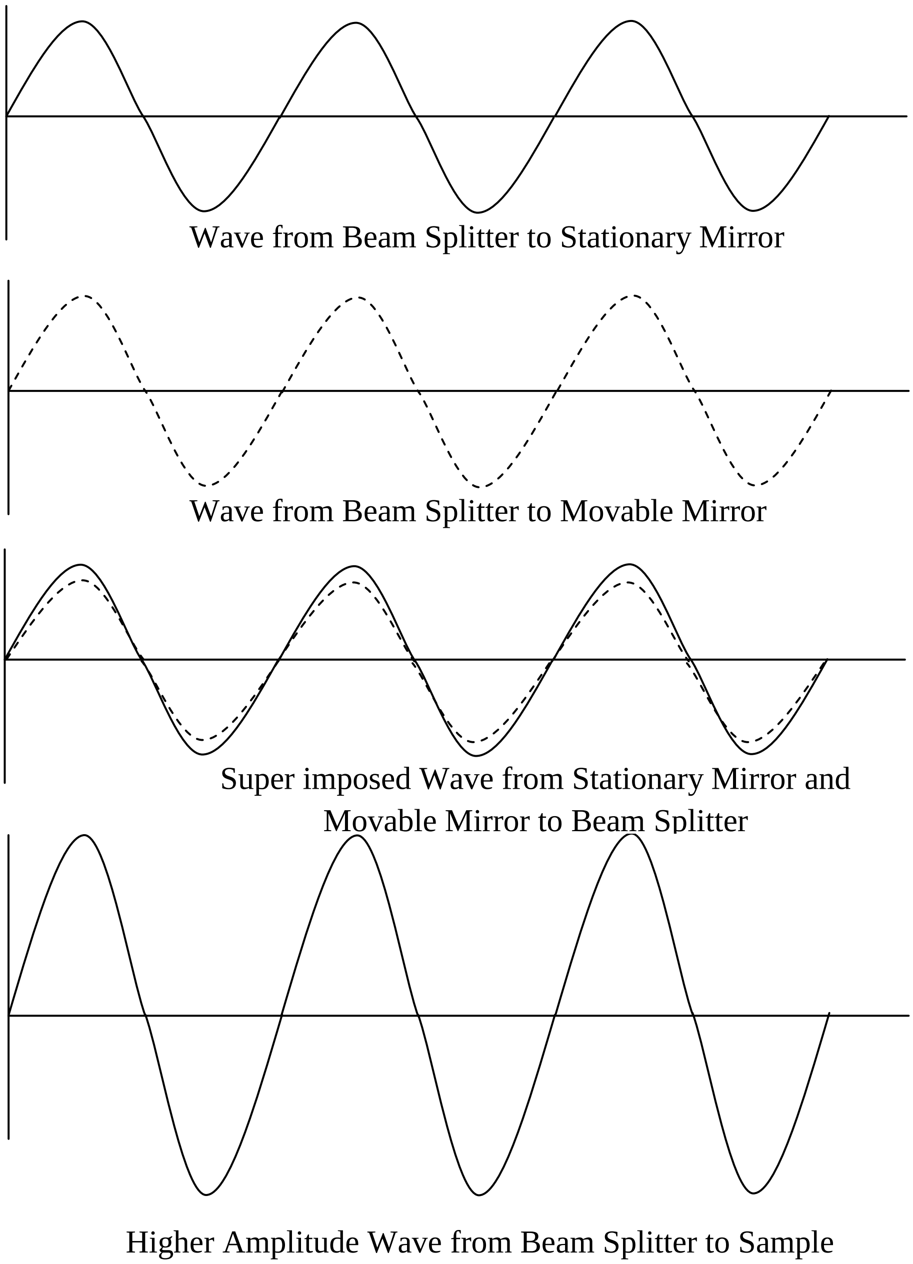
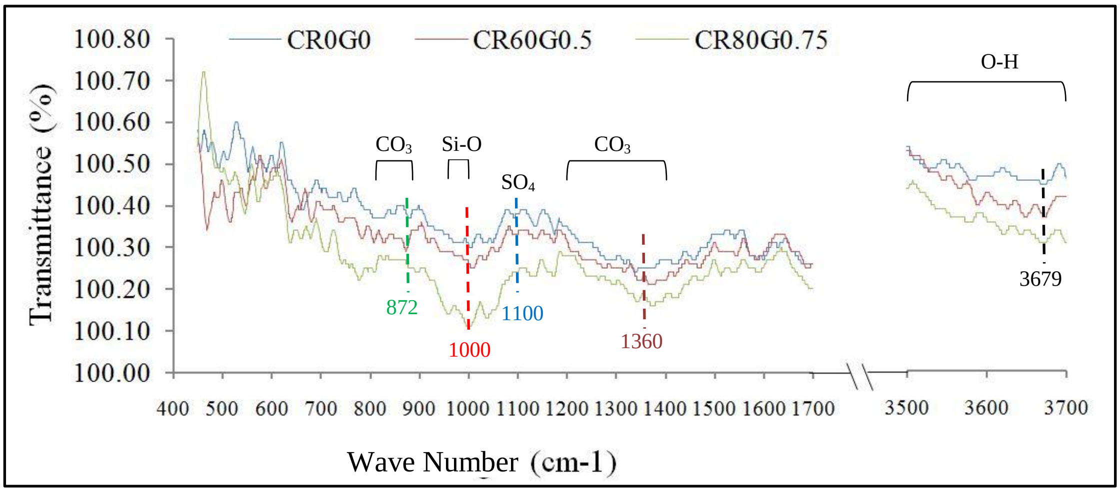



Figure 3.40: Wave Propagation from beam splitter to mirrors

The samples of age 310 days have been tested for Fourier transform infrared spectroscopy and it has been observed that $CO_3$ content was found more in CR60G0.5 and CR80G0.75 having wave number of 872 $cm^{-1}$ in wave number range of 820 - 880 $cm^{-1}$ and 1360 $cm^{-1}$ in wave number range of 1200-1400 $cm^{-1}$ as compared to normal concrete CR0G0. The peaks observed in wave number ranging from 960-1000 $cm^{-1}$ represents the stretching of Si-O bond in C-S-H which is found more in CR60G0.5

and CR80G0.75 with wave number of 1000 $cm^{-1}$ in comparison to CR0G0. The peak of Si-O for % transmittance has been observed lesser than as compared to peaks of $CO_3$. The wave number 1100 $cm^{-1}$ represents $SO_4$ bond stretching which gives low % transmittance in CR60G0.5 and CR80G0.75 as compared to normal concrete CR0G0. The peaks in wave number range 3500-3700 $cm^{-1}$ have been observed to represent vibration in bond O-H which relates with compound $Ca(OH)_2$ and have been found that at wave number 3679 $cm^{-1}$ CR60G0.5 and CR80G0.75 gives lower % transmittance as compared to normal concrete CR0G0 shows presence of higher amount of $Ca(OH)_2$ in CR60G0.5 and CR80G0.75.




Graph 3.22 : Fourier transform Infrared Spectroscopy for optimum mixes CR60G0.5 and CR80G0.75 compared with natural concrete CR0G0

# CHAPTER 4 : DISCUSSION ON FINDINGS

## 4.1 General

A detailed experimental program setup for testing various attributes of concrete brought a large data of results and in depth analysis was performed to signify the behaviour shown by various mixes in various tests performed. The Major tests performed were compressive strength on concrete cubes, Flexural strength on beams, Split tensile strength on cylinders, Fractural study on notched beams, Rapid Chloride Penetration test on cylindrical samples and XRD, SEM, EDS on powdered samples were analyzed with cost optimization and to verify the results FTIR is performed on samples of size 1 cm. The cylindrical samples were tested to find Young's Modulus and Poisson Ratio of the optimum mixes which were used to analyze beam model on software for verification of results. The results obtained have been discussed in clauses given below.

## 4.2 Compressive Strength Test of cubes

The compressive strength results after 28 days of curing of concrete cubes depicted a decrease in strength of concrete on addition of higher percentage of recycled aggregates but the mixes CR60G0.5 and CR80G0.75 showed better results as compared to results obtained of other mixes. The compressive strength of 33.39, 31.57 and 33.44 $N/mm^2$ had been obtained for normal concrete (CR0G0), mix CR60G0.5 and mix CR80G0.75 respectively. This shows an increase of 0.15% in compressive strength of mix CR80G0.75 with respect to normal concrete (CR0G0). The mix CR60G0.5 also gives strength nearly equal to the target strength of concrete which was 31.6 $N/mm^2$.

## 4.3 Flexural Strength of various Mix Designations

The flexural strength of concrete beams after 28 days of curing was tested under four point bend test and the results obtained depicted a decrease in flexural strength on increase of recycled aggregates but due to use of glass fiber the percentage reduction was not very much higher. The mix CR70G0.75 beams tested under flexural load gave flexural strength of 4.03 $N/mm^2$ which is only 0.74% less than flexural strength of normal concrete which was 4.06 $N/mm^2$.

### 4.4 Split Tensile Strength of various Mix Designations

The Split tensile strength of concrete cylinders after 28 days of curing were tested and the results obtained depicted a decrease in split tensile strength on increase of recycled aggregates but due to use of glass fiber the percentage reduction was not very much higher. The mix CR70G0.75 cylinders tested under split tensile load gave split tensile strength of 3.96 $N/mm^2$ which was only 0.5% less than split tensile strength of normal concrete which was 3.98 $N/mm^2$.

### 4.5 Fracture Toughness Behaviour Study

The fracture study is most important parameter to check the behaviour of concrete under flexural load and so to study the behaviour of fracture two parameters critical stress intensity ($K_{ic}$) and Crack tip opening displacement (CTOD) were evaluated on the values obtained experimentally. It had been found that fracture toughness of mix CR60G0.75 was obtained highest than all other mixes having 31.44% and 31.03% increment in critical stress intensity and crack tip opening displacement respectively as compared to normal concrete.

### 4.6 Cost Analysis

The results obtained were analyzed in depth and cost optimization had been carried out by finding the cost required in materials, labour and contingencies used for preparing 1 cubic meter of concrete of mixes CR0G0, CR60G0.75 and CR80G0.75. It had been found that the cost required in casting 1 cubic meter of concrete of mixes CR0G0, CR60G0.75 and CR80G0.75 were in Indian Rupees 7424.644, 8905.9 and 8839.34 respectively. The cost required for mix CR60G0.75 was found to be 19.95% higher than normal concrete (CR0G0). Therefore instead of using CR60G0.75 it has been observed that mix CR60G0.5 can be more better and economical as the cost required for casting mix CR60G0.5 was found to be 8345.61 Indian Rupees which was only 12.04% higher than cost required for casting of normal concrete (CR0G0). The fracture study results for mix CR60G0.5 had also been compared and found that for mix CR60G0.5 there was an increment of 22.01% and 10.74% in critical stress intensity and crack tip opening displacement respectively than normal concrete (CR0G0).

### 4.7 Rapid Chloride Penetration Test

The chloride penetration was tested on mixes CR0G0, CR60G0.5 and CR80G0.75 by using Rapid Chloride Penetration Test and found charge passed in coulombs to be 2794.5, 3415.5 and 3904.2 respectively. This shows an increment in chloride penetration on increment of recycled aggregates and glass fibers but the results are below 4000 Coulombs charge pass and which is in moderate limit.

### 4.8 X-Ray Diffraction analysis (XRD analysis)

To check the material composition of the crystalline structure of concrete mixes CR0G0, CR60G0.5 and CR80G0.75, XRD analysis was performed and results obtained revealed more number of peaks in CR60G0.5 of $SiO_2$ which represents the behaviour of mix to be more elastic. Further there was a reduction found in peaks of $CaCO_3$ for mixes CR60G0.5 and CR80G0.75 which shows that the workability reduces but the brittleness of concrete also reduces. There was a presence of Zinc Phosphates found in CR60G0.5 specimen represents the property of specimen to resist corrosion. Further in specimen CR80G0.75 there was a presence of Calcium Magnesium vanadates which shows improved binding strength and so this verifies the reason of higher strength in concrete specimen CR80G0.75.

### 4.9 SEM and EDS

The SEM and EDS analysis were performed on mixes CR0G0, CR60G0.5 and CR80G0.75 and in SEM analysis more pores were found in normal concrete CR0G0 but less in CR60G0.5 and further less in CR80G0.75. The structure of CR80G0.75 was found to be more composite than CR0G0 and CR60G0.5.

In EDS analysis the percentage of calcium silicates for specimen CR60G0.5 was found to be 71.32% which was less than specimens CR0G0, CR80G0.75 that was 85.21% and 87.09% respectively. The percentage of calcium silicates was found maximum in specimen CR80G0.75 which contributes to more strength than CR60G0.5. It had been found that presence of more Silicon dioxide that was 28.68% in mix CR60G0.5 as compared to that of 14.79% and 12.91% of silicon dioxide in mixes CR0G0 and CR80G0.75 respectively which represents more elastic behavior of mix CR60G0.5 and so verifies experimental behavior of specimen CR60G0.5 to have more fracture stress intensity and less crack width.

### 4.10 Software Verification using ANSYS Workbench

The software verification was performed on ANSYS Workbench and for which purpose Young's Modulus and Poisson Ratio of mixes CR0G0, CR60G0.5 and CR80G0.75 were evaluated and compared with other standards and error analysis showed the percentage of error to be less than 5% which is acceptable. The beam model had been analyzed for same loads but different mixes and the result of maximum deflection obtained for mix CR60G0.5 was found to be 500.11 Nanometer which was 0.79% higher than maximum deflection obtained when using normal concrete (CR0G0) and 1.42% higher than maximum deflection obtained when using mix CR80G0.75. This represents mix CR60G0.5 is having better elasticity as compared to normal concrete (CR0G0) and mix CR80G0.75. The minimum stress developed in mix CR80G0.75 was 3.07% and 1.29% higher than minimum stress developed on using normal concrete (CR0G0) and mix CR60G0.5 respectively. This represents the capability of mix CR80G0.75 to take more stress and so mix CR80G0.75 is having better strength than normal concrete (CR0G0) and mix CR60G0.5.

### 4.11 Fourier transform infrared spectroscopy (FTIR)

The Fourier transform infrared spectroscopy (FTIR) indicates that higher amount of carbonates were present in mix designations CR60G0.5 and CR80G0.75 as compared to normal concrete mix designation CR0G0 which exhibits higher strength to optimum mixes but increases the brittleness. The brittleness in contradictory had been overcome by the presence of more C-S-H obtained in optimum mixes CR60G0.5 and CR80G0.75. The presence of more amount of sulphates in CR60G0.5 and CR80G0.75 in comparison to normal concrete CR0G0 shows low resistivity towards sulphate attack which verifies the results obtained during RCPT. The higher amount of $Ca(OH)_2$ in CR60G0.5 and CR80G0.75 shows better strength of optimum mixes as compared to normal concrete CR0G0.

# CHAPTER 5 : **CONCLUSION**

## 5.1 General

After performing experimental analysis following conclusions can be extracted as

*5.1.1 The behaviour of fracture and cracks in beams under flexure on application of two point load using critical stress intensity factor ($K_{ic}$) and critical crack tip opening displacement (CTOD)*

With 60% recycled aggregates and 0.75% fiber material, the ultimate load was improved by 32.2 percent and fracture strength by 31.45 percent relative to normal concrete beams.

With 60% RA and 0.5 % fiber material ,the ultimate load in bending and shear was improved as well fracture strength relative to normal concrete also the cost compared was nearer to normal concrete and hence the final result interpretation that CR60G0.5 can be used for concrete structural members under flexure like beams and slabs.

By including S2 glass fibers, the mode of failure was changed from brittle to ductile flexural process.

The CTOD of concrete was found to be improved with addition of S2 glass fiber in replacement of 60% RA.

The fracture brittleness number of CR60G0.75 from experimental result was found to be 271 mm which is in range of 150-300 mm.

Correlation coefficient between CTOD and Kic for mixes having 60% and 80% recycled aggregates had been analyzed by using Karl Pearson's Correlation coefficient method and Spearman's Rank Correlation coefficient method and it was found that there is a strong positive correlation between CTOD and Kic which represents that an increase in Crack tip opening displacement (CTOD) will results in increase in stress intensity (Kic).

*5.1.2 Verification the experimental results by modeling and analyzing using FEM simulations in ANSYS.*

In software analysis using ANSYS workbench the maximum stress in beam specimens is obtained higher for normal concrete CR0G0 but less for specimens CR60G0.5 and CR80G0.75 and hence verifies the experimental behavior.

The specimen CR60G0.5 shows maximum deflection more than other two specimen CR0G0 and CR80G0.75 which shows the better elastic behavior of specimen CR60G0.5 and this verifies the fracture study.

*5.1.3 Analysis and designing optimum mix based on results for different structural applications.*

With 80% of recycled aggregates and 0.75% of glass fiber the compressive strength shows an increase of 0.15 percent which is very near to normal concrete and hence 80% of natural coarse aggregates can be replaced by recycled aggregates by using 0.75% of glass fibers in compression members like columns and struts.

The experimental Behaviour of mix compositions under flexure and shear tested for flexural and shear strength shows a variation of just 0.74 percent and 0.5 percent respectively which is very near to normal concrete.

The cost analysis of mixes exhibiting better strength and fracture are being analyzed for cost optimization and so mix designations CR0G0, CR60G0.75 and CR80G0.75 are been taken for cost analysis but it has been found that mix designation CR60G0.75 is having higher cost than CR60G0.5 but is having very less difference in flexural strength, split tensile strength and fracture toughness than mix designation CR60G0.75 and hence it is beneficial to use mix designation CR60G0.5 instead of CR60G0.75.

The RCPT conducted on specimens CR0G0, CR60G0.5 and CR80G0.75 shows an increase in chloride Ion penetration on increase of recycled aggregates but the value of charge comes in moderate range which is acceptable for practical applications but not to be used as exposed concrete.

The XRD analysis performed on specimens CR0G0, CR60G0.5 and CR80G0.75 shows higher peaks of $SiO_2$ for normal concrete and lower in CR60G0.5 but number of peaks are more for $SiO_2$ in CR60G0.5 and so this represents more elastic behaviour in CR60G0.5.

In XRD analysis the specimens with recycled aggregates and glass fibers CR60G0.5 and CR80G0.75 were having less peaks of $Ca(CO_3)$ which represents reduction in workability but increase in elastic behavior. This depicts the requirement of usage of admixtures to maintain workability and the concrete specimen is better for practical applications.

During XRD analysis Zinc Phosphates were found in CR60G0.5 specimens represents the property of specimen to resist corrosion. In specimen CR80G0.75 presence of Calcium Magnesium vanadates shows improved binding strength and so this verifies the reason of higher strength in concrete specimen CR80G0.75.

In SEM analysis it was found that pores in normal concrete CR0G0 are more but less in CR60G0.5 and further less in CR80G0.75. The structure of CR80G0.75 was found to be more composite than CR0G0 and CR60G0.5.

In EDS analysis the percentage of calcium silicates for specimen CR60G0.5 was found less than specimens CR0G0, CR80G0.75 and found maximum in specimen CR80G0.75 which represents the reason of more strength than CR60G0.5. Presence of more Silicon dioxide in CR60G0.5 represents more elastic behavior of mix and so verifies experimental behavior of specimen CR60G0.5 to have more fracture stress intensity and less crack width.

This research study if further prominent in future may prove to be an important milestone in the field of construction. Many researchers will find this study helpful in understanding the effects and Behaviour of fracture toughness of concrete at wider scope of environment.

The FTIR verifies the research findings.

# CHAPTER 6 : **FUTURE SCOPE**

## 6.1 General

The detailed research work is been carried out under a said scope and objectives with certain hypothesis. During the research and after concluding it had been found that there are still certain grey areas which can be explored and future researchers can work on to find more detailed study on certain findings.

## 6.2 Future scope of research

The future scope that can be researched on is listed in the following points

1. The mix methods are to be analyzed which can be used at site to mix the glass fibers to concrete.
2. The various water cement ratios can be checked on optimum mixes to have compatible mix with good strength and workability.
3. The mixes can be checked on building models of prototype or software simulation and can be analyzed under various loading combinations. This will give the behaviour of a building on using optimum mixes under structural loads and can be compared with building with normal concrete.
4. Fracture Mechanics investigations can be checked for similar type of research.
5. Response of recycled concrete mix with admixtures under dynamic loading can be checked.

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# APPENDIX 1

1) According to the RILEM-50 [83], the fracture toughness is determined using equation (1) as the critical stress intensity Kic.

$$\boldsymbol{Kic = \frac{3FS\sqrt{\pi a}}{2BW^2} f(\alpha)} \qquad (1)$$

Where, Kic =critical stress intensity (MPa√m), F – max. Load (N), S, W and B are the span, depth, and width in mm respectively of the testing beam.

f(α) is geometry factor, which depends on the ratio of the notch depth (W) /crack length (a) of the beam. In case S = 4W as applied in the current study, f(α) can be as shown in equation (2).

$$\boldsymbol{f(\alpha) = \frac{[1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)]}{\sqrt{\pi}(1+2\alpha)(1-\alpha)^{1.5}}} \qquad (2)$$

2) Crack opening displacement (COD) (curve fitting of numerical results ) can be given by following equation (11)

$$\mathrm{COD(x)=CMOD}\left[\left(\mathbf{1} - \frac{\boldsymbol{x}}{\boldsymbol{a}}\right)^{\mathbf{2}} + (\mathbf{-1.149}\boldsymbol{\alpha} + \mathbf{1.081})\left\{\frac{\boldsymbol{x}}{\boldsymbol{a}} - \left(\frac{\boldsymbol{x}}{\boldsymbol{a}}\right)^{\mathbf{2}}\right\}\right]^{\frac{\mathbf{1}}{\mathbf{2}}} \qquad (11)$$

where α = a/W and for CTOD , the value of x= initial crack length ( $a_0$ )

Applying Fourier transform to an interferogram obtains the intensity at each period, that is, at each wavelength.
If an interferogram $I(x)$ for infrared light at continuous wavenumbers can be created using the wavenumber ν instead of the wavelength λ, $I(x)$ can be expressed as

$$I(x) = \int_0^{\infty} S(\nu)\cos 2\pi\nu x d\nu$$
$$S(\nu) = \int_0^{\infty} I(x)\cos 2\pi\nu x dx$$

Where, $S(\nu)$ is the infrared light intensity at wavenumber ν.
$S(\nu)$ can be calculated by Fourier transform.
The data obtained is a power spectrum. The ratio between the background and the sample power spectrum produces a spectrum expressed as transmittance.

(Source: https://www.shimadzu.com/an/service-support/technical-support/analysis-basics/tips-ftir/apodization.html)

# APPENDIX 2 : Paper Published

| Sno. | Title of paper with author names | Name of journal / conference | Published date | Issn no/ vol no, issue no | Indexing in Scopus/ Web of Science/UGC-CARE list |
|---|---|---|---|---|---|
| 1. | Mechanical Properties of Glass Fiber Reinforced Concrete with Recycled Aggregates Anshul Garg and Dr. Pushpendra Kumar Sharma | Journal of Applied Science and Engineering | $24^{th}$ June, 2021 | ISSN (e): 2708-9975 ISSN (p): 2708-9967/ Vol. 24, No 6 | ESCI+SCOPUS |
| 2. | Fracture Toughness of Concrete by using Recycle Aggregates in Addition with S2 Glass Fiber Anshul Garg, Nitish Kumar Jha, Pushpendra Kumar Sharma | International Journal of Recent Technology and Engineering (IJRTE) | $15^{th}$ May, 2020 | ISSN: 2277-3878/ Volume-9 Issue-1 | SCOPUS 2018-19 |
| 3. | Review on Flexural Strength of Concrete by using Recycled Aggregates and | Our Heritage | $23^{rd}$ January, 2021 | ISSN: 0474-9030/ Vol-67-Issue-7 | UGC Care |

| | | | | | |
|---|---|---|---|---|---|
| | Glass Fibers<br>Navin Acharya, Dr. Pushpendra Kumar Sharma and Anshul Garg | | | | |
| 4. | Review on Fracture Study of Concrete by Critical Stress Intensity (KIC) & Crack Tip Opening Displacement (CTOD)<br>Nitish Kumar Jha, Dr. Pushpendra Kumar Sharma and Anshul Garg. | Our Heritage | 15th November, 2019 | ISSN: 0474-9030/ Vol-67-Issue-7 | UGC Care |
| 5. | A Critical Review on Behaviour of Glass Fiber Reinforced Concrete Using Recycled Aggregates<br>Anshul Garg and Dr. Pushpendra Kumar Sharma | IOSR Journal of Engineering (IOSR JEN) | 30th May, 2019 | ISSN (e): 2250-3021, ISSN (p): 2278-8719 | UGC CARE List SL. No. 4814 |
| 6. | Behaviour of Recycled Aggregate Concrete with Glass Fibers Under Compressive | International Conference on Experimental and | 15th & 16th November, 2019 | Volume-1 | International Conference |

| | | | | | |
|---|---|---|---|---|---|
| | Loads: A Sustainable Approach Anshul Garg and Dr. Pushpendra Kumar Sharma | Progression in Engineering, Research and Technology (EXPERT-2019) Held at Lovely Professional University, Phagwara, Punjab | | | |
| 7. | A Critical Review on Behaviour of Glass Fiber Reinforced Concrete Using Recycled Aggregates Anshul Garg and Dr. Pushpendra Kumar Sharma | International Conference on Sustainable Environment and Civil Engineering (ICSECE'19) held at Easwari Engineering College, Bharathi Salai, Ramapuram, Chennai-600089 | 28th & 29th March, 2019 | Volume-1 | International Conference |

# Mechanical Properties of Glass Fiber Reinforced Concrete with Recycled Aggregates

Anshul Garg[1] and Pushpendra Kumar Sharma[2*]

[1] *Research Scholar, Lovely Professional University, Phagwara, Punjab 144411, India*
[2] *Professor, Lovely Professional University, Phagwara, Punjab 144411, India*
[*] *Corresponding author. E-mail: p.sharmaji10@gmail.com*

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Scarcity of the construction resources such as money, labour, material, land and technology is creating a big chaos and so the nations are facing problems of low GDP's. This research focuses on reuse of laboratory waste used aggregate and studying the mechanical properties of concrete with glass fiber and varying percentages of recycled aggregates. The study focuses on use of higher percentages of recycled aggregates and analyse optimum mix that can be used for structural applications by adding glass fibers without compromising the strength parameters. The behaviour of compressive, flexural and split tensile strength of concrete using glass fibers is studied where normal aggregates are partially replaced with recycled aggregates in proportions of 40%, 60%, 70%, 80% and 100% and usage of 0.25% glass fibers as addition by weight. After analyzing results it was observed that on addition of recycled aggregates strength decreases but mix designation CR80G0.25 (80% replacement of normal aggregates with recycled aggregates and addition of 0.25% of glass fibers) has least reduction 8.23% in compressive strength. Flexural and split tensile strength shows a reduction of 2.96% and 1.70% respectively for mix designation CR70G0.25 (70% replacement of normal aggregates with recycled aggregates and addition of 0.25% of glass fibers). This shows that Mix designation CR80G0.25 can be used for compression members like columns in buildings and Mix designation CR70G0.25 can be used in construction of beams and slabs.

**Keywords:** Glass fibers, Recycled, Aggregate, Compressive strength, Flexural Strength, Split tensile strength



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## 1. Introduction

With rapid growth in urbanization and economic development emerges a huge scale of new construction which requires a large amount of materials. Scarcity in sources and environmental depletion arise a need to find methods to reuse the waste and a proper waste management technique. According to researches done previously it was suggested a limit of 30% of recycled aggregate in order to maintain the standard requirements of structural concrete [1, 2]. The higher percentages of water absorption of recycled aggregate, relates that concrete made with recycled coarse aggregates and natural sand needs 5% more water than conventional concrete in order to obtain the same workability [3–10].

Some researchers reported to use recycled aggregates in saturated conditions to maintain the water absorption requirements. A lower w/c ratio with less workability for conventional concrete use, gives optimum strength on using 100% of recycled aggregates but for pumpable concrete there is a need of higher w/c ratio or admixtures to maintain workability and strength on using 100% recycled aggregates [11]. Using proper measures high quality concrete can be produced by using recycled aggregates [12]. Partial replacement of different percentages of wood ash with cement and use of foundry sand as fine aggregate, reported that there is decrease in compressive strength but concrete produced can be used as M20 grade concrete [13]. Finding various methods of using waste materials in concrete by [14], researched on partial replacement of silica fumes with cement and ceramic tiles with coarse aggregates and founded that on replacing 15% of coarse aggregates with ceramic tiles and cement with silica fumes gives about 7.2% increase in compressive strength.

The study done on use of glass fiber in concrete by [15], investigated the effects of randomly oriented glass fibres on the flexural strength, compressive strength, splitting tensile strength, and Young's modulus of concrete, concluded that there was an increase in strength with an increase in fibre content. Study on flexural behaviour of a polyester polymer concrete by varying the polymer up to 18% by weight and glass fiber contents to 6% by weight of polymer concrete by [16], introduced increase in the flexural strength of 18% polymer concrete to 41.6 MPa (6,040 psi), almost doubling the strength of unreinforced 18% polymer concrete system due to adding of 6% glass fibers. Effects on different colours of glass fiber as partial replacement of cement done by [17] founded that green glass power is giving more strength than clear glass. Behaviour of coconut and hair fiber was experimentally studied by [18], reported that compression strength is better on replacing 1.5% of hair fiber and 2% of coconut fiber with cement.

Looking to appropriate methods to reuse recycled aggregates it was founded that using recycled aggregates is limited to certain percentages as reported by various researchers and so there is a need of addition a material that can enhance the strength properties of concrete when recycled aggregates are used in more amounts as reported in review paper by [19, 20].

## 2. Research Methodology

For this present study M25 grade concrete mix designed as per Indian Standards [21] is used where Natural sand, Cement, water, S2 Glass Fibers and recycled aggregates are the main constituents. S2 glass fiber are being added in proportion of 0.25% by weight of concrete and recycled aggregates are being used as partial replacement of natural coarse aggregates in proportions of 40%, 60%, 70%, 80% and 100% shown in Table 1. The length of S2 glass fibre is 12 mm and recycled aggregates are obtained from laboratory wastes are 20 mm graded aggregates. The mixing method used for research work is by hand mixing and there is a scope of finding a mixing method and comparing results of various mixing methods and finding the optimized method.

The physical properties of recycled aggregates are given in Table 2 and properties of S2 glass fiber is given in Table 3. The image of recycled aggregates used is shown in Fig. 1 and Fig. 2 shows the image of S2 glass fiber. The glass fiber is being obtained by cutting the glass fiber from sheet as shown in Fig. 3.

The workability test performed by slump cone as per Indian Standards [22] is shown in Table 4 and results are plotted in graphical representation in Fig. 4.

Compression test on cubes conducted according to Indian standards [23]. Three samples were tested for each designation and average value of results is considered. Standard Compression testing machine of capacity 1000 KN is used for testing as shown in Fig. 5. Results of compression test after 28 days of curing is shown in Table 5 are graphically represented in form of bar chart in Fig. 6.

Flexural test on beam samples 100 mm x 100 mm x 500 mm are conducted according to Indian Standards [23] and results are tabulated in Table 5 and graphically represented

**Table 1.** Percentage of Recycled aggregates used as partial replacement of natural coarse aggregates and percentage of glass fibers added by weight of concrete

| Mix Designations | Recycled aggregate | Glass Fiber |
|---|---|---|
| CR0G0 | 0.00 | 0.00 |
| CR40G0.25 | 40 | 0.25 |
| CR60G0.25 | 60 | 0.25 |
| CR70G0.25 | 70 | 0.25 |
| CR80G0.25 | 80 | 0.25 |
| CR100G0.25 | 100 | 0.25 |

**Fig. 1.** Recycled Aggregates

**Table 2.** Physical properties of recycled aggregates

| SN | Characteristics | Value |
|---|---|---|
| 1 | Water Absorption | 7.92% |
| 2 | Specific Gravity | 2.34 |

**Fig. 2.** S2 Glass Fiber

**Fig. 3.** Cutting of glass fiber from sheet done by vendor. (Demo picture Source: https://www.shutterstock.com/search/fiber+glass)

**Table 3.** Properties of S2 glass fiber

| Property | Results |
|---|---|
| Type of material | Magnesium alumina silicate glass without CaO |
| Fiber length (mm) | 12-15 (mixed) |
| SiO2 Content | 64-66% |
| Elastic Modulus(E) | 79-89 MPa |
| Aspect Ratio | 300-350 |

**Table 4.** Workability by Slump cone test (mm)

| Specimen | Slump |
|---|---|
| CR0G0 | 70 |
| CR40G0.25 | 50 |
| CR60G0.25 | 55 |
| CR70G0.25 | 60 |
| CR80G0.25 | 65 |
| CR100G0.25 | 60 |

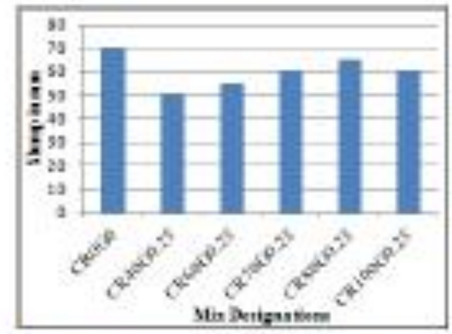


**Fig. 4.** Workability by Slump Cone Test in millimeters


**Fig. 5.** Compression Strength Testing of Cube specimens

in form of bar chart as shown in Fig. 7.

Split tensile tests are conducted on cylindrical samples of 150 mm diameter and 300 mm depth as per Indian Standards [24] and results tabulated in Table 5 and graphically represented in form of bar chart shown in Fig. 8.

The Fig. 9 shows the picture of the cylindrical specimen after split tensile strength testing.

The combined behaviour of mechanical strength of various mix designations is shown in Fig. 10.

## 3. Results and Discussion

After replacement of natural coarse aggregates with recycled aggregates and adding glass fiber the following observations are obtained.

1. There is a decrease in strength of concrete on increase of recycled aggregate content but glass fiber is helping in maintaining the decrease percentage to a low value.

2. The flexural strength test and split tensile strength test show a decrease in strength but for Mix designation CR70G0.25 percentage decrease in flexural strength is

**Table 5.** Mechanical Strength of Mix designations after 28 Days in MPa

| Mix Designations | Compressive Strength of samples | Average Compressive Strength | Flexural Strength | Split Tensile Strength | Ratio of Compressive Strength to Split Tensile strength | Ratio of Compressive Strength to Flexural strength |
|---|---|---|---|---|---|---|
| Normal Concrete | 35.49<br>32.15<br>32.54 | 33.40 | 4.06 | 3.98 | 8.392 | 8.227 |
| CR40G0.25 | 23.51<br>28.71<br>25.64 | 25.96 | 3.82 | 3.77 | 6.886 | 6.796 |
| CR60G0.25 | 21.11<br>21.58<br>22.80 | 21.63 | 3.85 | 3.80 | 5.745 | 5.670 |
| CR70G0.25 | 27.87<br>27.93<br>25.47 | 27.09 | 3.94 | 3.91 | 6.928 | 6.876 |
| CR80G0.25 | 29.94<br>31.97<br>30.04 | 30.65 | 3.76 | 3.68 | 8.329 | 8.151 |
| CR100G0.25 | 22.53<br>22.67<br>25.60 | 23.60 | 3.19 | 3.05 | 7.738 | 7.398 |

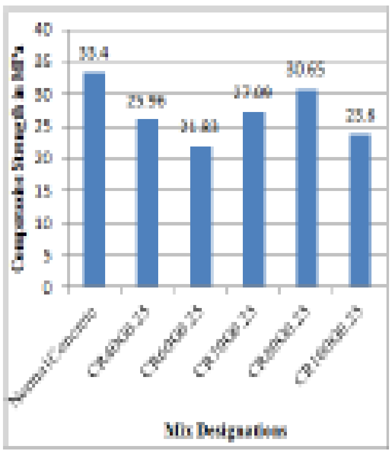


**Fig. 6.** Variation of compressive strength of different mix designations with age of 28 days in MPa

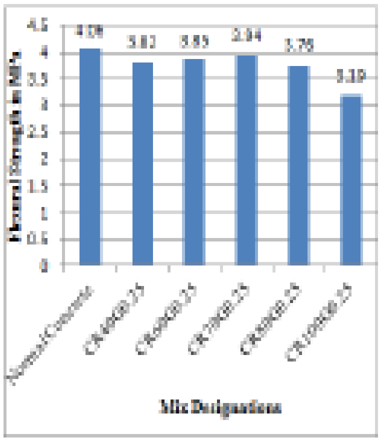


**Fig. 7.** Variation of flexural strength of different mix designations with age of 28 days in MPa

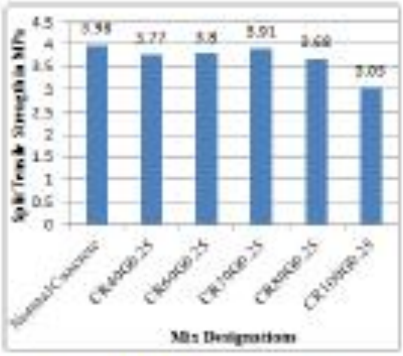


**Fig. 8.** Variation of split tensile strength of different mix designations with age of 28 days in MPa

**Fig. 9.** Cracking of concrete cylinder during split tensile strength

2.95% and percentage decrease in split tensile strength is 1.76% which is depicting values very near to flexural strength and split tensile values obtained for control mix.

3. The mix designation CR80G0.25 is giving 8.23% decrease in compressive strength of concrete which is very near to control mix designation compressive.

4. The ratios of compressive strength to split tensile strength and flexural strength is depicting that ratio CR80G0.25 has mechanical property very near to normal concrete and hence use of recycled aggregates till 80% replacement of normal coarse aggregate is possible by adding 0.25% of glass fiber.

5. The workability is found to be decrease while replacing 40, 60 and 70 percentages of natural aggregates by recycled aggregates and due to use of glass fiber also workability decreases.

## 4. Conclusion

Analyzing the experimental results of slump values and mechanical strength of various mix designations, it is concluded that mix designation CR80G0.25 can be used for general structural applications like Beams, columns, slabs and struts. It is also required to add admixtures to recycled aggregate concrete with glass fiber to maintain workability. Using more percentages of recycled aggregate which is a waste can reduce in depletion of environment and decrease the need of natural aggregates will make this mix designated concretes as sustainable method of concreting and will be environmental friendly.

## 5. Acknowledgements

The authors acknowledge the support from the School of Civil Engineering, Lovely Professional University for providing laboratory to perform these tests.

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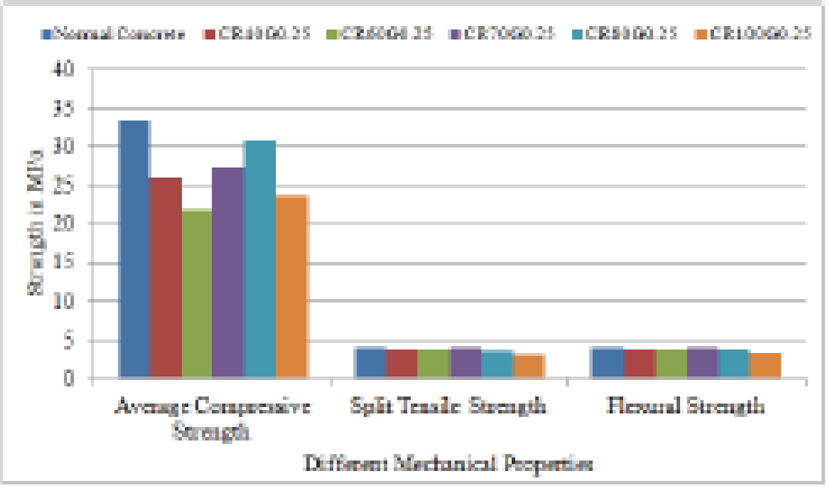


**Fig. 10.** Combined behaviour of different Mix Designations under Different Mechanical Properties


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# Fracture Toughness of Concrete by using Recycle Aggregates in Addition with $S_2$ Glass Fiber

**Anshul Garg, Nitish Kumar Jha, Pushpendra Kumar Sharma**

***Abstract:** The scarcity in conventional material to prepare concrete and a demand of reuse of demolished or abandoned waste of concrete structure gives a reason to study the ways of using more amount of recycled aggregates. Various studies reviewed the use of recycled aggregates but to a maximum limit of 50% whereas use glass fibers gave a better response to mechanical and chemical properties of concrete 1. For concrete the occurrence of cracks and pores is uncertain and it is important to investigate whether they are intact or not. The durability of the fracture tests depends on the ductile nature of concrete structures under load. It was found that there is a need to assess the strength of the concrete at fracture of the critical point. The present study aims at finding out how far the ductility of concrete with recycle aggregates can be improved by the addition of S2 glass fibers in terms of fracture toughness by varying the fiber content. The research work consist of replacement of recycle aggregates with five different mixes of concrete as 40, 60, 70, 80 & 100% and in each five mixes the addition of S2 glass fiber with 0.25%-1% by its weight with an increment of 0.25% is done. 3 point bending test on notched beams were conducted for determination of critical stress intensity. The tests were performed as per the guidelines of International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) 5.The research paper gives idea about optimum percentage of recycle aggregates and S2 glass fiber that can be used in concrete structures casting taking in account the study of fracture toughness.*

***Keywords:** Fracture Toughness, Critical Stress Intensity, RILEM, Crack propagation, S2 glass fiber*

## I. INTRODUCTION

Concrete is for most part versatile material utilized in the turf of structural designing. Reusing concrete is a feasible alternative to enhance the interest on great characteristic assets and breaking point the measure of waste arranged in landfills 2. Estimating the compressive or elasticity just won't ensure the exhibition of the solid structure attributable to the communication of the material conduct, previous splits and geometry of the structure 3. The solid fracture properties can give more portrayal of the potential burden conveying limit of the material in a given basic system 4.

Since concrete is a composite material, the nearness of breaks and pores inside cement can't be controlled. So it gets important to research whether these splits are steady or not 6. Fracture mechanics is a significant technique for examining solid conduct under static stacking. The fracture execution of reused total cement with expansion of S2 glass fiber has not been assessed to date in the writing and could give further understanding to the material execution when utilized for concrete 7. Research on fracture properties of different solid blends has discovered a noteworthy advantage with expansion of fiber fortification to plain concrete. Most of writing recommends the quality of cement containing reused solid total (RCA) is not exactly coarse total cement even at low water/bond proportions. A few nations have seen the reusing of development and destruction squander as another structure material as one of the primary objectives over terms of reasonable structure conduct 8. Numerous analysts have submitted their work to depict the properties of reused total, the base necessities for their utilization in concrete and the properties of reused total cement. Past examinations likewise show that glass strands are solid constituents and the utilization of glass filaments prompts an expansion in concrete flexural quality 9. Among the accessible glass fiber, S2 glass fiber has expanded solid quality. The utilization of strengthened cement with reused total S2 glass fiber will consequently have most extreme quality and effectiveness 10. The goal of this exploration was to initially decide the fracture properties of a regular concrete as contrasted and reuse total cement what's more with S2 glass fiber with comparable blend constituent and degree.

## II. METHODOLOGY

The experimental study consists of evaluating materials and preparing a regular M25 grade strength concrete with a total aggregate size of 20 mm. S2 glass fibers having an aspect ratio of 150-200 in volume fractions of 0.25%, 0.5%, 0.75% and 1% and recycle aggregates with five different mixes as 40, 60, 70, 80& 100% replacement were used for the study. The experimental system consists of a three-point bending test on volume 500x100x100 mm notched beam samples with an initial 30 mm notch depth and 3 mm width for all 400 mm period mixes and all the test are done as per guidelines of RILEM 5. The details of the specimen for the fracture test are shown in Fig. 1. The deflection was distinguished using dial gauge through testing.

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*Corresponding Author
**Anshul Garg**, School of Civil Engineering, Lovely Professional University, Phagwara, India. Email: anshulgarg2008@gmail.com
**Nitish Kumar Jha**, School of Civil Engineering, Lovely Professional University, Phagwara, India. Email: jha.nitish@rocketmail.com
**Dr. Pushpendra Kumar Sharma***, School of Civil Engineering, Lovely Professional University, Phagwara, India. Email: p.sharmaji10@gmail.com

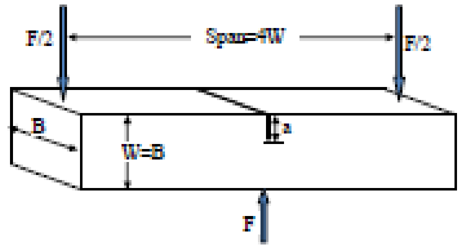


**Fig. 1. Details of Fracture Test Specimens**

According to the RILEM 5., the fracture toughness is determined using equation (1) as the critical stress intensity Kic.

$$Kic = \frac{3FS\sqrt{\pi a}}{2BW^2} f(\alpha) \quad (1)$$

Where, Kic =critical stress intensity (MPa√m), F – max. load (N), S, W and B are the span, depth, and width in mm respectively of the testing beam.

f(α) is geometry factor, which depends on the ratio of the notch depth/crack length (a) to the depth (W) of the beam. In case S = 4W as applied in the current study, f(α) can be as shown in equation 2.

$$f(\alpha) = \frac{[1.99-\alpha(1-\alpha)(2.15-3.93\alpha+2.7\alpha^2)]}{\sqrt{\pi}(1+2\alpha)(1-\alpha)^{1.5}} \quad (2)$$

The materials utilized for the investigation are Ordinary Portland Cement of Grade 43, locally available river sand utilized as fine aggregates, reused aggregates of demolished structures, coarse aggregates of 20 mm and S2 glass fiber of 15 mm length and 0.1 mm width, Master Glenium B233 as super plasticizer and water of drinking quality.

**Table- I: Physical Properties of Cement**

| Properties | Data obtained | Standard Data |
|---|---|---|
| Normal consistency | 33.5% | 26% -33% |
| Initial setting time | 49 min | 30 minimum |
| Final setting time | 242 min | 600 maximum |
| Fineness | 4.65 % | ≤ 10% |
| Specific gravity | 3.12 | 3.15 |

**Table- II: Physical Properties of Aggregates**

| Name | Water Absorption | Specific Gravity |
|---|---|---|
| Coarse Aggregates | 0.556% | 2.69 |
| Fine Aggregates | 0.9% | 2.59 |
| Recycled Aggregates | 7.92% | 2.34 |

Mix design of M25 grade concrete was carried out as per IS 10262-2019 11. Straight type S2 glass fiber with an aspect ratio of 150 was used in the experimental study which has Magnesium alumino silicate glass without CaO. The mix was confirmed based on a slump of 75 mm and 28 day cube compressive strength of 33.55 MPa. The final mix proportions and mix designations are shown in Table III and IV respectively.

**Table- III: Mix Proportion as per IS 10262:2019 11**

| Material | Cement | Fine aggregates | Coarse Aggregates | Water |
|---|---|---|---|---|
| Weight (kg/m$^3$) | 435.41 | 736.12 | 1035.29 | 191.6 |
| Ratio | 1 | 1.69 | 2.377 | 0.44 |

**Table- IV: Mix Designations and Percentages of Materials Added or Replaced in Concrete in Kg/m3**

| SN | Description | % replacement of coarse with recycled aggregates | % volume of S2 glass fiber |
|---|---|---|---|
| 1 | CR0G0 | 0 | 0 |
| 2 | CR40G0.25 | 40 | 0.25 |
| 3 | CR40G0.5 | 40 | 0.5 |
| 4 | CR40G0.75 | 40 | 0.75 |
| 5 | CR40G1.0 | 40 | 1.0 |
| 6 | CR60G0.25 | 60 | 0.25 |
| 7 | CR60G0.5 | 60 | 0.5 |
| 8 | CR60G0.75 | 60 | 0.75 |
| 9 | CR60G1.0 | 60 | 1.0 |
| 10 | CR70G0.25 | 70 | 0.25 |
| 11 | CR70G0.5 | 70 | 0.5 |
| 12 | CR70G0.75 | 70 | 0.75 |
| 13 | CR70G1.0 | 70 | 1.0 |
| 14 | CR80G0.25 | 80 | 0.25 |
| 15 | CR80G0.5 | 80 | 0.5 |
| 16 | CR80G0.75 | 80 | 0.75 |
| 17 | CR80G1.0 | 80 | 1.0 |
| 18 | CR100G0.25 | 100 | 0.25 |
| 19 | CR100G0.5 | 100 | 0.5 |
| 20 | CR100G0.75 | 100 | 0.75 |
| 21 | CR100G1.0 | 100 | 1.0 |

### A. Casting of Specimens

The moulds have been fitted for the beam test. For conducting fracture examination, specimens with and without recycled aggregates & S2 glass fiber are casted. For each combination, two samples were cast i.e. a total of 42 specimens of beams were cast. The samples of concrete beams were left without disruption until a hardened condition was reached. After 2 hours, the notch system was removed and after 24 hrs. the samples were submerged in water for 28 days.

**Fig. 2. Concrete Mix with Recycle Aggregates and S2 Glass Fiber**

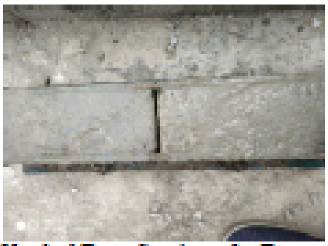

Fig. 3. Notched Beam Specimen for Fracture Test

## III. RESULTS & DISCUSSIONS

The specimen was subjected to 3-point bending in simply supported end condition. In order to determine the fracture strength, the 3-point bending tests were performed on beams with 100x100 mm cross section and an effective length of 400 mm. The results of peak load, Crack Length and critical stress intensity are shown in Table V. To represent the behavior of concrete beams due to central load the acquired data is plotted in Fig. 4, 5, 6.

**Table- V: Results of Fracture Toughness with Different S2 Glass Fiber and Recycle Aggregate on Concrete Beams**

| SN | Name | Peak Load (N) | Crack Length "a" (mm) | Kic (MPa√m) |
|---|---|---|---|---|
| 1 | CR0G0 | 4550 | 53.03 | 1.59 |
| 2 | CR40G0.25 | 4370 | 54.41 | 1.53 |
| 3 | CR40G0.5 | 4895 | 51.45 | 1.71 |
| 4 | CR40G0.75 | 5715 | 50.85 | 1.99 |
| 5 | CR40G1.0 | 4200 | 55.4 | 1.47 |
| 6 | CR60G0.25 | 4450 | 53.42 | 1.56 |
| 7 | CR60G0.5 | 5575 | 51.97 | 1.94 |
| 8 | CR60G0.75 | 6015 | 50.01 | 2.09 |
| 9 | CR60G1.0 | 4425 | 53.78 | 1.55 |
| 10 | CR70G0.25 | 4150 | 55.73 | 1.45 |
| 11 | CR70G0.5 | 4360 | 54.41 | 1.53 |
| 12 | CR70G0.75 | 4505 | 53.05 | 1.57 |
| 13 | CR70G1.0 | 4100 | 55.39 | 1.44 |
| 14 | CR80G0.25 | 4205 | 54.9 | 1.47 |
| 15 | CR80G0.5 | 4325 | 54.24 | 1.51 |
| 16 | CR80G0.75 | 4350 | 54.08 | 1.52 |
| 17 | CR80G1.0 | 4165 | 55.06 | 1.46 |
| 18 | CR100G0.25 | 3575 | 64.35 | 1.26 |
| 19 | CR100G0.5 | 3600 | 62.28 | 1.27 |
| 20 | CR100G0.75 | 3750 | 60.36 | 1.32 |
| 21 | CR100G1.0 | 3700 | 60.96 | 1.30 |

Fracture robustness increased with S2 glass fiber content with 60% recycled aggregate replacement and attained a maximum value for 0.75% fiber content and then decreased. With the introduction of S2 glass fibers, ductility was found to be improved and CR60G0.75 was found to be more ductile. The improvement in ductility was due to the active particle binding and containment. Flexural failure was the pattern of failure observed. Plain concrete beams failed by dividing into 2 halves, whereas GFRC beams only showed narrow cracks and no splitting. The results showed that the overall load and fracture capacity of GFRC beams were significantly increased relative to plain concrete beams.

## IV. CONCLUSION

The M25 grade concrete mix has been built with a total 20 mm aggregate volume. The effect of fiber content on concrete's fresh properties has been studied. The study's main goal was to investigate the effect of S2 glass fibers with recycled aggregates on the behavior of concrete beam fractures.

1. The application of S2 glass fiber in a concrete mix affects the fresh properties of concrete and requires a dosage of 0.25%-0.45% super plasticizer to keep the fresh properties within workable limits.
2. With 60 percent recycled aggregates and 0.75% fiber material, the ultimate load was improved by 32.2 percent and fracture strength by 31.45 percent relative to normal concrete beams.
3. There was a significant increase in the critical load and the fracture parameters of GFRC beams compare to plain concrete beams.
4. The fracture behavior of RAC and traditional concrete is identical under the same degree of concrete grade. If the RCA's replacement ratio is more than 60%, the strength of the fracture will be decreased by a total of 20%.
5. By including S2 glass fibers, the mode of failure was changed from brittle to ductile flexural process.

## ACKNOWLEDGMENTS

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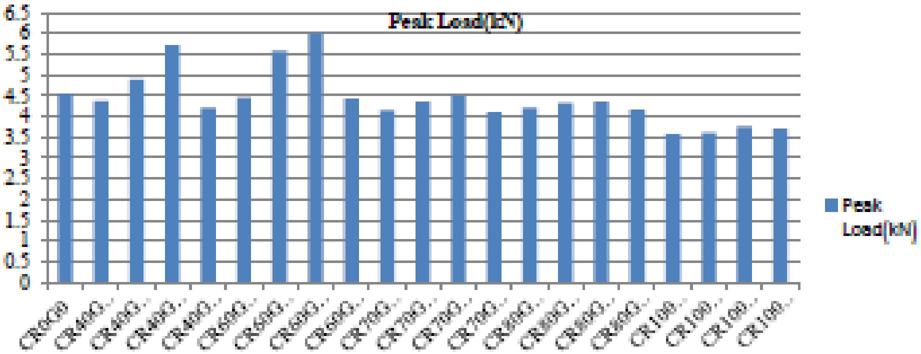


Fig. 4. Peak Loads for All Specimens

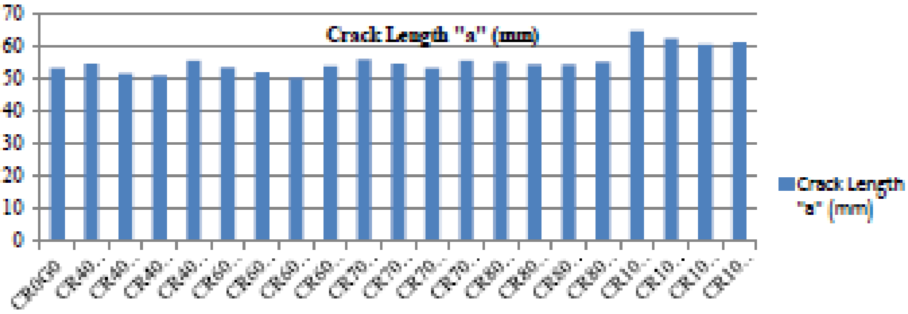


Fig. 5. Crack Length for All Specimens

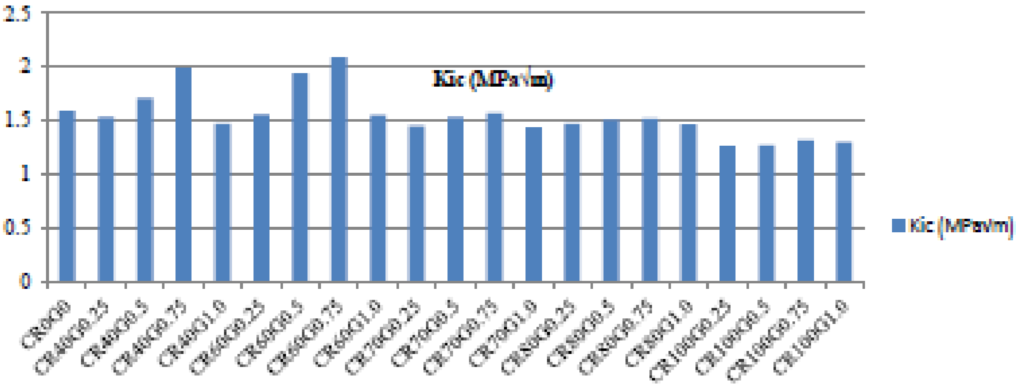


Fig. 6. Critical stress intensity of all test specimens


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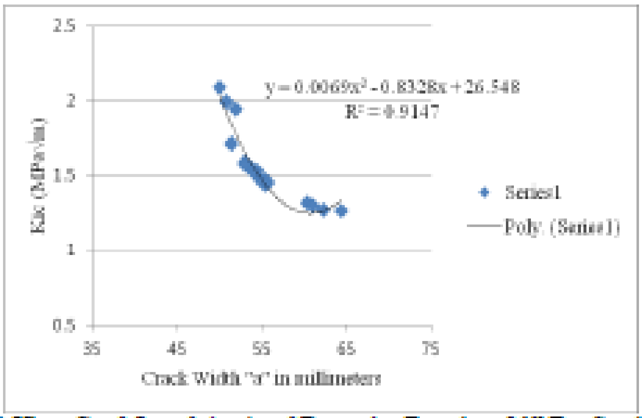
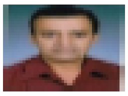



**Fig. 7. Kic vs Crack Length (mm) and Regression Equation of All Test Specimens**

## AUTHOR'S PROFILE

**Anshul Garg**, born in March 1983, Graduated from Institute of Engineering & Technology, Khandari, Agra affiliated to Dr. Bhimrao Ambedkar University, Agra in field of Civil Engineering in 2006 and Post Graduated from Manipal University, Karnataka in field of Structural Engineering in 2009 is presently pursuing Ph.D from Lovely Professional University, Phagwara, Punjab and is Assistant Professor in School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India. He is having a total experience of more than 11 years; 2.5 years construction industry and 8.5 years of teaching. He is having his areas of interest in Concrete Technology, Analyses of Structures, Design of Reinforced Concrete and Steel Structures, Earthquake Resistant Design of Structures etc. He has been the author of more than 10 International/ Conference research papers.

**Nitish Kumar Jha**, born in July 1992, Graduated from Nepal Engineering College ,Bhaktapur, Nepal in field of Civil Engineering in 2015 and Post graduation in Business Studies from Tribhuwan University, Nepal in 2018, is a research scholar currently enrolled in M.Tech Structural Engineering in School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India. He is having a total experience of more than 2 years in construction industry. His areas of interests are light weight structures, earthquake resistant structures, water supply & sanitation, structural design. He is life time member of Nepal Engineering Council.



**Dr. Pushpendra Kumar Sharma**, born in December 1963, Graduated and Post Graduated from Aligarh Muslim University, Aligarh, India in field of Civil Engineering in 1996 and with the same Research centre completed PhD in Civil Engineering with Specialization in Environmental and Water Resources Engineering in 2016, is a Professor in School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India. He is having a total experience of more than 28 years; 9.5 years construction industry and 20 years of teaching. He is having his areas of interests like Environmental and Water Resources, Green Buildings, Capacity buildings, earthquake resistant buildings, energy efficient buildings, water and wastewater treatment technologies, environmental designs, sustainable construction project management, river pollution control and industrial wastewater treatment etc.

**Dr. Pushpendra Kumar Sharma** in addition to teaching has served and officiated many administrative designation like Dean Academics, Dean Students Welfare, Warden, Chairman Construction Committee HCST etc. He has been the author of more than 60 International/Conference research papers. He is reviewer of Cogent Engineering International Journal of Tailor and Francis, Journal of Environmental Chemical Engineering and has reviewed many papers of the same. He has successfully organized National and International Conferences in the working institutions. He is life time member of Indain Molecular Society (IMS), Indian Science Congress Association (ISCA) and Institution of Engineers, India (IEI).
Currently he is guiding 8 PhDs in Civil Engineering on various topics @ LPU. He has guided one M.Tech and two more currently being guided in LPU. He has guided 150 B.Tech level projects on various topics of Civil Engineering. He has filed 8 patents out of which One recommended and one published and rest in pipe line. He attended many workshops of international and national repute. He is successfully trained under National Programme for Capacity Building of Engineers in Earthquake Risk Management (NPCBEERM), organized by Department of Civil Engineering, Indian Institute of Technology, Madras.

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# REVIEW ON FLEXURAL STRENGTH OF CONCRETE BY USING RECYCLED AGGREGATE AND GLASS FIBRE

**Navin Acharya[1], Dr. Pushpendra Kumar Sharma[2] and Anshul Garg[3*]**

*1 Research Scholar, Lovely Professional University, Phagwara, Punjab 144411, India, navinacharya71@gmail.com*

*2 Associate Professor, Lovely Professional University, Phagwara, Punjab 144411, India, p.sharmaji10@gmail.com*

*3 Professor, Lovely Professional University, Phagwara, Punjab 144411, India, anshulgarg2008@gmail.com*

**Corresponding Author: anshulgarg2008@gmail.com*

**Abstract**

Concrete is the material extensively used as construction material because of various advantages like low price, easy production, high compressive strength and good durability, but it is weak in flexural because of low tensile strength. After studying various research papers flexural strength of concrete is found to be increased by using glass fiber till 1% by weight. By the addition of glass fibers in concrete results in improving various other concrete properties such as split tensile strength, toughness and resistance to fatigue. On the other hand use of recycled aggregates on replacing natural aggregates in the concrete reduce the cost of construction and give the similar result as natural aggregates till an extent. The researches been done various researchers previously shows replacement of recycled aggregates till 50% only. For more usage of recycled aggregates it is necessary to add synthetic fibers like glass fibers. This will solve the disposal problem using recycled aggregates as a construction material. This review papers shows that the using the glass fiber and recycled aggregate at certain percentage improve the flexural strength of concrete and making low cost concrete.

**Keywords:** Concrete, Flexural strength, Glass fiber, Recycled aggregates.

## 1. Introduction

Concrete is a versatile material with numerous applications, but its low tensile strength and brittle behaviour are the main drawbacks. Today concrete is the most largely used construction material. In conventional concrete, we used only cement, fine aggregates, coarse aggregate and water[1,2]. But nowadays we are adding extra material in the concrete mix which increases some properties of the concrete than conventional concrete such as glass fibre. Glass fibre is the waste material of the glass industry which is used as additional material in the concrete mix[3–6]. We know that fibre is flexural in nature that way when the fibre is mix with concrete they increase the flexural properties of the concrete. Many countries are using glass fibre in the construction of structures because they sustain more load than conventional concrete in flexural. At the point when the total populace developments, the utilization of normal assets and vitality increments. One of the major ecological concerns today is identified with the over the top utilization of characteristic assets. The quest for an answer for this issue is as of now under route in a few areas. One of the parts with a significant obligation here is the development business, because of its utilization of characteristic assets and the measure of waste that is made, identified with solid use.[7]. In the event of failure to provide ecological material flow, natural resources may be depleted as they are not limitless. The present-day sustainable development demands the use of waste materials like BDW, Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), etc. The use of more recycled aggregates will help in solving problem of disposal which will decrease depletion of environment, apart from reducing the cost of construction materials. The recycled aggregate of BDW is also used in the making of concrete because due to waste of old concrete[8–10].

## 2. Literature Review

**Amon Katz et al.**[11]investigated that concrete of 28MPa crushed at age of 1, 3, 28 Days to take as recycled aggregate different result on the new concrete for precast concrete plants. The recycled aggregate replaced with the new concrete is about 100% were tested and tested were done by different sizes of aggregate. The results showed the concrete crushed at age of 3 days give good result than concrete crushed on other days. The concrete made with natural aggregate was stronger than concrete made with 100% of recycled aggregate. The flexural strength of concrete was reduced by 30-40% by using of 100% of recycled aggregate. **M.L.V. Prasad et al.** [12]investigated that concrete prepared with recycled aggregate of 0%, 50% and 100% and glass fiber gave good results. The flexural strength of concrete improved about 17.43% in fiber without recycled aggregates and 10.62% in fiber with recycled aggregates. They used grade of concrete M20 and M40 and semi-fill anti crack glass fiber. The recycled aggregate was of building demolished waste. **K.J. Rao et al.** [13]stated that use of recycled aggregate of building demolished waste and glass fiber mend the flexural strength of concrete. The mix design grade of concrete was M50 used in the study and recycled aggregate percentages were of 0% and 50% with glass fiber of 0% to 0.03%. The flexural strength of concrete with partial replacement RCA increased as fiber content amplified, The max value of strength were obtained at 0.03% of fiber content for both concrete of 0% and 50% RCA. **Mohsen et al.** [14] teams reconnoitered the flexural strength of recycled aggregate with glass fiber mix concrete. The percentage use of the recycled was 0%, 50%, 100% with glass fiber of 0.5% & 1%. The experiment was done in beam size of 100x100x50 mm. The value of flexural strength of control specimen was obtained 3.05 MPa which reached upto 3.42 and 3.51 Mpa by replacing 50% and 100%. **Hasan et al.** [15] groups has taken a shot at improving the mechanical properties of reused solid total utilizing hacked basalt strands and corrosive treatment. They researched the upgrading of the mechanical characteristic strengths of salvaged solid total (R. C. A.) delivered by including cleaved basalt strands (B. F.) with substance of 0.1 % to 1.5 % by complete volume of the blend to dry and untreated recycled aggregates. Increasing the content of chopped BF improved the flexural power significantly. A fiber of basalt content material of 1.5 % by way of complete extent of combine accelerated the flexural energy for NA, handled RCA & untreated RCA by way of 74.55%, 82.65% & 61.45% respectively. **S.T. Tassew et al.** [16] has worked on mechanical properties of glass fiber strengthened concrete. The experiment was done with glass fiber reinforced concrete using hewed glass fibers and phosphatic based cement. The volume of fibers used up to 2% by volume. The toting of glass fibers into concrete had shown improvement in flexural strength. The flexural strength of glass fibrous concrete amplified by the extension in percentage of glass fibers. The flexural strength of glass fibers reinforced ceramic concrete were increased 13-30%. **Salleshan et al.** [17] teams has worked on mechanical strength of concrete containing treated coarse recycled concrete aggregates their investigation said that modifying the surface of recycle aggregate by soaking in HCL and meta silicate improved the flexural strength of concrete. The flexural strength of of RCA with untreated recycled aggregate decreases. At different days, decreases in flexural strength of NR60 concrete by 3%, 10%, 12% and 13% compare with control concrete. The treated aggregate of 60% was decreased only 4%, 9%, 3% and 5% in 7, 28, 90, 180 days. **Devid et al.** [18] teams has worked on improving flexural strength of foamed concrete with glass fibers. In this experiment 40 beam were tested in 3 bending test on lesser balance of lathered concrete beam. The percentage of fibers is about 0.2 to 1.2%. Its increases the mechanical properties of concrete using bi-direction of grids glass fiber sited close to lowermost external face of the beam. The bi- directional nets increase the bending strength up to 31% on average. **Geroge et al.** [19] groups has taken a shot at refining the mechanical assets of cement by utilizing reused total. This investigations show the distinction in reused total concrete and normal cement is the mortar follow on RCA. The impact of RCA to concrete is Improved the flexural quality of cement by utilizing some treatment technique. The test demonstrated the misfortunes of flexural quality of RCA by utilizing 100% of reused total by common total. The results for the 100% replacement of CA with RCA showed losses of 16.4%, 19.6%, & 23.5% for RT100, RL100 and RF100 respectively. **Zhuming et al.** [20] has taken a shot at mechanical properties of cement by utilizing reused powder created from Development and crushed waste. The researched demonstrated the mechanical properties and breaking conduct of reused powder concrete by making two water covers proportion and distinctive level of RP. At 0.4 w/b proportion, supplanting 15% and 30% of concrete with RP prompts just a unimportant decline of about 1.3% and 3.2% in the flexural quality of RPC. Besides, the higher proportion of w/b of 0.5 by supplanting 15% and 30% of concrete with RP is found to prompt slight enhancements in bowing quality of RP with 2.4% and 1.6% expanded. **Ngoc et al.**[21] teams has worked on improving mechanical properties of recycled aggregate concrete by exchanging natural aggregate with increasing percentage of recycled aggregate. This paper showed the result of altered proportion of recycled mixture with natural aggregate up to 50%. The experimental result suggests that 30% recycled mixture substituted with natural

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combination enhancing the bending capability of RCA. J.Xaio et al. [22] has worked on the mechanical properties of recycled aggregate concrete and also worked on strength of RCA at elevated temperature. This paper exposed that flexural strength of RCA is decreased at preeminent temperature. The ratio between compressive strength and flexural strength of RCA is 0.5 at elevated temperature. The compare with compressive strength to flexural strength of RCA at different percentage with RA is not good at elevated temperature. A. Gornale et al. [23] teams has worked on the strength of glass fiber reinforced concrete. They are using glass fibers instead of steel reinforcement because of the light weight and also condense the cost of the construction. They are using M20, M30 and M40 grade of concrete. The experimental result shoed that the flexural strength of M20, M30 and M40 grade of concrete at 3, 7, 28 day is increased by 20 to 30%, 25% to 30% and 25 to 30% as compare with 28 days of plain cement concrete. Y. Muthy et al. [24] teams has worked on the compressive strength, flexural strength and workability of glass fiber reinforced concrete with different of glass fibers (0%, 0.5%, 0.7%, 0.9%, 1.2% and 1.5%).In this worked they are replacing fine aggregate with glass fiber and water-cement ratio is 0.45. The flexural members was cast in the mould of 700 X 150 X 150 mm & the test were checked in 7 and 28 days. The result showed that the flexural power of beam through 1.52% of glass fiber shows 30.5% surges in power as associate with 0% of glass fiber. M. Khan et al. [25] teams had worked on hardened properties of S-glass fiber strengthened concrete by partial replacement through 2% of nano silica. The glass fibers used in concrete is about 0.25 to 1% and grade of concrete is M40. The results showed that the concrete made with 0.75% glass fiber and 2% Nano silica increases of about 54% of flexural strength.

## 3. Conclusion

By the study of the various research paper it found that with an increase in glass fibers and recycled aggregate content from volume of concrete splitting tensile strength and flexural strength were enhanced. The value of glass fiber reinforced concrete beams compared to plain concrete beams, physically noted while experimentation, indicate an improved ductility and energy absorption capacity of glass fiber strengthened with RCA concrete. In these review paper it showed that up to 1.5% addition of glass fiber upgraded the strength of glass reinforced concrete. The replacement of natural aggregate with recycled aggregate without glass fiber about 100% also decreased the flexural strength of concrete and up to 50% strength of concrete was improved.

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# Review on Fracture Study of Concrete by Critical Stress Intensity (KIC) & Crack Tip Opening Displacement (CTOD)

**Nitish Kumar Jha[1], Dr. Pushpendra Kumar Sharma [2] and Anshul Garg[3#]**

*1 Research Scholar, Lovely Professional University, Phagwara, Punjab 144411, India,*
*jha.nitish@rocketmail.com*
*2 Professor, LPU, Phagwara, Punjab 144411, India,*
*p.sharmaji10@gmail.com*
*3 Assistant Professor, LPU, Phagwara, Punjab 144411, India,*
*anshulgarg2008@gmail.com*

*#Corresponding Author: anshulgarg2008@gmail.com*

## Abstract

Fracture study is a study of material used in the structure about the behavior of structure on influence of loads. Much work on fracture study in concrete is going on now-a-days. The previous researches showed the study of Critical stress intensity (Kic) and CTOD on concrete in equally linear elastic and elastic plastic crack propagation. It had been found that care is required while measuring the fracture toughness value at critical point. The review paper gives idea about fracture mechanics which is study of crack propagation in materials. The review paper consist the past investigation and current advances in fracture parameters test methodology as per ASTM. Here it gives description on the most useful fracture parameters i.e. stress intensity factor (Kic) and CTOD with its definition and basic concept as well as ASTM test method. The fracture toughness test on metal as well as concrete is studied. The ASTM code E399 and E1290 are used for testing the critical stress intensity (Kic) and CTOD respectively.

***Keyword***—Fracture Mechanics, CTOD, Critical Stress Intensity, ASTM, Crack propagation

## Introduction

The field of fracture mechanics evolved in the nineteenth century with Griffith's work on crack of brittle material [1]. Fracture study of concrete is the area of technicalities that addresses the need for material propagation of cracks [2]. A crack might be nucleated and the machine components or structure may begin to grow during service [3]. For big, complicated structures such as bridges, boats, aircraft, the chance of cracking /flawing is greater [4]. When a current crack is present, fracture study are used to determine the permissible pressure amount that the material can resist in order to shun fracture on it [5, 6]. The need of fracture mechanics is very essential in construction sector as it deals with design of elements. The hypothesis on fracture mechanics is that here exists a crack in design elements [7]. The crack like hole, notch, a slot, a corner can be manmade."The conventions on the Linear Elastic Fracture Mechanics (LEFM) remain considered as the material to be isotropic plus linear elastic"[8].If inelastic deformation occurs near the tip of the crack and the amount of the plastic region is very short compared to the amount of the crack (which we call tiny resilient), LEFM can also be implemented efficiently [9]. The stress turf nearby the crack tip is calculated by means of the theory elasticity. If the stresses nearby the crack tip surpass the toughness of the material fracture, the crack will increase [10]. The strength of fracture in LEFM is defined by factor of stress intensity (K) [11]. The material was regarded by elastic plastic fracture mechanics (EPFM) as an isotropic which

is elastic-plastic deformation occurred during fatigue loading". EPFM relates when big areas of the fabric are subject to plastic deformation almost the crack tip[12,13].The stress energy turfs or the notch displacement nearby the crack tip are calculated in EPFM and the shell will develop when the opening energy exceeds the critical value [14]."The fracture strength in EPFM is characterized by J-integral (recommended by Rice) or CTOD (suggested by Well)".As one of the best important fields of science, fracture mechanics is used to evaluate material conduct in construction[15,16].The tension-softening curvature can be regarded as a basic concrete constraint. The curve reflects the material's post ultimate load ability [17]. The

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most important characteristics of concrete for evaluating fracture conduct is the tension-softening diagram [18]. Fracture energy is the factor of cohesive plant designs; it represents the cracking strength and the toughness of quasi-brittle plastics such as concrete. [19].The models can capture the vital characteristics of a gradually fracturing apparent and its development up to the failure. The cohesive stress- separation connection can fully characterize the energy dissipation for crack propagation [20]. The selection of softening feature (or cohesive law) affects the structural reaction forecast and the behavior of the local fracture [21]. In the mathematical representations of multiple

finite-element programs for non-linear modeling, fracture energy was also implemented [22, 23].

**Literature Review**

As per ASTM E 399, to compute the stress intensity factor, **John E.Srawley** suggested polynomial expression, K, from the applied force, P, and sample size.

For the three-point bend specimen, the suggested expression is:

$$\frac{KBW^{1/2}}{P} = \frac{3(S/W)\left(\alpha^{1/2}\left(1.99-\alpha(1-\alpha)(2.15-3.93\,\alpha+2.7\,\alpha^{2}\right)\right)}{2(1+2\alpha)(1-\alpha)^{1.5}}$$

For: $0 \leq \alpha = a/W \leq 1$:

Wherever: B = breadth, W = width (depth), a = average length of crack, and S =support span = 4W +0. 01 W [24]. **Newman** evaluated the alternatives suggested for a surface fracture in a finite plate subject to standardized strain for the stress-intensity factor. Over the previous sixteen years, these alternatives have been created using rough analytical methods, experimental techniques, and estimates of engineering. Comparison of the different alternatives at the peak depth level showed excellent agreement for crack, depth-to-specimen thickness ratios below about 0.3 (+ 5 percent). For bigger crack, depth-to- specimen thickness ratios (0.3 to l), however, the alternatives were in significant disagreement (20 to 80 percent), particularly for rocks with tiny crack-depth-to- crack-length ratios (0.2 to 0.6) [25].**Tanaka et al.** researched the Kic identified at the critical efficient crack tip as the stress intensity factor calculated using the peak load measured. The critical CTOD is defined as the opening of crack tip which is calculated at the original notch tip of the specimen utilizing the deliberate most extreme load and the critical, effective cracking length [26]. Based on the load-CMOD curve, the critical stress intensity factor Kic, the Young's modulus E and the critical CTOD, **Eanique et al.** researched fracture parameters. For each specimen, complete load- CMOD curve, peak load P max, original Ci compliance and Cu unload compliance [27]. **Tracey** researched the finite element operation of separating the cracked setup into triangular shaped singularity components around the crack tip with adjacent isoperimetric trapezoidal shaped components. Here the rigidity of the tip component is calculated by an accurate integration of the anticipated singular field, resulting in incompatibility on the boundary of the circular element by joining straight-edged triangular elements [28]. **Jun** researched concrete that is comparatively brittle material on Portland cement. As a consequence, crack propagation critically influences the mechanical conduct of concrete and fiber strengthened concrete. There have been many attempts to apply

fracture mechanics ideas to composites based on cement, such as mortar and concrete[29]. **Zhu et al.** journal described the foremost vital fracture constraints of the potential energy unharness rate G, the strain intensity factor K, the J-integral, the crack-tip displacement d and the crack-tip angle (CTOA) and conferred, primarily within the written account request, the important and progressive developments of those fracture parameter take a look at and analysis methods. It is likely that this journal will function a brief technical manuscript for tracing the significant improvement of fracture robustness testing and investigation, for higher considerate and victimization correct fracture constraints and fracture strenghth take a look at ways. For additional up ASTM fracture take a look at standards within the future [30]. The case of high- strength concrete was studied by **Pal et al**. the cracking performance may equal the minimum value of the tensile strength of the mixture and the power of the matrix / aggregate bond. The distinction between cracking force and tensile strength becomes tiny because the cracking force is controlled by the original size of the defect in the matrix or the interfacial matrix / aggregate area. A high-

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strength matrix will enhance the matrix-aggregate bond and result in increased cracking strength [31]. **Ince** only researched the two-parameter model fracture parameters that were evaluated using regression analysis. However, the findings of this assessment can readily be tailored to other concrete fracture models like as the size impact model and the efficient crack model, which also suggests two parameters for concrete fracture modeling [32]. **Tagawa et al.** explored silicone rubber reproduction of charged crack tips by opening shapes and crack tip displacement (CTOD) in single edge notch bend (SENB) samples. Their dimensions showed that CTOD in BS7448 overestimated the genuine CTOD for low yield-to-tensile steel and encouraged the investigation of a new method of CTOD calculation, consideration of variability in the reducing conduct of the crack tip owing to strain hardening. The silicone rubber repetition of charged crack tips in SENB samples for various YR steels was experimentally explored with crack opening profiles and CTOD. In BS 7448, CTOD settled with the real CTOD in YR=0.9 material. In YR=0.6 material, still an overestimation was obviously noted. These ways led from the location of the plastic strain influenced by the various hardening characteristics of the strain. An innovative CTOD calculation has been proposed, $CTOD_{JWES}$. In that CTOD calculation, $CTOD_{JWES}$ could offer a precise assessment regardless of the material yield-to-tensile ratio besides the sample thickness [33]. **Shinde et al.** addressed the impacts of precisely small weld beam and high resistance overmatching on the fracture strength of laser beam repaired parts with focus on the plastic restraint variance in fracture toughness specimens and structural elements with pop in repair metal. The equivalent CTOD ratio, β, was evaluated numerically to correct CTOD toughness for restrictive failure in structural elements [34]. **Patil et al.** noted that Al-alloy A384 acquired the mild fracture toughness value around 22.91 MPa. For Al- alloy A384 material, the fatigue pre cracking load is 1.97 KN which is required to produce sharp crack close to the crack tip. The peak load (Pmax) achieved prior to

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complete sample fracture is approximately 2.67 KN. The fracture load (PQ) acquired for Al-alloy A384 is approximately 2,068 KN. Al-alloy A384's temporary fracture toughness was noted around 18.53 MPa. Analytical calculation such as temporary fracture toughness and Al-alloy A384 fracture toughness was calculated to be 18.44 MPa and 23.78 MPa respectively. Comparative research is produced between the test and the analytical value of the toughness of the fracture and it is found that there is only 3% mistake between them [35]. **Brandão et al.** suggested a method for estimating CTOD as a driving force for elastic-plastic fracture and is used for assessing faults in welded constructions. A semi- empirical CTOD design curvature has been created by the Japan Welding Engineering Society (JWES) to calculate CTOD. Moreover, with a crack, there is individual sort of welded joint, namely a semi-welded corner boxing fillet. Additional investigations should be carried out for other welded joints and crack dimensions [36]. **Khor** calculated crack tip opening by means of the equations BS 7448-1/ISO 12135, ASTM E1820 and JWES were
contrasted with the outcomes acquired by SRC and FE modeling experiments. The ASTM approach provides a technique for determining CTOD from J without necessarily measuring the displacement of the crack mouth, while confirming practical precision through a spectrum of strain-hardening materials [37]. **Yasuhito et al.** addressed the impacts of little weld bar and high opposition overmatching on the crack durability of laser bar fixed parts with an attention on the distinction in plastic requirement of break strength examples and auxiliary components with fix metal disfigurement. Then comparing CTOD proportion equivalent to β, for the rectification of CTOD strength in basic robustness [38]. **Abdel et al.** demonstrate the reliance on the sample density and ligament length of the fracture toughness. For all samplings with different ligament lengths, a critical foundation radius was originated in which the fracture's strength is entirely independent of the core radius of the notch. The expected fracture toughness is in excellent agreement with the measured information using the established models [39].

## Conclusion

This gives a deliberate specialized review of fracture strength testing, test assessment, test strategies and institutionalization for materials in reference to both the straight flexible fracture mechanics and the versatile plastic fracture mechanics. This analysis outlined the best significant fracture parameters i.e. the stress intensity factor Kic, the CTOD, the J integral and the opening mouth of the crack-tip (CTOM). The fundamental idea, meaning, experimental assessment, early fracture testing practice, latest growth, decisive point value assessment of stiffness and resistance curve testing are explained in detail. The ASTM standardization exertion of fracture test on Kic, J, CTOD, and CTOM fracture parameters wereoutlined in detail. The impacts of load rate, crack-tip restraint, temperatures and fracture unsteadiness on fracture strength measurements were also explained.

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# A Critical Review on Behaviour of Glass Fiber Reinforced Concrete Using Recycled Aggregates

Anshul Garg[1] and Dr. Pushpendra Kumar Sharma[2]
*1 Lovely Professional University, Phagwara, 144411, India*
*2 Lovely Professional University, Phagwara, 144411, India*

***Abstract:*** *Glass fiber reinforced polymer has become an alternative reinforcement in concrete structures due to its excellent corrosion resistance, making it possible to combine with concrete composed of seawater and sea sand. It has been observed that usage of glass fiber increases strength of concrete and repletion of concrete towards acid and alkali. Many researchers have reported that there exists a clear difference between properties such as porosity, water absorption, surface density, crushing value etc. of recycled coarse aggregates (RCA) and natural coarse aggregates (NCA). It has also been established that on replacing normal aggregates with recycled aggregates there is a slow depletion in strength properties where flexural properties depict a clear reduction in strength. It has been further detected that maximum limit of using recycled aggregates is not more than 50 percent. Therefore according to the specific performance requirements of concrete, choosing appropriate raw materials and then designing the most economic, high-quality concrete, based on the proper mix proportion methods, is the best way to overcome the shortcomings of the traditional design materials and this puts forward new thoughts and finding an appropriate mix that can be used for incorporating more percentage of recycled aggregates. It developed a backbone for the study of glass fibers addition in concrete with partial replacement of normal aggregates with recycled aggregates considering the strength parameters and workability. This paper reviews on previous findings on use of RCA and glass fibers.*
***Keywords:*** *Glass fibers, RCA, NCA, workability, repletion, recycled.*

## I. Introduction

In recent years, certain countries have considered the reutilisation of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities. The recent study on partial replacement of normal aggregates with Recycled aggregates using 0%, 20%, 30% and 40% of recycled aggregates with 5%, 10% and 15% recycled hydrated cement(RHC) have reported better performance of concrete with 20% RCA and 5% RHC[1]. Similarly many researchers have dedicated their work to describe the properties of recycled aggregate, the minimum requirements for their utilisation in concrete and the properties of concretes made with recycle aggregates. Past studies also depicted that glass fibers are good constituents of concrete and usage of glass fibers ranging 0% to 2% results in increase in flexural strength of concrete[2].

Therefore, usage of glass fiber reinforced concrete with recycled aggregate will give optimum strength and economy. In this study, fracture behaviour of glass reinforced concrete with recycled aggregates will be tested.

## II. Literature Review

A detailed study on the researches done is carried out and founded out that using recycled aggregates results in decreasing the strength attributes and increasing water absorption and carbonation whereas addition of glass fiber in concrete give better strength and credibility. Usage of recycled aggregates in concrete in higher percentages will only be fruitful when glass fibers are added with concrete. The research works done by various researchers on glass fiber reinforced concrete are been described in chronological order like in 1974 Junji Takagi et al., investigated the effect of randomly oriented glass fibres on the flexural strength, compressive strength, splitting tensile strength, and Young's modulus of concrete, and concluded that there was an increase in strength with an increase in fibre content[3]. Further in 1996 C. Vipulanandan et al., studied flexural behaviour of a polyester polymer concrete by varying the polymer up to 18% by weight and fiber contents to 6% by weight of PC. In general, addition of fibers increased the flexural strength, failure strain (strain at peak stress), and fracture properties, but the flexural modulus of PC remained almost unchanged. Addition of six percent fiber content and silane treatment of aggregates and fibers increased the flexural strength of 18% PC to 41.6 MPa (6,040 psi), almost doubling the strength of unreinforced 18% PC system[4]. In continuation to this research S. H. Alsayed, et al., in 2001, studied the performance of glass fiber reinforced plastic bars as reinforcing material for concrete structures and revealed that as GFRP bars have low modulus of elasticity, deflection criteria may control the design of intermediate and long beams reinforced with FDRP bars[5]. Then after K. Ramesh, et al., in 2003, studied experimentally the stress–strain behaviour of confined fiber reinforced concrete (CFRC) and tested nine prisms of size 150x150x300 mm under strain control rate of loading and resulted increase in strength and strain of CFRC[5]. In 2004 J.M.L. Reis et al., observed in their study that the fracture toughness of carbon fiber reinforced polymer concrete can increase up to 29% while glass fiber polymer concrete can increase up to 13% when comparing with epoxy non reinforced polymer concrete[6]. Yeol Choi, et al., in 2005, have conducted an experimental study on the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC) and founded that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength[7]. Further in 2007 G. Barluenga, et al., evaluated the cracking control ability of Alkali Resistant (AR) glass fibers in standard concrete and SCC and founded that amounts of glass fiber around 600 $g/m^3$ shown the maximum cracking control ability, but larger amounts did not increase the fiber efficiency[9]. Then P. Srinivasa Rao, et al., also conducted durability studies on alkali resistant glass fiber reinforced concrete in 2012 and find out workability, resistance of concrete due to acids, sulphate and rapid chloride permeability test of M30, M40 and M50 grade of glass fiber reinforced concrete and ordinary concrete resulted increase in durability of concrete, reduction in bleeding and increase in acid resistance[10]. In year 2012 may researches were been done like Avinash Gornale, et al., reported that there is an increase in compressive strength, flexural strength, split tensile strength of glass fiber reinforced concrete for M20, M30 and M40 grade of concrete at 3, 7 and 28 days by 20% to 30%, 25% to 30% and 25% to 30% respectively[11] and Kavita Kene, et al., conducted studies using steel and glass Fiber Reinforced Concrete Composites with steel fibers of 0% and 0.5% volume fraction and alkali resistant glass fibers containing 0% and 0.25% by weight of cement of 12 mm cut length and founded that addition of glass fibers results in increase of compressive strength, flexural strength and split tensile strength[12]. Further in 2012 itself Muna M .Abdullah et al., investigated to find out the effect of glass fiber content (0, 600, 1000, and 1400) $gm/m^3$ on the mechanical properties of glass fiber reinforced concrete at 28 days, resulted increase in the splitting tensile strength by approximately (1, 4.3, 12.5)% and and compressive strength of concrete increased by ratios (3.6, 7.1, 9.3)%. Based on this study the young modulus of GFRC increased by (9.7, 56.6, 84) % due to glass fibers content in concrete[13]. Then Yogesh Murthy, et al., studied the performance of Glass Fiber Reinforced Concrete revealed that the flexural strength of the beam with 1.5% glass fiber shows almost 30% increase in the strength but reduction in slump observed with the increase in glass fiber content[14]. In 2013, G. Jyothi Kumari, et al., studied the behaviour of concrete beams reinforced with glass fiber reinforced polymer flats and observed that beams with silica coated glass fiber reinforced polymer (GFRP) flats showed shear reinforcement failure at higher loads and exhibit fairly good ductility[15]. Further Tassew et al., in 2014, conducted experimental studies using glass fiber volume fractions between 0% and 2% founded that addition of glass fibers into ceramic concrete had little influence on the compressive strength and modulus of elasticity but resulted in significant increases in flexural strength and direct shear strength, regardless of the matrix type or fiber length, while the workability decreased with an increase in fiber content[16]. Then in 2015, Ahmet B. Kizilkanat et al., studied the mechanical properties and fracture behaviour of basalt and glass reinforced concrete for different combinations of 0.25, 0.5, 0.75 and 1.0 percentage of basalt and glass fiber and observed that Fracture energy increased significantly after 0.25% dosage for both basalt and glass reinforced concrete[17].

The studies done on glass fiber reinforced concrete summarizes that use of glass fiber in concrete results in increase in flexural and split tensile strength and there is very less variation in compressive strength of concrete and so glass fiber reinforced concrete can be well applied in flexural members. This review is focused on the possibility of use of glass fibers to increase the use or percentage of recycled aggregates in concrete and so further research works reported by researchers on recycled aggregate concrete is too reviewed for getting an overview of the further scope of research that can be suggested to obtain positive research outcomes.

The researches done with recycled aggregates in been arranged in chronological order starting from 2001 the Leite campaign, at the Federal University of Rio Grande do Sul, Brazil, where the RA used in the production of RCA were coarse and fine ceramic and recycled concrete, several replacement PA/RA ratios were selected within each family of RCA, defined by a predetermined w/c ratio (0.4, 0.45, 0.60, 0.75, and 0.80), and a high percentage of fine RA was used. The hardened concrete was tested for compressive strength, splitting and flexural tensile strength and modulus of elasticity[18]. Then in 2002, F. Buyle-Bodin et al., studied water absorption, air permeability and carbonation of recycled aggregate concrete by using both coarse and fine recycled aggregates and founded that water absorption is more while using recycled aggregates. The carbonation rate of recycled aggregate concrete is also higher which leads to a weaker resistance of recycled aggregate concrete to environmental attacks[19]. In the study done by Said Kenai et al., compared mechanical properties with a concrete to 100% of natural granulates and of a recycled concrete partially replacing 0, 25, 50, 75 and 100% of natural aggregates. Results showed that it is possible to manufacture a concrete to basis of ground of physical feature concrete and acceptable and in the same way comparable mechanics to those of a concrete to natural granulates basis so long as the percentage of granulates recycled is limited to 75% for the thick and to

50% for ends[20]. In the Katz campaign, (2003) at the Israel Institute of Technology, the RA were produced in the laboratory by crushing concrete specimens 1, 3 and 28 days old. The PA were replaced with RA for the following fractions: 2.36-9.5 mm (0.093- 0.374 in) and 9.5-25 mm (0.364-0.984 in) (both coarse), and 0-2.36 mm (0-0.093 in) (fines). Fine RCA was used in small amounts and only to improve workability. The traditional cement class was lower than the white cement class, and that had some influence on the results. The hardened concrete was tested for compressive strength, splitting and flexural tensile strength, modulus of elasticity, water absorption, carbonation penetration and shrinkage. The properties of the RCA with nearly 100% of aggregate replacement, were tested. Various particle size group showed significant differences between the properties of the recycled aggregates where as the crushing age had almost no effect. The properties of the concrete made with RA were inferior to those of concrete made with virgin aggregates. Concrete made with aggregates crushed at age 3 days exhibited better properties than those made with aggregates of the other crushing ages[21]. Steam curing method was used for curing recycled aggregate concrete with fly ash using 0, 20%, 50% and 100% of recycled aggregates with 0.45 water-cement ratio and fly ash of 0%, 25% and 35% by weight replacements of cement and was tested for compressive strength, modulus of elasticity, chloride penetration and shrinkage in Kou Shi C et al., research in 2004 and founded that there in decrease in strength of concrete on increase in content of recycled aggregate in concrete. It was founded that for incorporating higher percentages of recycled aggregate in concrete, fly ash between 25-35% can be used with steam curing[22]. In the Cervantes et al., campaign, (2007) at the University of Illinois, USA, the RCA families were defined in terms of the addition of synthetic fibers in the concrete production. Only the coarse fraction of PA was replaced with different ratios of recycled concrete RA (0, 50, and 100%) and with 0.2% of synthetic fibers. The effective w/c ratio remained constant at 0.51. The hardened concrete was tested for compressive strength, splitting tensile strength, modulus of elasticity and shrinkage. The test results reported that use of 50% RCA with 0.2% synthetic fibers produced a pavement quality concrete with similar fracture and shrinkage properties to that of the virgin coarse aggregate concrete[23]. M. Etxeberria in 2007 experimentally tested shear behaviour and strength of beams considering four concrete mixes with different percentages of recycled aggregates with partial replacement 0%, 25%, 50% and 100% with different transverse reinforcement taking same compressive strength and founded a substitution of less than 25% of coarse aggregate, scarcely affects the shear capacity of RC beams[24]. In year 2009 A. Bordelon et al., studied fracture behaviour of paving concrete made with recycled concrete as a coarse aggregate, virgin coarse aggregate, and a blend of recycled concrete and virgin coarse aggregate with Discrete structural fibres and observed that 50–50 blend of virgin and recycled concrete coarse aggregate produced similar fracture properties to VAC and both were 53% higher than the total fracture energy of the 100% RCA concrete. With the addition of synthetic macrofibres to RCA concrete, the total fracture energy was greater than the plain VAC[25]. Experimental results were used to establish a relationship between some properties of hardened concrete (compressive strength, splitting and flexural tensile strength, modulus of elasticity, abrasion resistance, shrinkage, water absorption, carbonation penetration and chloride penetration) and the density and water absorption of the aggregates by Jorge de Brito, et al., in 2010 and founded The use of concrete with recycled aggregates should always take into consideration that in most cases they perform worse than conventional concrete but that the variability of their properties are similar. Therefore, the decrease in the concrete with recycled aggregate performance in comparison to the conventional one can be anticipated with the knowledge of the substitution rate and of the aggregates properties[26]. In year 2015 Kutalmis Recep Akça et al., replaced normal aggregate with recycled aggregates and used polypropylene fiber 0%, 1% and 1.5% by volume and Compressive strength, splitting tensile strength, flexural tensile strength, static and dynamic modulus of elasticity experiments were conducted in order to determine mechanical performance of the concrete series. It was founded that there is a remarkable increase in split tensile and flexural strength on increment of fibre content[27]. There after Faisal Sheikh Khalid, et al., in 2017 studied on Mechanical Properties of Concrete Containing Recycled Concrete Aggregate (RCA) and Ceramic Waste as Coarse Aggregate Replacement and used 25%, 35%, and 45% RCA and ceramic waste as coarse aggregate in producing concrete and reported that 35% RCA and 35% ceramic waste showed the best properties compared with the normal concrete[28]. Mohsen Ahmadi, et al., replaced natural coarse aggregates with recycled aggregates in percentage by weigths of 0, 50 and 100%, with steel waste fiber obtained from waste tyres percentage being 0.5 and 1% of concrete volume. Main results indicate that by adding recycled fibers into the concrete with recycled aggregates lead to the production of structural concrete by 50% replacement of aggregates. Moreover, adding recycled fibers by 0.5 and 1% of concrete volume reduces the thickness of concrete pavement for the amount of 8 and 16%, respectively[29]. In year 2017 Ngoc Kien Bui researched on properties of recycled aggregate concrete (RAC) by using sodium silicate and silica fume. The method proposed was applied to 100% coarse recycled concrete aggregate compared to untreated RAC was able to improve compressive strength up to 33-50%, splitting tensile strength 33–41%, and elastic modulus 15.5–42.5%. From the experimental data, the compressive strength of the treated RAC can be estimated at any age[30]. The paper by Hasan Katkhuda in 2017 presents the results of a study that investigated the improvement of the mechanical properties of recycled concrete aggregate (RCA) produced by adding chopped basalt fibers (BF) with contents of 0.1%, 0.3%, 0.5%, 1%, and 1.5% by total volume of the mix to treated and untreated recycled aggregates.

The recycled aggregates were surface treated by pre-soaking them in a 0.1 M hydrochloric acid (HCl) solution for 24 h to remove the adhered mortars to improve the bond between the recycled aggregate and the cement. In addition, chopped BF was added to normal concrete (NA) mixes as a control for comparison. The results showed that using chopped BF minimally enhanced the compressive strength of the concrete mix but significantly improved its flexural and splitting tensile strength. Furthermore, the optimum BF content that produced the same splitting tensile and compressive strength as NA was 0.5% for untreated RCA and 0.3% for treated RCA, while the flexural strength was 0.3% for untreated RCA and 0.1% for treated RCA[31]. Then in year 2018, Christiana Alexandridou et al., have conducted experimental study where concrete mixtures were prepared using partial replacement of natural aggregates with percentages of recycled aggregates ranging from 0% to 75%, results indicate that the compressive strength of recycled concrete ranges from significantly lower (37% reduction) to equal, compared to conventional concrete, depending on the composition of recycled aggregate[32]. Then in 2018 again G. Wardeh et al., studied experimental behaviour of compressive strength and flexural strength on usage of recycled aggregate in concrete and founded that compressive strength on introduction of recycled aggregates results in a decrease in elastic modulus and showed more cracks than conventional concrete members[33]. As per article published in IOP conference series by Kaiyun Wu et al., stated the experimental study of fracture behaviour of recycled aggregate concrete using 50%, 70% and 100% partially replacing normal aggregates and tested initial cracking load and fracture energy. In the experimental procedure and result prediction it was found that initial cracking load was high with normal aggregate concrete which is founded less in case of recycled aggregate concrete. Further the same is depicted in fracture energy behaviour and was founded a remarkable decrease of fracture energy using recycled aggregate concrete[34]. In year 2018 Jianzhuang Xiao, Studied behaviour of Recycled Aggregate Concrete in comparison to partial replacement of Normal Aggregates, where 0, 30, 50, 70 and 100 percentage replacement of normal aggregates were done and checked compressive strength and founded that compressive strength of recycled aggregate concrete (RAC) is lower than that of natural aggregate concrete (NAC) under the condition that water-cement ratios (w/c) are same[35]. As per the review paper written by Ali Akhtar et al., collecting data from 40 countries it was founded that till 2012 the construction and demolition waste generated per year is more than 3 billion and is increasing constantly. The various researches studied in his review paper founded that the use of 30% to 50% recycled aggregate was suggested to achieve the strength requirements which is not sufficient for developing countries India and China[36]. Yijie Huang et al., compared mechanical properties of concrete with natural coarse aggregate, recycled coarse aggregate and coral coarse aggregate considering 50% and 100% recycled aggregate. Compressive strength of specimens were checked and it was founded that on using more percentage of recycled aggregates there is remarkable decrease in compressive strength where as coral recycled aggregates give more strength than 100% usage of recycled aggregates[37]. In the research done by B. Cantero, assessed the performance of structural concretes containing 20%, 25%, 50%, 75% or 100% mixed recycled coarse aggregate, analysing fresh concrete workability, density and air content and hardened concrete compressive, flexural and splitting tensile strength. The decline in strength relative to conventional concrete was smaller at longer curing ages. Concretes bearing up to 50% recycled aggregate exhibited declines in performance of 10% or under in most of the properties studied, even at late ages. In light of the present findings, the mixed recycled aggregates used in this research may be deemed apt for use in structural concrete with a characteristic strength of up to 30 MPa[38]. In the study done by George Dimitriou in year 2018 founded a method to improve the behaviour of recycled aggregate and reported that 50% replacement is the optimum value for usage in concrete[39]. F. Fiol in 2018 used Recycled Aggregates (RA) from structural precast elements substituting 20%, 50% and 100% normal aggregates. Three Control Concretes (CC-30, CC-37.5, CC-45) manufactured with Natural Aggregates (NA), and their corresponding Recycled Aggregate Concretes (RAC-20, RAC-50, RAC-100) are evaluated in terms of physical and mechanical properties. The in-fresh properties results (flowability, viscosity and passing ability) of the RAC were suitable for their use as SSC. Furthermore, the tests of compressive, splitting tensile and flexural strength, as well as density, porosity, water absorption, ultrasonic pulse velocity, stiffness, and both dynamic and static modulus provided results close to those of the SCC with Normal Aggregates[40]. R.V. Silva et al., in 2018 reviewed 130 research papers where the major focus was on fresh properties of concrete and reported that water absorption of recycled aggregates is much higher than normal aggregates and so use of admixtures can help to obtain workability[41].

## III. Results and Conclusions

After performing a detailed literature review it has been analyzed that using recycled aggregates is limited to maximum 50% replacement of coarse aggregate as beyond this there is a remarkable decrease in concrete properties like compressive strength, flexural strength and split tensile strength [42]-[50], [55]-[56] and so for using more replacement of normal coarse aggregate it is suggested to use some fibres and on studying previous researches on glass fibers it was founded that use of S2 glass fiber enhance the properties of concrete [57] and therefore there is a possibility of attaining an optimum mix with more percentage of recycled aggregate and adding a blend of glass fiber to it. Fracture study is being performed on glass fiber and recycled aggregate concrete using ANSYS software [53] which can be used further to check effect of glass fiber on fracture of recycled aggregate concrete.

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[Under the Aegis of Lovely Professional ... Delhi G.T. Road, Phagwara (Punjab)]

*Certificate No. 183240*

## Certificate of Recognition

*This is to certify that Dr./Mr./Ms.* ***Anshul Garg***

*from* ***Lovely Professional University***

*presented a research paper titled* ***Behaviour of Recycled Aggregate Concrete with Glass Fibers Under Compressive Loads: A Sustainable Approach***

*in the* ***International Conference on Experimentation and Progression in Engineering, Research and Technology ( EXPERT - 2019 )"*** *held on 15th and 16th of November 2019, organized by School of Civil Engineering at Lovely Professional University, Punjab, India.*

*Date of Issue : 15-11-2019*
*Place of Issue: Phagwara (India)*

Prepared by (Administrative Officer-Records) | Chairman (EXPERT - 2019) | Organizing Secretary (EXPERT - 2019)

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(A Unit of SRM Group of Educational Institutions)
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Approved by Govt. of Tamil Nadu & AICTE, ISO 9001:2015 Certified
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## International Conference on Sustainable Environment and Civil Engineering (ICSECE'19)

ICSECE'19

## CERTIFICATE OF PARTICIPATION

This is to certify that Dr./Mr./Ms. ........ANSHUL GARG........................................of ..LOVELY.....PROFFESSIONAL......UNIVERSITY...., PUNJAB........has presented / participated paper entitled ..A. CRITICAL....REVIEW...ON.BEHAVIOUR...OF..GLASS...FIBRE....REINFORCED...CONCRETE.....USING...RECY..AGG. in the "*International Conference on Sustainable Environment and Civil Engineering (ICSECE'19)*" organized by Department of Civil Engineering, Easwari Engineering College on 28th & 29th March, 2019.

Convener

POORVIKA

Principal

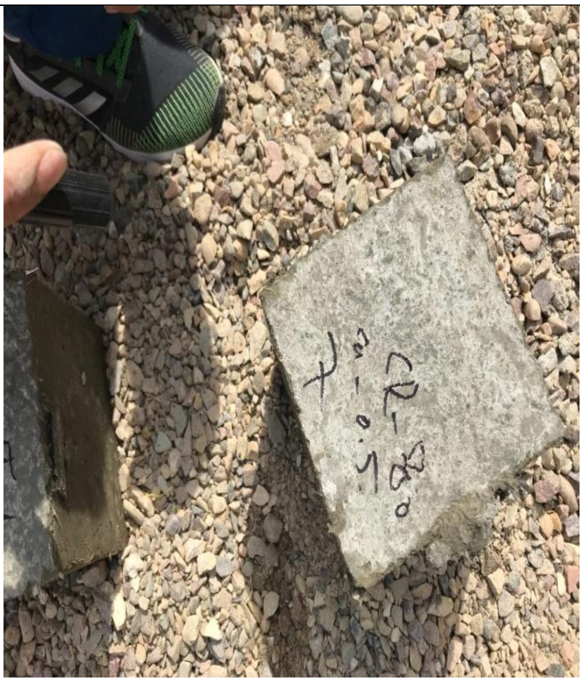
# APPENDIX 3: Picture Gallery

Picture 1: Cube Moulds ready for casting

Picture 2: Use of drum mixture for concrete mixing

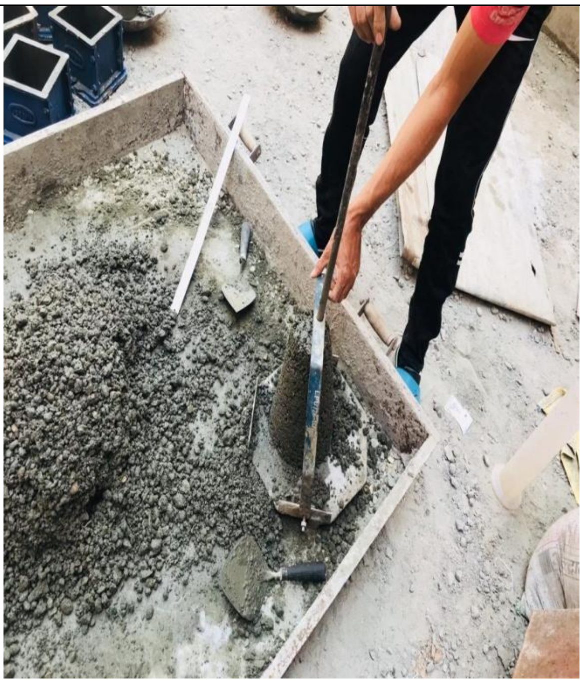
Picture 3: Mix with recycled aggregates and S2 Glass Fiber

Picture 4: Compacting of concrete cubes over vibrator table



Picture 5: Denotation of specimen designation on cube sample

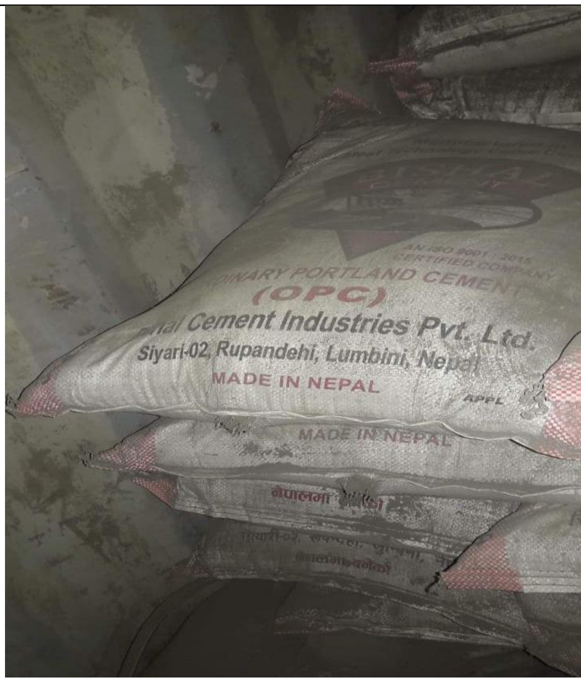
Picture 6: Use of weighing Balance to measure the amount of material mixed in preparing samples



Picture 7: Workability of concrete without admixture

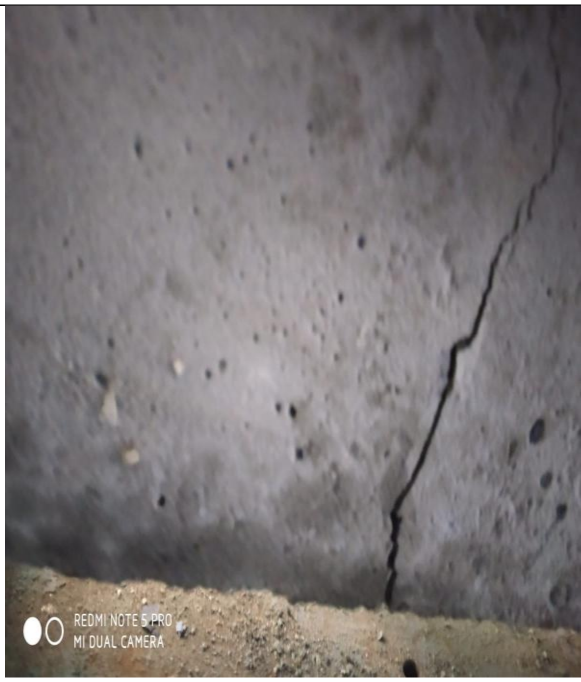

Picture 8: Standard Consistency test on Cement using Vicat Apparatus


Picture 9: Specific Gravity of Cement using Le-Chatelier flask




Picture 10: Cement OPC Grade 43 used in research work

Picture 11: Universal Testing Machine used for fracture study




Picture 12: Cracked beam specimen showing initial notch

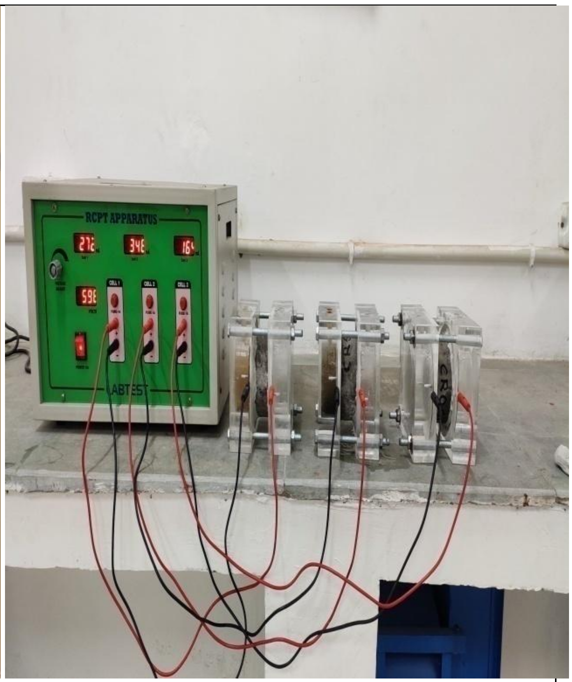

Picture 13: Concrete mix with recycled aggregates and glass fibers


Picture 14: Concrete mix prepared for casting

Picture 15: Use of Drum mixer for casting fracture behaviour beam specimens

Picture 16: Notched beam specimen casted for study of fracture behaviour


Picture 17: Curing of beam specimens




Picture 18: RCPT test on Mix designations CR0G0, CR60G0.5 and CR80G0.75

Picture 19: Vacuum Desiccator for removing air void and replacing with water

Picture 20: Air voids replaced with water in RCPT samples

Picture 21: Split tensile test on cylindrical sample

Picture 22: Flexural beam sample cracked but still not breaked into two parts due to presence of glass fibers

Picture 23: Cylindrical specimen still compacted after cracking due to presence of glass fibers


Picture 24: Cylindrical specimens tested for Young’s Modulus


Picture 25: Graph obtained between load and displacement

LOVELY PROFESSIONAL UNIVERSITY

Centre for
Research Degree Programmes

*LPU/SRDP/EC/230618/032*
Dated: 24 May 2021

Anshul Garg
Registration Number: 41600329
Programme Name: Doctor of Philosophy (Civil Engineering)

**Subject: Letter of Candidacy for Ph.D.**

Dear Candidate,

We are very pleased to inform you that the Department Doctoral Board has approved your candidacy for the Ph.D. Programme on 15 Jun 2018 by accepting your research proposal entitled: "STUDIES ON FRACTURAL BEHAVIOUR OF GLASS FIBER REINFORCED CONCRETE WITH RECYCLED AGGREGATES" under the supervision of Dr. Pushpendra Kumar Sharma.

As a Ph.D. candidate you are required to abide by the conditions, rules and regulations laid down for Ph.D. Programme of the University, and amendments, if any, made from time to time.

We wish you the very best!!

In case you have any query related to your programme, please contact Centre of Research Degree Programmes.

Head

Centre for Research Degree Programmes

Note:-This is a computer generated certificate and no signature is required. Please use the reference number generated on this certificate for future conversations.

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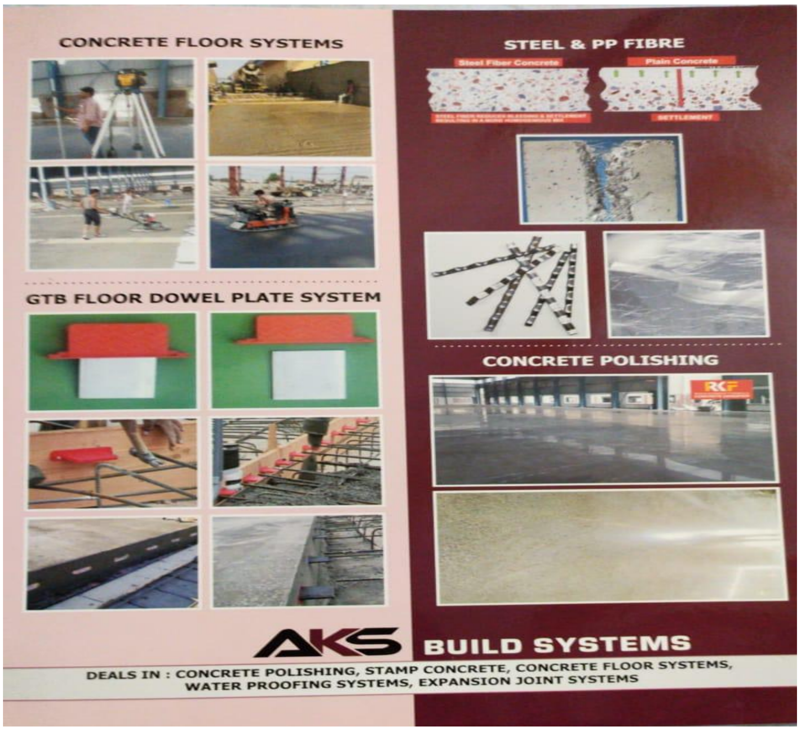
Picture 26: Ph.D Candidacy Letter

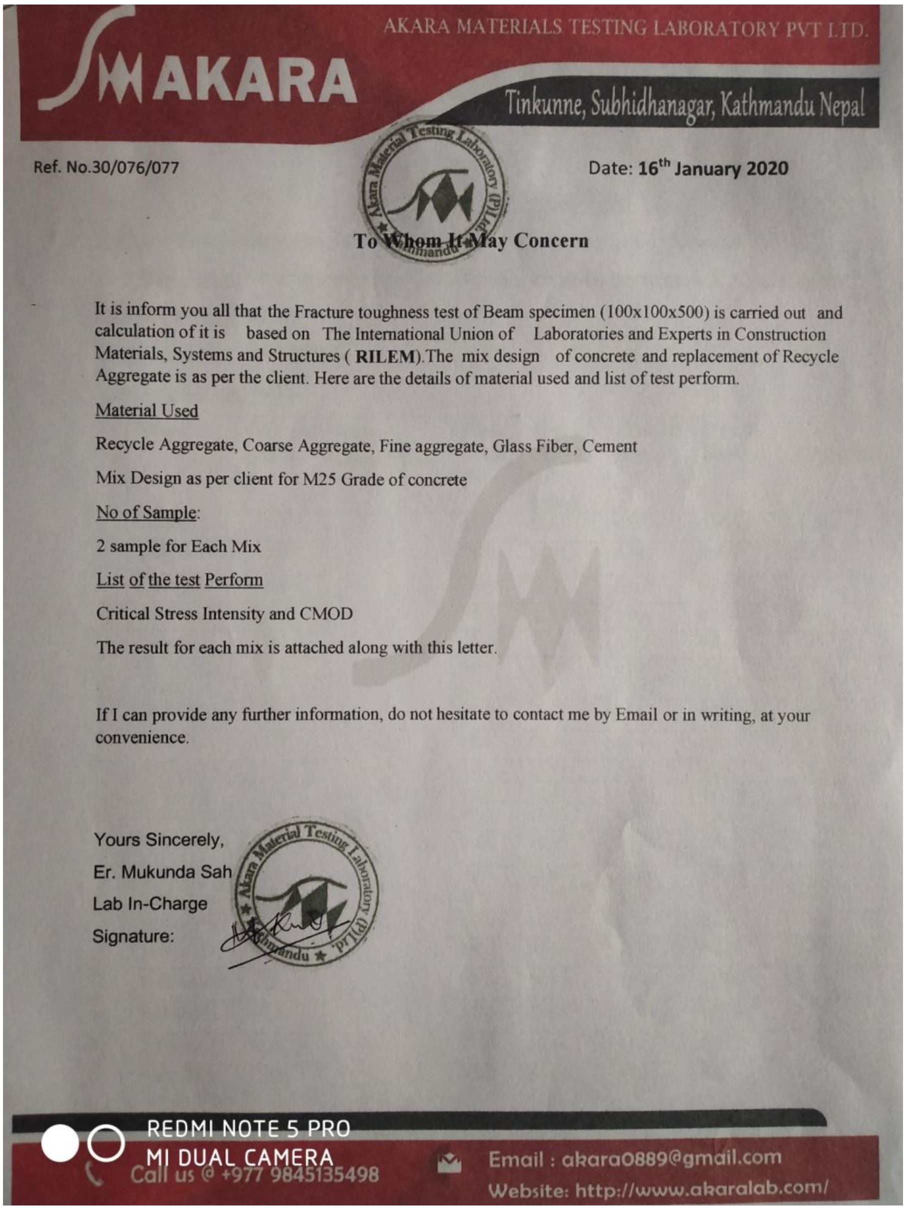
## APPENDIX 4: Vendor Detail for Glass Fiber




Picture 1: Vendor using glass fiber for various structural purposes


Picture 2: Vendor Address and contact information

# APPENDIX 5: Test Report obtained from Testing Laboratory



AKARA MATERIALS TESTING LABORATORY PVT LTD.

AKARA

Tinkunne, Subhidhanagar, Kathmandu Nepal

Ref. No.30/076/077

Date: 16th January 2020

**To Whom It May Concern**

It is inform you all that the Fracture toughness test of Beam specimen (100x100x500) is carried out and calculation of it is based on The International Union of Laboratories and Experts in Construction Materials, Systems and Structures ( **RILEM**).The mix design of concrete and replacement of Recycle Aggregate is as per the client. Here are the details of material used and list of test perform.

Material Used

Recycle Aggregate, Coarse Aggregate, Fine aggregate, Glass Fiber, Cement

Mix Design as per client for M25 Grade of concrete

No of Sample:

2 sample for Each Mix

List of the test Perform

Critical Stress Intensity and CMOD

The result for each mix is attached along with this letter.

If I can provide any further information, do not hesitate to contact me by Email or in writing, at your convenience.

Yours Sincerely,

Er. Mukunda Sah

Lab In-Charge

Signature:

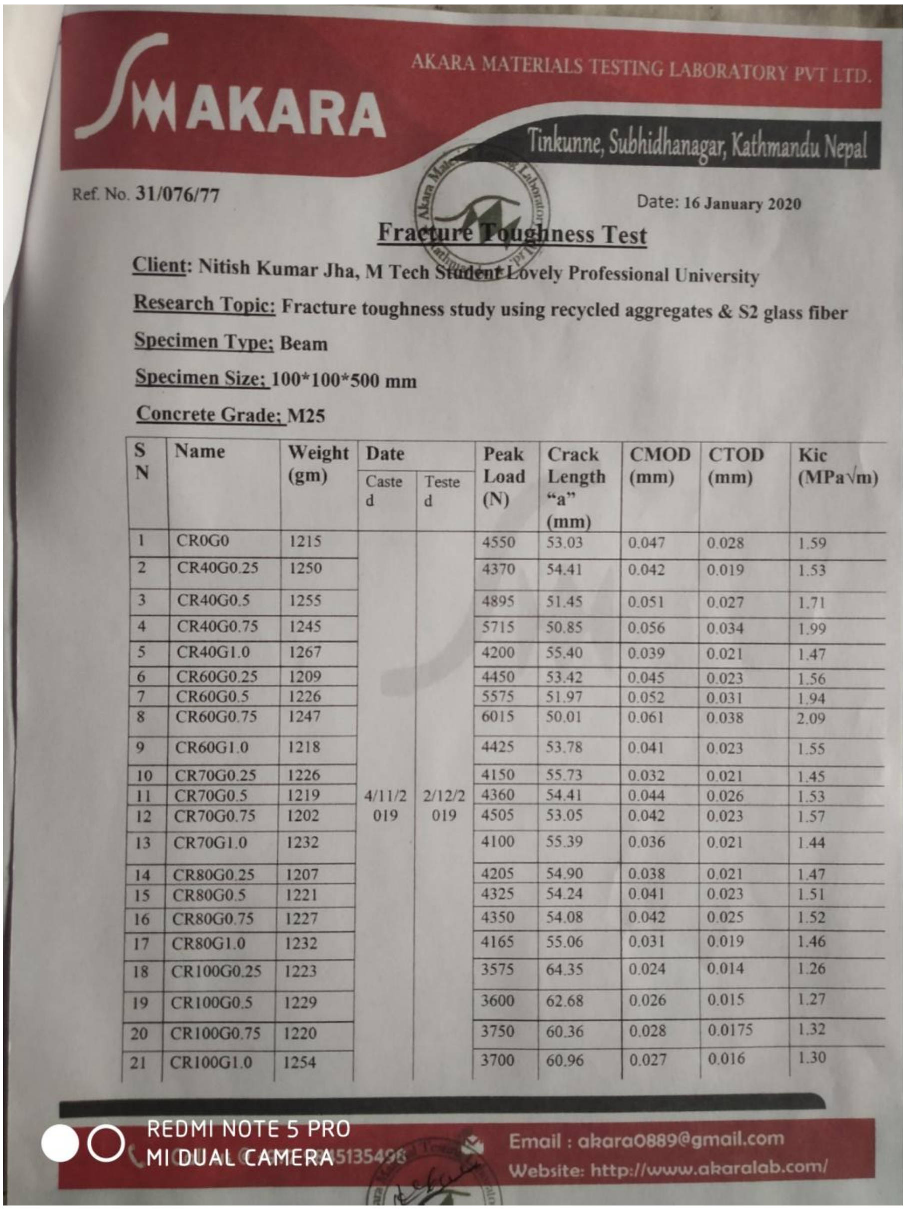
REDMI NOTE 5 PRO
MI DUAL CAMERA

Call us @ +977 9845135498

Email : akara0889@gmail.com

Website: http://www.akaralab.com/

Picture 1: Testing report Covering Letter



AKARA

AKARA MATERIALS TESTING LABORATORY PVT LTD.

Tinkunne, Subhidhanagar, Kathmandu Nepal

Ref. No. 31/076/77

Date: 16 January 2020

**Fracture Toughness Test**

**Client:** Nitish Kumar Jha, M Tech Student Lovely Professional University

**Research Topic:** Fracture toughness study using recycled aggregates & S2 glass fiber

**Specimen Type;** Beam

**Specimen Size;** 100*100*500 mm

**Concrete Grade;** M25

| S N | Name | Weight (gm) | Date | | Peak Load (N) | Crack Length "a" (mm) | CMOD (mm) | CTOD (mm) | Kic (MPa√m) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Casted | Tested | | | | | |
| 1 | CR0G0 | 1215 | 4/11/2019 | 2/12/2019 | 4550 | 53.03 | 0.047 | 0.028 | 1.59 |
| 2 | CR40G0.25 | 1250 | | | 4370 | 54.41 | 0.042 | 0.019 | 1.53 |
| 3 | CR40G0.5 | 1255 | | | 4895 | 51.45 | 0.051 | 0.027 | 1.71 |
| 4 | CR40G0.75 | 1245 | | | 5715 | 50.85 | 0.056 | 0.034 | 1.99 |
| 5 | CR40G1.0 | 1267 | | | 4200 | 55.40 | 0.039 | 0.021 | 1.47 |
| 6 | CR60G0.25 | 1209 | | | 4450 | 53.42 | 0.045 | 0.023 | 1.56 |
| 7 | CR60G0.5 | 1226 | | | 5575 | 51.97 | 0.052 | 0.031 | 1.94 |
| 8 | CR60G0.75 | 1247 | | | 6015 | 50.01 | 0.061 | 0.038 | 2.09 |
| 9 | CR60G1.0 | 1218 | | | 4425 | 53.78 | 0.041 | 0.023 | 1.55 |
| 10 | CR70G0.25 | 1226 | | | 4150 | 55.73 | 0.032 | 0.021 | 1.45 |
| 11 | CR70G0.5 | 1219 | | | 4360 | 54.41 | 0.044 | 0.026 | 1.53 |
| 12 | CR70G0.75 | 1202 | | | 4505 | 53.05 | 0.042 | 0.023 | 1.57 |
| 13 | CR70G1.0 | 1232 | | | 4100 | 55.39 | 0.036 | 0.021 | 1.44 |
| 14 | CR80G0.25 | 1207 | | | 4205 | 54.90 | 0.038 | 0.021 | 1.47 |
| 15 | CR80G0.5 | 1221 | | | 4325 | 54.24 | 0.041 | 0.023 | 1.51 |
| 16 | CR80G0.75 | 1227 | | | 4350 | 54.08 | 0.042 | 0.025 | 1.52 |
| 17 | CR80G1.0 | 1232 | | | 4165 | 55.06 | 0.031 | 0.019 | 1.46 |
| 18 | CR100G0.25 | 1223 | | | 3575 | 64.35 | 0.024 | 0.014 | 1.26 |
| 19 | CR100G0.5 | 1229 | | | 3600 | 62.68 | 0.026 | 0.015 | 1.27 |
| 20 | CR100G0.75 | 1220 | | | 3750 | 60.36 | 0.028 | 0.0175 | 1.32 |
| 21 | CR100G1.0 | 1254 | | | 3700 | 60.96 | 0.027 | 0.016 | 1.30 |

Email : akara0889@gmail.com

Website: http://www.akaralab.com/

REDMI NOTE 5 PRO

MI DUAL CAMERA

Picture 2: Testing Report