COMREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN HOT BITUMINOUS MIXES

Submitted in partial fulfilment of the requirement of the degree of

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in

CIVIL ENGINEERING

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DECLERATION

I, **Ashish Kumar** (11200174), hereby declare that this submission is my own work and that to the best of my insight and conviction, it contains no material beforehand distributed or composed by other individual or office. No material which has been acknowledged for reward of some other degree or certificate of the college or other organization of higher learning with the exception of where due affirmations have been made in the content. It was arranged and displayed under the direction and supervision of **Mr. Rishi Singh Chhabra** (Assistant Professor).

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This is to certify that **Ashish Kumar** under Registration No.11208221 has prepared the dissertation-2 report titled "**COMPREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN HOT BITUMINOUS MIXES**" under my direction. This is a bonafide work of the above competitor and has been submitted to me in fractional satisfaction of the prerequisite for the honor of Masters of Technology in Civil Engineering.

Signature of Supervisor

Mr. Rishi Singh Chhabra

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Finally, I would like to thank almighty god and my parents and friends who stood by me during the tenure of my project work.

Signature of Student

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ABSTRACT

The study is a attempt in performing analysis and design of **“COMPREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN HOT BITUMINOUS MIXES”** by comparing with different materials in order to find the accuracy level of the results as well as to overcome the complexity in designing such highly typical roads. Also, this may be helpful for those researchers who are performing research related to complex Roads.

Dissertation topic (COMPREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN HOT BITUMINOUS MIXES) which is of adding iron slag or the utilization in the bitumen mixes from which vehicle can reasonably be expected to traverse a point.

Penetration is influenced by number of lanes, lane width, number and spacing of access points, shoulder presence and width, gradient of the road, driving population etc. The time period normally used for type, usually the passenger car. The capacity is then expressed in passenger car unit (PCUs) per hour. The traffic conditions in India is highly heterogeneous in nature and vehicles do not follow lane discipline in turn causes abrasion on the roads and decreases the life span and results in the cracks and surface loosening of the roads.

Filler mixed in the bituminous seek to describe in a mathematical way the interaction between vehicles and operators. So, in my dissertation topic “**COMPREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN HOT BITUMINOUS MIXES**” I will analysis the increase in the bitumen properties. The expected outcome is that the utilization of iron slag will definitely enhance the properties of bitumen and make it more durable and long lasting. The good resistance to stripping by the Iron Slag aggregates indicates that the material is more superior to natural granite as road surfacing material. The use of Iron slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources and reducing the need for dumping ground. Screening of the Iron Slag will be done to ensure the aggregates are suitable for use as construction material.

The superior adhesion Iron slag with bitumen would also minimize potential moisture damage of the Iron slag mix. This will increase the skid resistance and will prevent water from drains and rain to enter into the roads at great extent.

KEYWORDS: Filler, Bituminous, skid resistance, durability, superior adhesion, prevention of water entering surface, cost effective.

CONTENTS

CHAPTER 1

INTRODUCTION

As one knows Roads have been part and parcel of humans since the beginning as they severed in fulfilling various needs entitled to the men. The Roads which has been proposed in this Dissertation is a very complex Roads and highly typical in its origin. In the modern scenario roads are mostly analysed using grades of bituminous and the fillers as it provides better understanding on the overview. When using the fillers, the major advantage is that one would be having a better control and coordination over the analysis which is being performed. Roads when being analysed manually may or may not show deviations in the form of faulty results but if the same analysis is carried out using software the majority chances are that results shown will be accurate. In this Dissertation, we shall be encountering various problems that might be arising as we go on with the Dissertation work. In the past when there were no Roads/vehicles the modes of transportation were so difficult and time consuming that the dead line for the accomplishing the analysis had always to be revised as many errors occurred while manipulating. Today the scenario has completely changed with the emerging new technology and the wide spreading construction skills. From few years men have understood the necessity of incorporating bitumen by adding fillers to their research work.

Roads prove to be the useful mode for transportation for a smoother and effective solution in some of the mind-blowing problems faced by the researchers and thus we can't think of analysing a Road without indulging filler/s.

In India, there is a great requirement of aggregates mainly from civil engineering industries for road and concrete constructions. The construction of highways and development of several expressways for high speed corridors exert tremendous pressure on natural resources. Many highway agencies, private organisations, and individuals are in the process of completing a wide range of studies and research projects concerning the feasibility, environmental suitability, and performance of using waste industrial products in highway construction.

These studies and researches tries to match society's need for safe and economic disposal of waste materials with the highway industries need for better and more cost-effective construction materials.

The study aims to explore the potential use of Iron slag (FeS) as a filler in the design of bituminous like bituminous macadam(DM), dense bituminous macadam(DBM), bituminous concrete (BC)and semi dense bituminous concrete (SDBC) which enhance the property of bituminous mixes.

1.1 ANALYSIS OF THE IRON SLAG

The primary components of iron slag are limestone (SiO2) and silica (SiO2). Other components of ballast furnace slag include alumina (Alsub>2O3) and magnesium oxide (MgO), as well as a amount of sulfer (S), while iron making slag contains oxides of iron (FeO) and magnesium oxide (MgO). In the case of iron making slag, the slag contains the metal elements (such as iron) in oxide form, however because the refining time is short and amount of limestone contained is large, a portion of the limestone auxiliary material may remain undissolved as free CaO.

These components exist in the natural world in places such as Earth's crust, natural rock, and minerals, and the chemical composition is similar to that of ordinary Portland cement. The shape and physical characteristics of iron slag are similar to ordinary crushed stone and sand, however due to differences such as the chemical components and cooling processes, it is possible to provide different types of slag with a wide variety of unique properties. For example, there are some types of slag that harden when alkali stimulation occurs. Many applications utilizing the physical and chemical characteristics of slag have these features.

Examples of iron and steel slag composition

Type component	Ballast furnace Slag	Converter slag	Electric arc furnace slag	
			Oxidizing Slag	Reducing Slag
CaO	41.7	45.8	22.8	55.1
SiO2	33.8	11.0	12.1	18.8
MgO	7.4	6.5	4.8	7.3
Al2O3	13.4	1.9	6.8	16.5
S	0.8	0.06	0.2	0.4
P2O5	< 0.1	1.7	0.3	0.1
MnO	0.3	5.3	7.9	1.0

1.2 BRIEF IDEA ON THE IRON SLAG

In this Dissertation, the Road's which is being utilized in the analysis of the 'COMPREHENSIVE STUDY FOR THE UTILIZATION OF IRON SLAG IN THE HOT BITUMINOUS MIXES' is "BITUMINOUS ROADS". Accordingly, the bituminous roads are suitable for adding fillers into it for enhancing its properties. Fillers are very popular amongst the Roads designers due their compatibility and user friendly environment.

Iron Slag contains significantly higher calcium oxide and iron oxide compared to granite rock. Granite rock contains high silica and aluminium content and is generally hydrophilic. The good resistance to stripping by the Iron Slag aggregates indicates that the material is more superior to natural granite as road surfacing material. The superior adhesion Iron slag with bitumen would also minimize potential moisture damage of the Iron slag mix. The formulation of the road mixes using Iron slag as a binder/filler in the bituminous mixes will definitely increase the strength, binding properties and increase the skid resistance.

Iron slag is the waste material from the industries/also can be called as the ballast furnace. It is generated by the electric arc furnace iron making process that uses the iron-scrap as the raw material. Iron slag consists of converter slag i.e. basic oxygen furnace slag which is generated by the conversion of the electric furnace slag. Iron slag has good compaction value. The waste material is neutral and non-hazardous in nature as per chemical analysis report of Central Pollution Control Board (CPCB), India (under hazardous waste rules, 2008, Ref. no.-19). The quantity of generation of this slag is about 36 lacs MT per year from different Iron industries in India (According to the report of CRRI, 2010).

The manufacture of iron-carting away the waste materials of the industries, an 1873 wood engraving. Slag is the glass like by-product left over after a desired metal. Today slag are used in many fields where there characteristics features can be used into an effective way. Slags contain sulphide ions. Slags contain metal oxide and sulphur dioxide.

1.3 UTILIZATION OF THE IRON SLAG IN BITUMINOUS

Change in the modern traffic properties has led to the higher vehicle loads, tire pressures, coefficient of friction and increase in traffic volumes. Current research illustrates that truck weights over 113.4 ton (250,000lb) and tire pressures of 150 psi have been frequently reported. These amendments a various and serious challenge to the pavement layers as they have caused predatory occurrence of distress, permanent deformation /rutting and fatigue failure.

This deformation causes map cracking, chuck holes, settlement and undulations similar to those observed in some Egyptian Roads. Certainly, accumulation of these deformations reduces the pavement life, increases the maintenance costs and may cause the complete failure of the pavement. Increasing the resistance of flexible pavement layers, against permanent deformation, definitely, will increase pavement life, decrease maintenance costs as well as prevent the early reconstruction. Researches on the available aggregates have shown that there is a general scarcity of good quality aggregates since most of the available limestone aggregates are friable carbonates of sedimentary origin. Henceforth, these natural resources or rocks need high binding solvent or great filler that will complete the demand /requirement of the rock to behave as same as the natural rock, and fulfil all its shortcomings. These aggregates have low crushing strength, low resistance to weathering, and low resistance to traffic abrasion.

Thus, they are not suitable for the use in the areas where a high skid resistance is required (egs. -round-about, slopes, wet surfaces and intersections).

Iron-slag is a by-product formed during the iron manufacturing process. It is a non-metallic ceramic material formed from the reaction of the flux such as calcium oxide with the inorganic non-metallic components present in the Iron scrap. The use of Iron slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources and reducing the need for dumping ground. Screening of the Iron Slag will be done to ensure the aggregates are suitable for use as construction material. Since 1993, Iron Slag has been used commercially as a region for the road surfacing (eg. -1. Mascot Airport and 2. Federal Airport Australia.)

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Iron slag may be used as the landfills cover. It is studied feasibility of the Granulated Blast Furnace Slag (GBFS). Iron slag may be used as the production of high performance concrete. Uses of iron slag minimizes potential expansion and takes advantages of the positive features in giving high stability, stripping resistant asphalt mixes with excellent skid resistance.

Presently, the ballast furnace or the slag from the industries are not used widely or utilized and is dumped into the costly land present near the industries or the plants. Studies are carried out to utilize the slag into different layers of the road construction. Basically, slag was investigated for its feasibility in bituminous layers.

Being cohesion less material, in the studies so far it is mixed in the range of 5-25% in the soils/bituminous as a filler or as sometimes acting as the replacing member in the construction ,like replacing the aggregates or the cement.

CHAPTER 2

ELOBORATED RIVEW ON THE FILLER USED

In this Dissertation work we will be analysing and designing the roads by the utilization of filler in the hot bituminous mixes i.e.: -

- IRON SLAG
- CEMENT
- BITUMEN

IRON SLAG

Iron-slag is a by-product formed during the iron manufacturing process. It is a non-metallic ceramic material formed from the reaction of the flux such as calcium oxide with the inorganic non-metallic components present in the Iron scrap. The use of Iron slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources and reducing the need for dumping ground. Screening of the Iron Slag will be done to ensure the aggregates are suitable for use as construction material. Since 1993, Iron Slag has been used commercially as a region for the road surfacing (eg.-1. Mascot Airport and 2. Federal Airport Australia.)

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Researches regarding recycling and utilization of steel slag in different fields have been carried out in recent years. It was used in mineral additive for cement-based materials to improve mechanical properties of concrete. Some studies used iron slag to produce Portland cement with steel slag and limestone, and confirmed that the comprehensive strength of concrete was above standard values.

Both frictional force components are influenced by the texture of the road surface. In particular, adhesion depends on the micro texture of the road surface, whereas hysteresis relies greatly on macro texture. Accordingly, the aggregate for pavement mixture is one of the most important influences on the road surface texture and on pavement skid resistance. In the National Cooperative Highway Research Program (NCHRP) guidelines (2009), aggregates from different locations were tested as per recommended standard procedures. In general, it was found that in the case of standard-compliant aggregates unavailable from one source, pavement aggregates could be selected from at least two main sources and combined to achieve the correct design gradation, along with the other previously mentioned characteristics. The testing process is usually performed prior to the start of a project. This ensures a satisfactory grading of the aggregate characteristics, which in turn should ensure road pavement of adequate, if not high, quality. In addition to the standard requirements of other countries, the polishing resistance of a selected aggregate, estimated from polished stone values (PSVs), is one of the recommended design parameters in the NCHRP guidelines for high resistance. The objectives of this study are Characterization of bituminous with different grades and enhancing its different properties making it more durable, and Development of a predictive skid-resistance model of bitumen with adding filler i.e. Iron slag at the construction stage based on the aggregate and mixture characteristics.

Generally, pavement asphalt concrete is classified into dense-grade, gapped-grade, and porous types. In this study, the skid-resistance predictive model was proposed for the dense-grade asphalt concrete because it is the typical pavement in Asian countries.

CEMENT

A cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together. Cement is seldom used solely, but is used to bind sand and gravel (aggregate) together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete.

Cements used in construction are usually inorganic, often lime or calcium silicate based, and can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Non-hydraulic cement will not set in wet conditions or underwater; rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.

Hydraulic cements (e.g., Portland cement) set and become adhesive due to a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack. The chemical process for hydraulic cement found by ancient Romans used volcanic ash (pozzolana) with added lime (calcium oxide).

The word "cement" can be traced back to the Roman term opus caementicium, used to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain a hydraulic binder, were later referred to as cementum, cimentum, cäment, and cement. In modern times, organic polymers are sometimes used as cements in concrete.

Alternatives to cement used in antiquity

Cement, chemically speaking, is a product that includes lime as the primary curing ingredient, but is far from the first material used for cementation. The Babylonians and Assyrians used bitumen to bind together burnt brick or alabaster slabs. In Egypt stone blocks were cemented together with a mortar made of sand and roughly burnt gypsum ($CaSO_4 \cdot 2H_2O$), which often contained calcium carbonate ($CaCO_3$).

Macedonians and Romans

Lime (calcium oxide) was used on Crete and by the ancient Greeks. There is evidence that the Minoans of Crete used crushed potshards as an artificial pozzolan for hydraulic cement. It is uncertain where it was first discovered that a combination of hydrated non-hydraulic lime and a pozzolan produces a hydraulic mixture (see also: Pozzolanic reaction), but concrete made from such mixtures was used by the Ancient Macedonians and three centuries later on a large scale by Roman engineers.

There is... a kind of powder which from natural causes produces astonishing results. It is found in the neighborhood of Baiae and in the country belonging to the towns round about Mt. Vesuvius. This substance when mixed with lime and rubble not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set hard under water.

The Greeks used volcanic tuff from the island of Thera as their pozzolan and the Romans used crushed volcanic ash (activated aluminum silicates) with lime. This mixture was able to set under water increasing its resistance. The material was called pozzolana from the town of Pozzuoli, west of Naples where volcanic ash was extracted. In the absence of pozzolana ash, the Romans used powdered brick or pottery as a substitute and they may have used crushed tiles for this purpose before discovering natural sources near Rome. The huge dome of the Pantheon in Rome and the massive Baths of Caracalla are examples of ancient structures made from these concretes, many of which are still standing. The vast system of Roman aqueducts also made extensive use of hydraulic cement.

Bitumen

The primary use (70%) of asphalt/bitumen is in road construction, where it is used as the glue or binder mixed with aggregate particles to create asphalt concrete. Its other main uses are for bituminous waterproofing products, including production of roofing felt and for sealing flat roofs.[10]

The terms asphalt and bitumen are often used interchangeably to mean both natural and manufactured forms of the substance. In American English, asphalt (or asphalt cement) is the carefully refined residue from the distillation process of selected crude oils. Outside the United States, the product is often called bitumen. Geologists often prefer the term bitumen. Common usage often refers to various forms of asphalt/bitumen as "tar", such as at the La Brea Tar Pits.

Naturally occurring asphalt/bitumen is sometimes specified by the term "crude bitumen". Its viscosity is similar to that of cold molasses while the material obtained from the fractional distillation of crude oil boiling at 525 °C (977 °F) is sometimes referred to as "refined bitumen". The Canadian province of Alberta has most of the world's reserves of natural bitumen, covering 142,000 square kilometers (55,000 sq. mi), an area larger than England.

The components of asphalt are classified into four classes of compounds:

- saturates, saturated hydrocarbons, the % saturates correlates with softening point of the material
- Naphthene aromatics, consisting of partially hydrogenated polycyclic aromatic compounds.
- Polar aromatics, consisting of high molecular weight phenols and carboxylic acids
- Asphaltenes, consisting of high molecular weight phenols and heterocyclic compounds

The naphthene aromatics and polar aromatics are typically the majority components. Additionally, most natural bitumens contain organosulfur compounds, resulting in an overall sulfur content of up to 4%. Nickel and vanadium are found in the <10 ppm level, as is typical of some petroleum.

The substance is soluble in carbon disulfide. It is commonly modelled as a colloid, with asphaltenes as the dispersed phase and maltenes as the continuous phase. and "it is almost impossible to separate and identify all the different molecules of asphalt, because the number of molecules with different chemical structure is extremely large".

Asphalt/bitumen can sometimes be confused with "coal tar", which is a visually similar black, thermoplastic material produced by the destructive distillation of coal. During the early and mid-20th century when town gas was produced, coal tar was a readily available byproduct and extensively used as the binder for road aggregates. The addition of tar to macadam roads led to the word tarmac, which is now used in common parlance to refer to road-making materials. However, since the 1970s, when natural gas succeeded town gas, asphalt/bitumen has completely overtaken the use of coal tar in these applications. Other examples of this confusion include the La Brea Tar Pits and the Canadian oil sands, both of which actually contain natural bitumen rather than tar. Pitch is another term sometimes used at times to refer to asphalt/bitumen, as in Pitch Lake.

Occurrence

Bituminous outcrop, Ferrand, France.

The great majority of asphalt used commercially is obtained from petroleum. Nonetheless, large amounts of asphalt occur in concentrated form in nature. Naturally occurring deposits of asphalt/bitumen are formed from the remains of ancient, microscopic algae (diatoms) and other once-living things. These remains were deposited in the mud on the bottom of the ocean or lake where the organisms lived. Under the heat (above 50 °C) and pressure of burial deep in the earth, the remains were transformed into materials such as asphalt/bitumen, kerogen, or petroleum.

Natural deposits of asphalt/bitumen include lakes such as the Pitch Lake in Trinidad and Tobago and Lake Bermudez in Venezuela. Natural seeps of asphalt/bitumen occur in the La Brea Tar Pits and in the Dead Sea.

Asphalt/bitumen also occurs in unconsolidated sandstones known as "oil sands" in Alberta, Canada, and the similar "tar sands" in Utah, US. The Canadian province of Alberta has most of the world's reserves of natural bitumen, in three huge deposits covering 142,000 square kilometres (55,000 sq mi), an area larger than England or New York state. These bituminous sands contain 166 billion barrels (26.4×10^9 m^3) of commercially established oil reserves, giving Canada the third largest oil reserves in the world. and produce over 2.3 million barrels per day (370×10^3 m^3/d) of heavy crude oil and synthetic crude oil. Although historically it was used without refining to pave roads, nearly all of the bitumen is now used as raw material for oil refineries in Canada and the United States.

The world's largest deposit of natural bitumen, known as the Athabasca oil sands is located in the McMurray Formation of Northern Alberta. This formation is from the early Cretaceous, and is composed of numerous lenses of oil-bearing sand with up to 20% oil. Isotopic studies attribute the oil deposits to be about 110 million years old. Two smaller but still very large formations occur in the Peace River oil sands and the Cold Lake oil sands, to the west and southeast of the Athabasca oil sands, respectively. Of the Alberta bitumen deposits, only parts of the Athabasca oil sands are shallow enough to be suitable for surface mining. The other 80% has to be produced by oil wells using enhanced oil recovery techniques like steam-assisted gravity drainage.

Much smaller heavy oil or bitumen deposits also occur in the Uinta Basin in Utah, US. The Tar Sand Triangle deposit, for example, is roughly 6% bitumen.

Asphalt/bitumen occurs in hydrothermal veins. An example of this is within the Uinta Basin of Utah, in the US, where there is a swarm of laterally and vertically extensive veins composed of a solid hydrocarbon termed Gilsonite. These veins formed by the polymerization and solidification of hydrocarbons that were mobilized from the deeper oil shales of the Green River Formation during burial and diagenesis.

2.1 MIX DESIGN

Mix design is a very important part in initiating any analysis of any type of Roads in case of using fillers or replacing any element. So, here in this Dissertation we shall be considering using VG10/VG30 penetration grade of bituminous.

According to viscosity (degree of fluidity) grading, higher the grade, stiffer the bitumen. Tests are conducted at 60 C and 135 C, which represent the temperature of road surface during summer (hot climate, similar to the northern parts of India) and mixing temperature respectively. The penetration at 25Cwhich is annual average pavement temperature, is also retained.

Different grades of bitumen marketed:

VG-10 BITUMEN: is widely used in spraying applications such as surface dressing and paving in very cold climate in lieu of old 80/100 penetration grade. It is also used to manufacture bitumen emulsion and modified bitumen products.

VG-20 BITUMEN: is used for paving in cold climate and high altitude regions.

VG-30 BITUMEN: is primarily used to construct extra heavy duty bitumen pavements that need to endure substantial traffic loads. It can be used in lieu of 60/70 penetration grade.

VG- 40 BITUMEN: is used in highly stressed areas such as intersections, near toll booths and truck parking lots in lieu of cold 30/40 penetration grade. Due to its higher viscosity, stiffer bitumen mixes can be produced to improve resistance to shoving and other problems associated with higher temperature and heavy traffic loads.

2.1.1 Main objectives of bituminous mix design are to find:

1. Optimum bitumen content to ensure a durable pavement,
2. Sufficient strength to resist shear deformation under traffic at higher temperature,
3. Proper amount of air voids in the compacted bitumen to allow for additional compaction done by traffic,
4. Sufficient workability, and
5. Sufficient flexibility to avoid cracking due to repeated traffic load.

2.1.2 Requirements of bituminous mixes

Bituminous mixture used in construction of flexible pavement should have following Properties;

1. Stability
2. Durability
3. Flexibility
4. Skid resistance
5. Workability

2.1.3. Different layers in a pavement

Bituminous base course Consist of mineral aggregate such as stone, gravel, or sand Bonded together by a bituminous material and used as a foundation upon which to Place a binder or surface course.

In bituminous binder course a bituminous-aggregate mixture is used as an intermediate course between the base and surface courses or as the first bituminous layer in a two-layer bituminous resurfacing.

Asphaltic/Bituminous concrete consists of a mixture of aggregates continuously graded from maximum size, typically less than 25 mm, through fine filler that is smaller than 0.075 mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties.

2.2 TYPES OF BITUMINOUS MIX

2.2.1 Dense-Graded Mixes

Dense mix bituminous concrete has good proportion of all constituents. It offers good compressive strength and some tensile strength.

2.2.2. Gap-graded mix

Some large coarse aggregates are missing and have good fatigue and tensile strength.

2.2.3. Open-graded mix

Fine aggregate and filler are missing; it is porous and offers good friction, low strength.

2.2.4. Hot mix asphalt concrete

HMA is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at 150 °C for virgin asphalt.

2.2.5. Warm mix asphalt

It is produced by adding zeolites waxes, asphalt emulsions, or sometimes even water to the Asphalt binder prior to mixing. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon Dioxide, aerosols and vapours.

2.2.6. Cold mix asphalt

It is produced by emulsifying the asphalt in water with prior to mixing with the aggregate. It Results less viscous asphalt and the mixture is easy to work and compact. The emulsion Breaks after evaporation of water and the cold mix asphalt ideally behaves as cold HMA.

2.2.7. Cut-back asphalt concrete

It is produced by dissolving the binder in kerosene or another lighter fraction of petroleum Which makes asphalt less viscous and the mix is easy to work and compact. After the mix is Laid down the lighter fraction evaporates. Because of concerns with pollution from the Volatile organic compounds in the lighter fraction, cut-back asphalt has been largely replaced By asphalt emulsion.

2.2.8. Mastic asphalt concrete

Mastic asphalt is produced by heating hard grade blown bitumen (oxidation) in a green Cooker (mixer) until it has become a viscous liquid before it is added to aggregates. Then Bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the Mastic asphalt mixer is transported to the work site where it generally laid to a thickness of Around 34–13⁄16inches (20-30 mm) for footpath and road applications and around 3/8of an Inch (10 mm) for flooring or roof applications.

2.2 RAW MATERIALS: CONSTITUENTS OF MIXES

Granulated blast furnace slag (GBFS) is a by-product obtained in the manufacture of pig iron in the blast furnace and is formed by the combination of iron ore with limestone flux. If the molten slag is cooled and solidified by rapid water quenching to air on slaggy state, it results granulated blast furnace slag of sand size fragments, usually with some friable clinker- like material. The physical structure and gradation of granulated slag depend on the presence of chemicals such as lime, alumina, silica and magnesia, whose percentages may vary depending on the nature of iron ore, the composition of limestone flux and the kind of iron being produced. In present study granulated blast furnace slag is used as fine aggregates by replacing some gradation of natural aggregates.

The most quoted and referred capacity manual in the transportation community international is the United States Highway Capacity Manual (US-HCM) first developed in 1950. Since then, this manual has undergone significant improvements with major restructuring and rewrites in 1965, 1985, 2000 and the recent publication in 2010. For example, the US-HCM 2000 (TRB, 2000) suggested that a maximum flow rate that can be achieved on a multilane highway is 2200 Passenger Car Units (PCU)/hour/lane. The HCM is a modification of US-HCM to suit their conditions. The adjustment factors in the method caused steeper capacity reduction than in US-HCM 2000 as the conditions become less ideal and therefore, the capacity under ideal conditions on a four-lane highway has been estimated as 2300 PCUs / hour/ lane on highways (Nielsen and Jorgensen, 2008). Similarly, in Finland and Norway, US-HCM 2000 (TRB, 2000) has been followed with minor modifications to suit the local situations and the roadway capacities obtained by the Finnish and Norwegian methods for multi-lane highways is 2000 PCU/hour/lane. The Australian method for analysis of roadway capacity is basically same as that of US-HCM method with the basic difference being additional modification has been suggested for specific problems. Under ideal conditions, the average minimum headway of 1.8 seconds is considered and maximum flow of 2000 vehicles per hour per lane has been assumed. Hence, it is evident that these evolved manuals coexist with roadway design and traffic control practices prevailing in a specified country and cannot be simply transferred to any other country for direct applications.

Several researchers have tried to incorporate bottom as hand fly ash in various layers of pavement (Huang 1990). Fly ash has been used as bulk filler in construction of embankments and flyovers (Yoon et al. 2009).

However, due to corrosive nature of bottom ash, its usage near metallic Roads is limited (Ke 1990). Studies have indicated that bituminous concrete containing bottom ash is susceptible to rutting but more resistant to stripping.

Fly ash consists of extremely fine siliceous iron slag with particle size ranging from to 10 and 100 micron (FHWA2012a). Due to its smaller particle size, fly ash has been used as mineral filler in bituminous mix. Due to increased surface area of aggregates, overall demand for binder may increase when fly ash is used as filler (FHWA 2012c). Due pozzolanic nature, fly ash with lime has been widely used in base/sub-base courses as binder (Wen et al. 2011). Lack of homogeneity, sulphates, and slow strength development are some of the issues in using fly ash in road construction (Sherwood 1995). Waste iron slag has been used as bulk filler in layers beneath bituminous layers (Ahmed 1991). Due to the presence of inherent porosity in usual stone aggregates, bitumen adheres to the surface strongly, compared to broken iron slag pieces used as substitute for aggregates. Thus, the strength of bituminous mix with iron slag as aggregates are found to show lower strength than normal bituminous mix (Su and Chen 2002). It has been also observed that iron slag particles break under traffic and finally leads to ravelling (Larsen1989). Some studies indicated that resilient modulus and indirect tensile strength of bituminous concrete containing waste materials such as slag of kind Steel, Copper, Iron, Aluminium, etc. And other wastes of industries and polymers are unaffected up to 15% of wastes mentioned above (Sultan 1990).

Bituminous Binder

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Bitumen must be treated as a viscous-elastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. At low temperature, it behaves like an elastic material and at high temperatures its behaviour is like a viscous fluid. Asphalt binder VG30 is used in this research work. Grade of bitumen used in the pavements should be selected on the basis of climatic conditions.

CHAPTER 3

RESEARCH METHODOLOGY AND EXPERIMENTS

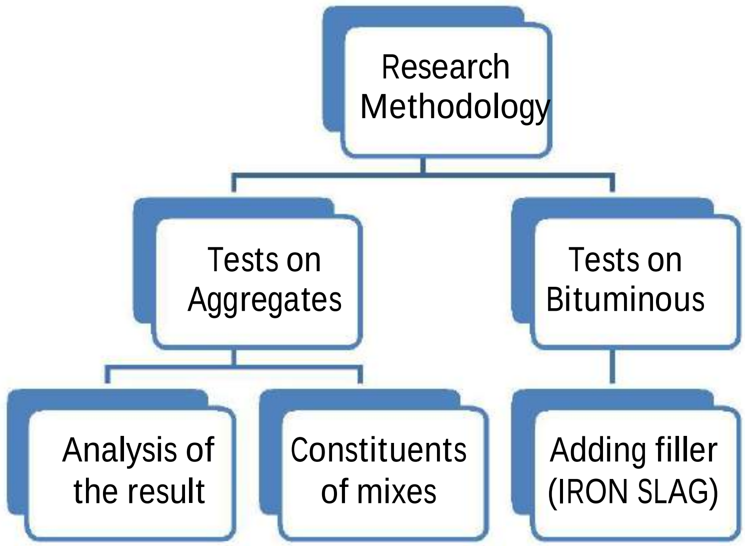
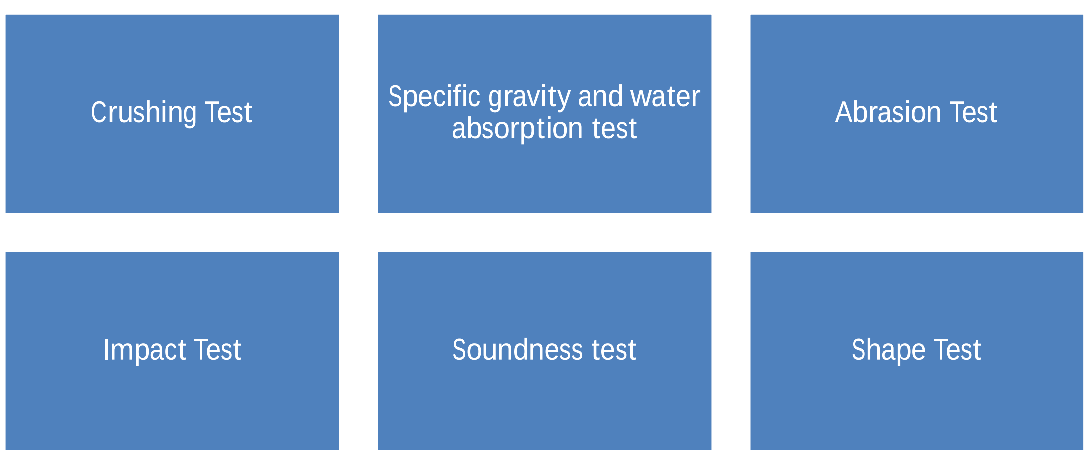


fig no 3.1 flow chart on research methodology

3.1 TESTS ON AGGREGATES



3.1.1. Crushing Test for Aggregate

The aggregate sample: The material for the standard test consists of aggregates sized 20.0mm to 25.5mm. The aggregates may be dried at heating at 100^0-110^0 C for not more than 4 hours and cooled at room temperature before testing, if necessary.

- Sieve the materials through 25 mm and 20 mm IS sieves. The aggregates passing through 25 mm sieve and retained on 20.0 mm sieve comprise the test material.
- Take about 3.25 kg of this material.
- Pour the aggregates to fill about just more than 1/3rd depth of measuring cylinder.
- Compact the material by giving 25 gentle blows with rounded end tamping rod.
- Add 2 more layers in similar manner, such that the cylinder is full.
- Remove the excess material with a straight edge.
- Empty the cylinder and weigh the aggregates, accurate up to 1gm.
- Transfer the whole of this weighed quantity to the test mould by filling it in 3 layers.
- Level off the surface and place the plunger horizontally over it.
- Place the assembly on the pedestal of the compression testing machine.
- Apply the load at auniform rate of 4 tones per minute until the total applied load is 40 tones.
- Release the load.
- Take the aggregate out of the cylinder and sieve through 4.75mm IS sieve.
- Weigh the fraction passing through it to an accuracy of 0.1 gm

	Sample 1
Total weight of the dry sample (W1)	2913
Weight of portion passing 4.75mm sieve (W2)	771
Aggregate crushing value (%)=$(W_2/W_1)*100$	26.43

Aggregate crushing value = 26.43%

3.1.2. Abrasion test for aggregate

The test sample consists of clean aggregates dried in oven at 105° – 110°C. The sample should conform to any of the gradings shown in table 1.

- Select the grading to be used in the test such that it conforms to the grading to be used in construction, to the maximum extent possible.

- Take 5 kg of sample for gradings A, B, C & D and 10 kg for gradings E, F & G.
- Choose the abrasive charge as per Table 2 depending on grading of aggregates.
- Place the aggregates and abrasive charge on the cylinder and fix the cover.
- Rotate the machine at a speed of 30 – 33 revolutions per minute. The number of revolutions is 500 for gradings A, B, C & D and 1000 for gradings E, F & G. The machine should be balanced and driven such that there is uniform peripheral speed.
- The machine is stopped after the desired number of revolutions and material is discharged to a tray.
- The entire stone dust is sieved on 1.70 mm IS sieve.
- The material coarser than 1.7mm size is weighed correct to one gram

Sieve Size	**Weight of sample test in gm**							
Passing mm	Retained in mm	A	B	C	D	E	F	G
80	63					2500		
63	50					2500		
50	40					5000	5000	
40	25	1250					5000	5000
25	20	1250						5000
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			

3.1.3 SPECIFIC GRAVITY AND WATER ABSORBTION OF AGGREGATE

- About 2kg of the aggregate sample is washed thoroughly to remove fines, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22 to 32^0C with a cover of at least 50 mm of water above the top of the basket

- Immediately after the immersion the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second. The basket and the aggregate should remain completely immersed in water for a period of 24±0.5 hours afterwards.

- The basket and the sample are then weighed while suspended in water at a temperature of 22 to 32^0C. The weight is noted while suspended in water (W_1) g.

- The basket and the aggregate are then removed from water and allowed to drain for a few minutes, after which the aggregates are transferred to one of the dry absorbent clothes.

- The empty basket is then returned to the tank of water, jolted 25 times and weights in water (W_2) g.

- The aggregates placed in the dry absorbent clothes are surface dried till no further moisture could be removed by this clothe.

- Then the aggregate is transferred to the second dry cloth spread in a single layer, covered and allowed to dry for at least 10 minutes until the aggregates are completely surface dry. 10 to 60 minutes drying may be needed. The surface dried aggregate is then weighed W_3 g.

- The aggregate is placed in a shallow tray and kept in an oven maintained at a temperature of 110^0C for 24 hours. It is then removed from the oven, cooled in air tight container and weighed W_4 g.

3.1.3.1 CALCULATION

Weight of saturated aggregate suspended in water with basket = W_1 = 3 kg

Weight of basket suspended in water = W_2 = 0.6 kg

Weight of saturated aggregate in water = (W_1-W_2)g = W_s =2.6 kg

Weight of saturated surface dry aggregate in air = W_4 = 2.0 kg

Weight of water equal to the volume of the aggregate = (W_3-W_s) = 2.935 kg

$$\text{Specific gravity} = \frac{W_4}{W_3 - (W_1 - W_2)}$$

Specific Gravity = 3.13

$$\text{Apparent sp.gravity} = \frac{W_4}{(W_4 - (W_1 - W_2))}$$

Apparent sp. Gravity =4.74

$$\text{Water absorption} = \frac{(W_3 - W_4)}{W_4} \times 100$$

Water absorption =2.21%

3.1.4. IMPACT TEST FOR AGGREGATE

- The test sample consists of aggregates sized 10.0 mm 12.5 mm. Aggregates may be dried by heating at 100-110° C for a period of 4 hours and cooled.
- Sieve the material through 12.5 mm and 10.0mm IS sieves. The aggregates passing through 12.5mm sieve and retained on 10.0mm sieve comprises the test material.
- Pour the aggregates to fill about just 1/3 rd depth of measuring cylinder.
- Compact the material by giving 25 gentle blows with the rounded end of the tamping rod.
- Add two more layers in similar manner, so that cylinder is full.
- Strike off the surplus aggregates.
- Determine the net weight of the aggregates to the nearest gram(W).
- Bring the impact machine to rest without wedging or packing up on the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.
- Fix the cup firmly in position on the base of machine and place whole of the test sample in it and compact by giving 25 gentle strokes with tamping rod.

- Raise the hammer until its lower face is 380 mm above the surface of aggregate sample in the cup and allow it to fall freely on the aggregate sample. Give 15 such blows at an interval of not less than one second between successive falls.
- Remove the crushed aggregate from the cup and sieve it through 2.36 mm IS sieves until no further significant amount passes in one minute. Weigh the fraction passing the sieve to an accuracy of 1 gm. Also, weigh the fraction retained in the sieve.
- Compute the aggregate impact value. The mean of two observations, rounded to nearest whole number is reported as the Aggregate Impact Value.

3.1.4.1. OBSERVATIONS

	Sample 1	Sample 2
Total weight of dry sample (W_1 gm)	670	620
Weight of portion passing 2.36 mm sieve (W_2 gm)	620	580
Aggregate Impact Value (percent) = W_2 / W_1 X 100	7.4	7.37

Mean **= 7.39**

3.1.4.2. RESULT:

Aggregate Impact Value = 7.435

3.1.4.3. RECOMMENDED VALUES

Classification of aggregates using Aggregate Impact Value is as given below:

Aggregate Impact Value	Classification
<20%	Exceptionally Strong
10 – 20%	Strong
20-30%	Satisfactory for road surfacing
>35%	Weak for road surfacing

Specified limits of percent aggregate impact value for different types of road construction by Indian Roads Congress is given below.

Sl No	Type of pavement	Aggregate impact value not more than
1.	Wearing Course	30
a)	Bituminous surface dressing	
b)	Penetration macadam	
c)	Bituminous carpet concrete	
d)	Cement concrete	
2.	Bitumen bound macadam base course	35
3.	WBM base course with bitumen surfacing	40
4	Cement concrete base course	45

3.1.5. SHAPE TEST

3.1.5.1 APPARATUS

Name	**Capacity**	**Least count**
Balance	500 g	0.1 g
Balance	5000 g	1 g
Oven	105 to 110^0C	
Sieves	80 mm, 63 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, 8.0 mm, 4.75 mm, 4.0 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, 150 micron	
Wire mesh basket		
Container		

Chemicals and wire mesh basket

3.1.5.2 CHEMICAL SOLUTION

- Sodium Sulphate Solution
- Magnesium Sulphate Solution

3.1.5.3 PREPARATION OF TEST SAMPLE FOR FINE AGGREGATE

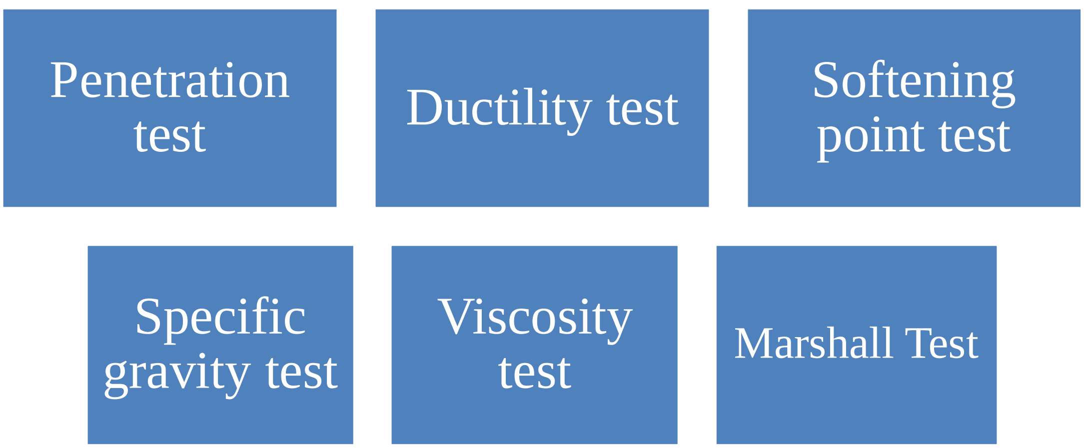
- Wet sieve the sample through a nest of IS sieves, the lower being 300 microns and the upper being 10 mm size.
- The material passing 10 mm sieve and retained on 300-micron sieve is then dried and taken for the test.
- The sample collected as above is again sieved through a series of sieves such as 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 microns and 300 microns.
- The amount of sample to be taken for sieving is such that, it will yield not less than 100 g of each of the following sizes.

Passing	Retained
10 mm	4.75 mm
4.75 mm	2.36 mm

2.36 mm	1.18 mm
1.18 mm	600 micron
600 micron	300 micron

- Weigh 100 g of sample from each of the separated fraction and place it in separate containers for the test.
- Note- Fine aggregates sticking in the meshes of the sieves is not used in preparing the sample.

3.2. TESTS ON BITUMEN



3.2.1 PENETRATION TEST

- Preparation of test specimen: Soften the material to a pouring consistency at a temperature not more than 60°C for tars and 90°C for bitumen above the approximate softening point and stir it thoroughly until it is homogeneous and is free from air bubbles and water. Pour the melt into the container to a depth at least 10mm in excess of the expected penetration. Protect the sample from dust and allow it to cool in an atmosphere at a temperature between 15° to 30° C for one hour. Then place it along with the transfer dish in the water bath at 25° ± 0.1 °C, unless otherwise stated.
- Fill the transfer dish with water from the water bath to depth sufficient to cover the container completely, place the sample in it and put it upon the stand of the penetration apparatus.
- Clean the needle with benzene, dry it and load with the weight. The total moving load required is 100 ± 0.25 gms, including the weight of the needle, carrier and super-imposed weights.
- Adjust the needle to make contact with the surface of the sample. This may be done by placing the needlepoint in contact with its image reflected by the surface of the bituminous material.
- Make the pointer of the dial to read zero or note the initial dial reading.
- Release the needle for exactly five seconds.
- Adjust the penetration machine to measure the distance penetrated.
- Make at least 3 readings at points on the surface of the sample not less than 10 mm apart and not less than l0mm from the side of the dish. After each test return the sample and transfer dish to the water bath and wash the needle clean with benzene and dry it. In case of material of penetration greater than 225, three determinations on each of the two identical test specimens using a separate needle for each determination should be made, leaving the needle in the sample on completion of each determination to avoid disturbance of the specimen.

Penetration dial reading	**Test 1**	**Test 2**	**Test 3**
(a) Initial	375	377	375
(b) Final	400	400	400
Penetration Value	2.5	2.3	2.5

Table: Conventional test for bitumen

Penetration dial reading	Test 1	Test 2	Test 3
(a) Initial	330	245	320
(b) Final	395	390	380
Penetration Value	4.5	4.5	6.0

Table: Mix design (Bituminous with iron slag)

3.2.2 DUCTILITY TEST

- Melt the bituminous test material completely at a temperature of 75°C to 100° C above the approximate softening point until it becomes thoroughly fluid.
- Strain the fluid through IS sieve 30.
- After stirring the fluid, pour it in the mould assembly and place it on a brass plate. In order to prevent the material under test from sticking, coat the surface of the plate and interior surfaces of the sides of the mould with mercury or by a mixture of equal parts of glycerin and dextrin.
- After about 30-40 minutes, keep the plate assembly along with the sample in a water bath. Maintain the temperature of the water bath at 27° C for half an hour.
- Remove the sample and mould assembly from the water bath and trim the specimen by levelling the surface using a hot knife.
- Replace the mould assembly in water bath for 80 to 90 minutes.
- Remove the sides of the mould.
- Hook the clips carefully on the machine without causing any initial strain.
- Adjust the pointer to read zero.
- Start the machine and pull clips horizontally at a speed of 50 mm per minute.
- Note the distance at which the bitumen thread of specimen breaks.
- Mean of two observations rounded to nearest whole number is ductility value.

	1	2	3
(a) Initial Reading	0	0	0
(b) Final Reading	76.8	75.8	76.6
(c) Ductility (b-a)	76.8	75.8	76.6

Ductility Value = 76.4 cm

3.2.3 SOFTENING POINT OF THE BITUMEN

Procedure to determine Softening Point of Bitumen
Materials of softening point below 80^{o} C:

- Assemble the apparatus with the rings, thermometer and ball guides in position.
- Fill the beaker with boiled distilled water at a temperature 5.0 ± 0.5^{o}C per minute.
- With the help of a stirrer, stir the liquid and apply heat to the beaker at a temperature of 5.0 ± 0.5^{o}C per minute.
- Apply heat until the material softens and allow the ball to pass through the ring.
- Record the temperature at which the ball touches the bottom, which is nothing but the softening point of that material.
- Materials of softening point above 80^{o}C:
  The procedure is the same as described above. The only difference is that instead of water, glycerine is used and the starting temperature of the test is 35^{o}C

Paving grade	**Softening Point**
Vg 10	40^{0}C
Vg 30	47^{0}C

3.2.4 MARSHALL TEST

The Marshall method of asphalt-concrete (AC) mix design is a well-established standardized method (AASHTO 1990, AI 1984, ASTM 1991, BS 1990) that is used by highway agencies in many parts of the world (including Kuwait (MPW 1987)) to design AC mixes for highway construction.

The standard method of Marshall mix design requires the preparation and testing of at least 15 specimens of AC mixes. The mixes are prepared by mixing different amounts of asphalt cement with an approved aggregate blend. The specimens are then tested in the Marshall testing machine and the results are represented graphically. From the graphs, an *optimum* binder content is determined and the corresponding properties of the optimum mix are checked against specifications.

As noted, the Marshall method of mix design starts with a known particle size-gradation of an aggregate blend. And the total surface area of an aggregate blend is directly related to its particle size-distribution. In fact, the total surface area can be calculated using the sieve analysis results of an aggregate blend (Roberts 1991).

The finished (hardened) AC mix develops its strength (compressive, tensile, and shear) mainly from the bond between aggregate particles and the asphalt cement. Therefore, the optimum binder content required for an AC mix is that which would be just sufficient to coat all surface areas of the aggregate particles plus an amount necessary to fill the voids in the aggregate matrix (such voids are named "voids in the mineral aggregate," VMA). And both the surface area and VMA of an aggregate blend are dependent upon its particle size distribution.

In this research, actual Marshall test results were used to develop a model that would estimate the optimum binder content for a given aggregate blend.

About 250 actual Marshall test results (from the Ministry of Public Works, MPW) were used to calibrate the proposed model. The results are from Marshall tests performed to design actual AC mixes used to build pavements in Kuwait. Obviously, all aggregates used in such tests satisfy the quality, durability, chemical composition, and other requirements stipulated by the MPW specifications (MPW 1987).

3.2.4.1 Background

The Marshall method has been used for asphalt-concrete (AC) mix design for a long time. It is widely used and known for its time and labour demand. The method is standardized by many agencies (method (AASHTO 1990, ASTM 1991, BS 1990, MPW 1987). The method involves laboratory trials on AC mixes with different values of asphalt cement content. The standard method states that at least 15 AC specimens must be tested. The results obtained from measuring different properties of such specimens are used to identify an optimum value for asphalt cement (binder) content.

3.2.4.2 Objectives

The overall objective of the study was to develop a mathematical model that can be used to predict the optimum amount of asphalt cement required for an asphalt concrete mix given the particle size-gradation of its aggregate blend.

More specifically the objectives of the study were to:

- Test the effect of size-gradation of aggregate blends on the optimum binder content in a mix design.
- Calibrate, evaluate, and validate a mathematical model for the prediction of optimum binder content in a mix design, based on particle size-gradation.
- Test the effect of asphalt-concrete mix type on the developed model.

3.2.5 THE MARSHALL METHOD OF MIX DESIGN

The Marshall method is a widely used laboratory procedure for the determination of the optimum amount of asphalt cement (termed optimum binder content, OBC) required to be mixed with a given aggregate blend to produce an asphalt-concrete mix of which properties conform to certain specifications regarding such values as stability, flow, air voids, VMA, and density. The procedure is described in details by the Asphalt Institute's Manual Series No. 2 (AI 1984).

The method is time and effort consuming and requires skilled labor for specimen preparation, testing, and analysis of results. Usually, 15 specimens are prepared and tested to develop relationships of the aforementioned five Marshall parameters with the amount of added binder. An example showing such relationships is shown in Figure 1. From these relationships, the OBC is determined as being the average of the asphalt cement content values corresponding to maximum density, maximum stability, and given air voids.

Results of Marshall mixes were obtained from the Ministry of Public Works. These results represent the asphalt-concrete mixes used in Kuwait (as described in the following section) and are used for the analysis described in this paper.

3.2.6 ASPHALT-CONCRETE MIXES USED

Roads in Kuwait are classified by Kuwait Municipality into four main categories: Special Road Network (SRN), Primary Road Network (PRN), Secondary Roads (SR), and Local Roads (LR) (MPW 1987). The Ministry of Public Works (MPW) further classified the roads in Kuwait into sub-categories according to specific functions (industrial/residential, divided/undivided). These sub-categories are shown in Table 1. The materials used for different layers (Type I, Type II, Type III, and PMS) are according to MPW standards (MPW 1987) that specify their required properties (such as aggregate gradation, grade of asphalt cement, Marshall values, etc).

Figure 2 shows a typical pavement section used in Kuwait. The subgrade material is selected to meet certain standards concerning density and strength (CBR). Typical thickness of different layers are shown in Table 1, based on the class of the road for which the pavement is constructed. Structural (thickness) design is performed using the Kuwait Design Manual (MPW 1987).

3.2.7 EFFECT OF PARTICLE SIZE GRADATION ON OPTIMUM BINDER CONTENT

The objectives of the Marshall method of mix design is to determine (among other parameters) the optimum amount of asphalt cement to be added to an aggregate blend. The objective of asphalt cement in asphalt-concrete mixes is to bind (glue) the aggregate particles together. Therefore, the effective binder content is the portion that coats the particle surfaces. And since smaller particles have greater specific surface area (surface area per unit weight of aggregate blend), finer aggregate blends require more bitumen contents. Therefore, the optimum binder content of blend 1 in Figure 3 would be greater than that of blend 2.

For a given mass of one-size spherical particles, all having a diameter d, the total surface area can be determined using the following equation:

$$A_S = \frac{6\,M}{G_S\,\rho_w}\,\frac{1}{d} \qquad (1)$$

A_S = total surface area of all particles;
M = total mass of particles;

G_S = specific gravity of particles;

ρ_W = density of water;

d = diameter of particles.

Equation 1 shows that the total surface area of a given mass of particles is inversely proportional to the particle size. For example, assuming the following values:

$G_S = 2.67$ and $\rho_W = 1000$ kg/m^3,

a 1-kg sample of 10-mm particles has a total surface area of 0.2 m^2, whereas a 1-kg sample of 74-μm particles has a total surface area of 30 m^2.

Using this principle, aggregate particle-size gradations can be used to calculate the total surface area per unit mass of an aggregate blend. Table 2, for example, is used to calculate the total surface area of an aggregate blend by multiplying the factor by the cumulative percentage passing for each sieve size and totaling for all sieve sizes. The units of such calculations would be square meters per kilogram.

The factors in Table 2 show that smaller particles have substantially more contribution to the total surface area of an aggregate blend than coarser particles. Consequently, they have more effect on the optimum binder content required for an asphalt concrete mix (refer to Figure 3).

Table 2 shows that there is a relationship between particle size gradation of an aggregate blend and the optimum binder content required to make an optimum asphalt-concrete mix. This relationship is objectively determined in the following section.

3.2.8 MODEL DEVELOPMENT

The relationship between aggregate gradation and their associated optimum binder content (OBC) was tested using the Marshall mix design parameters of about 250 specimens. They represent different asphalt-concrete mixes used in Kuwait, as described previously in this paper.

The gradation-OBC relationship is calibrated using multivariate linear regression analysis with OBC as the dependent variable and the cumulative percent passing each sieve size as the independent variables. The model has the form

$$OBC = a_o + \sum_{i=1}^{n} a_i \; P_i \qquad (2)$$

where,

OBC = optimum binder content;

a_o = regression constants (Table 3);

a_i = regression coefficients (Table 3);

P_i = cumulative percent passing sieve i;

n = number of sieves in the gradation table.

The model of Equation 2 was calibrated for each mix using the available data of different mix designs for the five asphalt-concrete mix types used namely, Type I, Type II, Type III, Type IV, and PMS. The regression analysis results are shown in Table 3. A combined model for mix types I, II, III, and IV was also calibrated as shown in the same table.

The R^2 values in Table 3 show that there is a strong relationship between the aggregate gradation and the required binder content to make an optimum asphalt-concrete Marshall mix. This was expected since the amount of binder depends on the total surface area of the aggregate particles which has a relationship with its size gradation as shown in Table 2.

The models of Table 3 can be used to estimate the required optimum binder content by multiplying the cumulative percent passing each sieve size by the corresponding coefficient and totalling for all sieves plus the constant.

3.2.9 MODEL EVALUATION AND VALIDATION

The models of Table 3 were evaluated using the available Marshall mix results for the tested mix types. Equation 2 was applied on each aggregate blend to predict the optimum binder content (OBC). Each predicted OBC value was plotted against its corresponding observed OBC. The correlations of predicted and observed OBC are shown graphically in Figures 4 to 9. R^2-values on the graphs of Figures 4 to 9 represent the goodness of fit of the equality line (45°-line) with respect to the plotted points.

Additional Marshall mix results were obtained from a different agency (Military Engineering Projects, Ministry of Defense). These results represent mixes of Types I, II, III, and IV. Therefore, they were used to validate the combined model of Table 3. The results of applying the developed model to such mixes are shown in Figure 10, which indicated that the developed model was successful in predicting the actual OBC values with an overall R^2-value of 0.73.

3.2.9.1 CONCLUSIONS

This paper presents the results of a study attempting to determine the relationship between the particle size-gradation and the optimum binder content (OBC) in a Marshall asphalt-concrete mix. The analysis was based on Marshall results of more than 250 mixes, all of which conform to the Ministry of Public Works' specifications. Multivariate linear regression analysis was used to calibrate the model shown in Equation 2.

The analysis of results showed a high correlation between the OBC and the particle size distribution. The cumulative percent passing values were used to describe the particle size distribution. A separate model was calibrated for each of the asphalt-concrete mixes: Type I, Type II, Type III, Type IV and PMS. A combined (aggregated) model was developed for mix types I, II, III and IV due to the similarity of sieve sizes used to describe their aggregate-blends' size gradations.

The developed models of Table 3 were evaluated using the same data from which they were developed and the calculated (predicted) OBC showed high correlations with actual (observed) OBC for all models.

Additional data were used to validate the aggregated model for mix types I, II, III, and IV. This resulted in a correlation between the predicted and observed OBC with an R^2 of 0.73.

The developed models can be used to estimate the required OBC for a given aggregate blend. Using this calculated OBC, three identical specimens of a Marshall mix may be prepared, tested, and checked for compliance to specifications for air voids, stability, density, flow, and VMA. This results in major time and effort savings of laboratory work.

Additional results of other mixes are needed to further validate the use of the developed models. This can be accomplished by calculating OBC values using the models of Table 3, and comparing the results with the actual OBC values obtained by conducting a conventional Marshall test.

Similar analysis can be performed on any asphalt-concrete mix design results (such as those of Super pave mixes); but this remains to be determined. However, high correlations are always expected because of the high dependency of OBC on the particle size distribution of the used aggregate blend, which is described by the cumulative percent passing of the sieve analysis results.

3.2.9.1 ACKNOWLEDGEMENTS

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TABLE 1 Typical Pavement Layer Thickness for Different Road Classes.

Functional Class	**Description**	**Layers Thickness (cm)**				**Design ESWL**
		TYPE I	TYPE II	TYPE II	PMS	

SRN	Freeways	10	8	0	2	$1*10^9$
PRN 1	Border Roads	10	6	0	2	$6*10^8$
PRN 2	Urban Arterials	10	6	0	0	$6 * 10^8$
SR 1	Commercial - Divided	10	6	0	0	$3 *10^8$
SR 2	Residential – Divided	10	0	4	0	$3*10^8$
SR 3	Residential - Undivided	8	0	5	0	$3*10^8$
LR 1	Residential Driveways	8	0	4	0	$1*10^8$
SR 4	Industrial – Divided	10	6	0	0	$6*10^8$
SR 5	Industrial – Undivided	10	4	0	0	$3*10^8$

TABLE 2 Factors for Calculating Total Surface Area of an Aggregate Blend (After Roberts 1991)

Sieve Size (mm)	**Surface Area Factor**
Maximum sieve size	0.41
4.75	.41
2.36	0.82
1.18	1.64
0.600	2.87
0.300	6.14
0.150	12.29
0.075	32.77

3.2.9.2 RESULTS AND CALCULATION

Material	**Specific Gravity**	**Mixture Composition % by wt of**

	Apparent	Bulk Dry	Total Mix	Dry Aggr
Asph Cement	1.010		6.96	7.48
Coarse Aggr	2.759	2.606	51.45	55.30
Fine Aggr	2.905	2.711	41.59	44.70

Paving Mixture: Bulk specific gravity of compacted paving mixture sample.

G_{mb} (KT-15) = 2.344

Maximum specific gravity of paving mixture sample.

G_{mm} (KT-39) = 2.438

The calculations are simplified by converting from percent by dry weight of aggregates to percent by total weight of mixture. This is accomplished by use of the following formulas:

P_b = (P x 100)/ (100 + $P_{b'}$)

P_1 = (P x 100)/ (100 + $P_{b'}$)

Where,

P_b = Percent asphalt, total mixture basis.

P'_b = Percent asphalt, dry weight basis.

P_1 = Percent Coarse Aggr., total mixture basis.

P'_1 = Percent Coarse Aggr., dry weight basis. Example:

P_b = (7.48 x 100) = 6.96% (asphalt) (100 + 7.48)

P_1 = (55.30 x 100)/(100+7.48) = 51.45% (coarse aggr.)

P_2 and P_3 are calculated in the same manner as P_1.

Bulk Specific Gravity of Aggregate: When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities, the bulk and apparent specific gravities for the total aggregate are calculated as follows:

Bulk Specific Gravity,

$G_{sb.}$ = (P_1 + P_2 + ...P_n)/(P_1/G_1) + (P_2/ G_2) + ... (P_n/ G_n)

Gsb = Bulk dry specific gravity of the total aggregate

P1,P2,Pn = Percentages by weight of aggregates,

G1,G2,Gn = Bulk specific gravities of aggregates

The bulk specific gravity of mineral filler is difficult to determine accurately at the present time. However, if the apparent specific gravity of the filler is used instead, the error is usually negligible. Calculation

G_{sb} = (51.450 + 41.590)/((51.450/2.606)+(41.590/2.711)) = 2.652

Effective Specific Gravity of Aggregate: When based on the maximum specific gravity of a paving mixture, Gmm, the effective specific gravity of the aggregate, Gse, includes all void spaces in the aggregate particles except those that absorb asphalt. It is determined as follows

G = (P_{mm} – Pb)/((P_{mm}/G_{mm})-(P_b-G_b))

Where,

G_{se} = Effective specific gravity of aggregate

P_{mm} = total loose mixture = 100%

P_b = asphalt, percent by total weight of mixture

G_{mm} = maximum specific gravity of paving mixture (no air voids),

Gb = specific gravity of asphalt

Gse =(100-6.960)/((100/2.438)-(6.960/1.01))) =2.726

The volume of asphalt binder absorbed by an aggregate is almost invariably less than the volume of water absorbed. Consequently, the value for the effective specific gravity of an aggregate (Gse) should Page 4/14 5.10.4 04-10 be between its bulk (Gsb) and apparent specific gravities (Gsa). When the effective specific gravity falls outside these limits, its value must be assumed to be incorrect. If this occurs; the calculations, the maximum specific gravity of the total mix (KT-39) and the composition of the mix should then be rechecked for the source of the error. If the apparent specific gravity of the coarse aggregate is 2.759 and the apparent specific gravity of the fine aggregate is 2.905

Fig: Marshall Apparatus

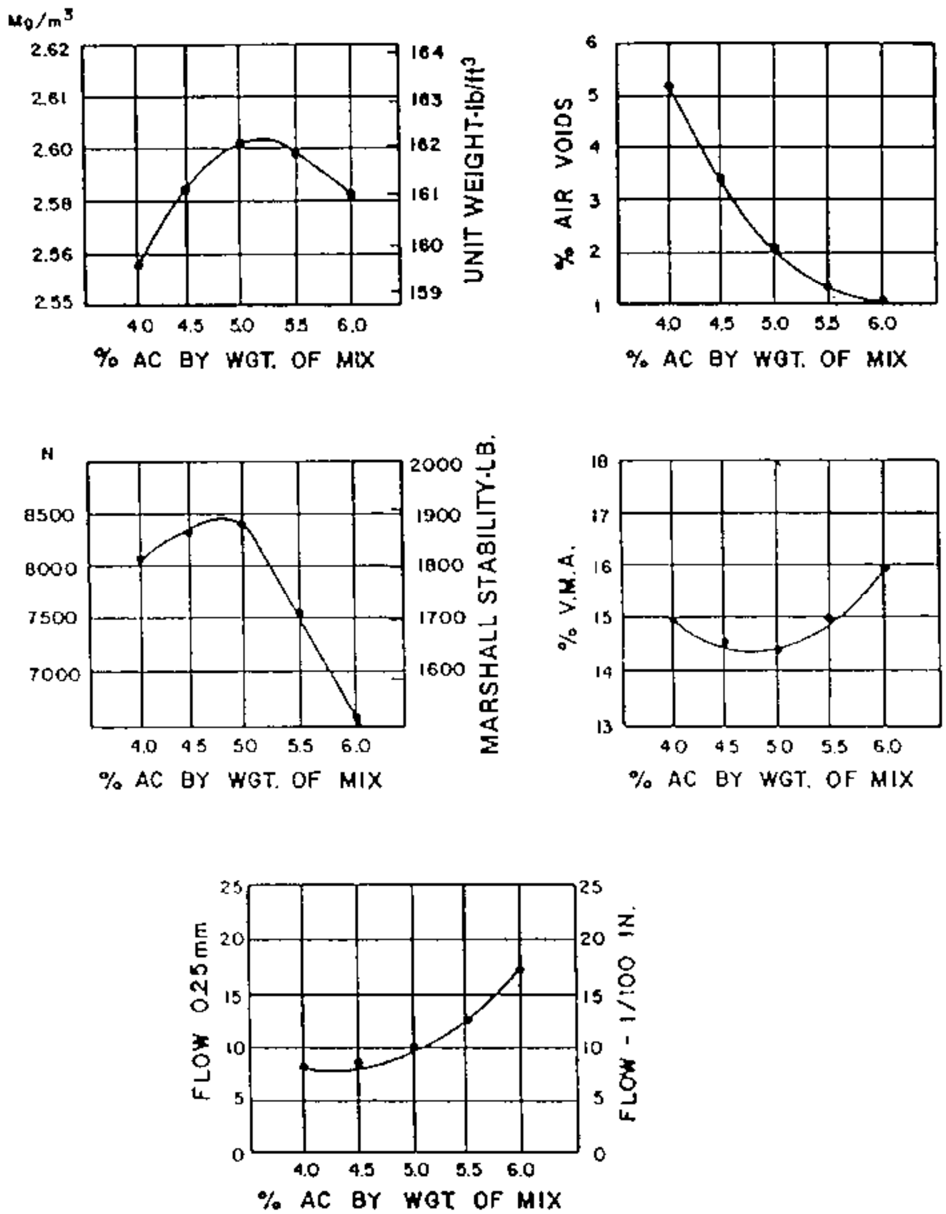

Figure 1 Typical Marshall Results (AI 1988)

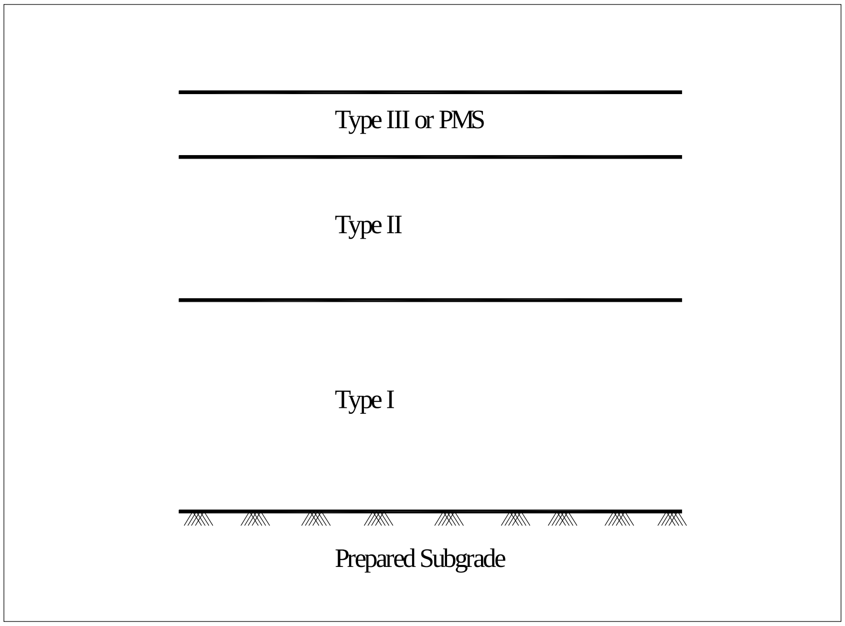

Figure 2 A Typical Pavement Section .

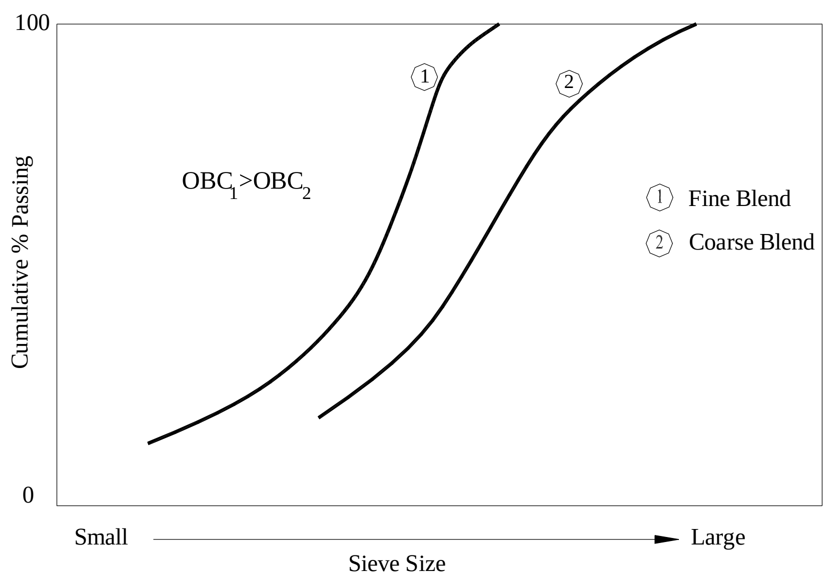

Figure 3 Size Gradation of Two Aggregate Blends

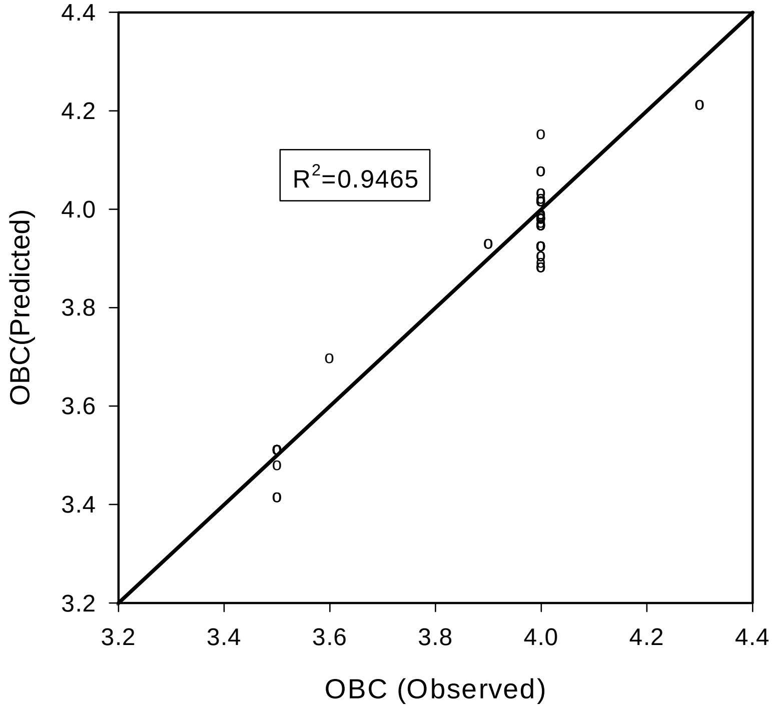

Figure 4 The Correlation of Predicted to Observed OBC for Asphalt-Concrete Type I

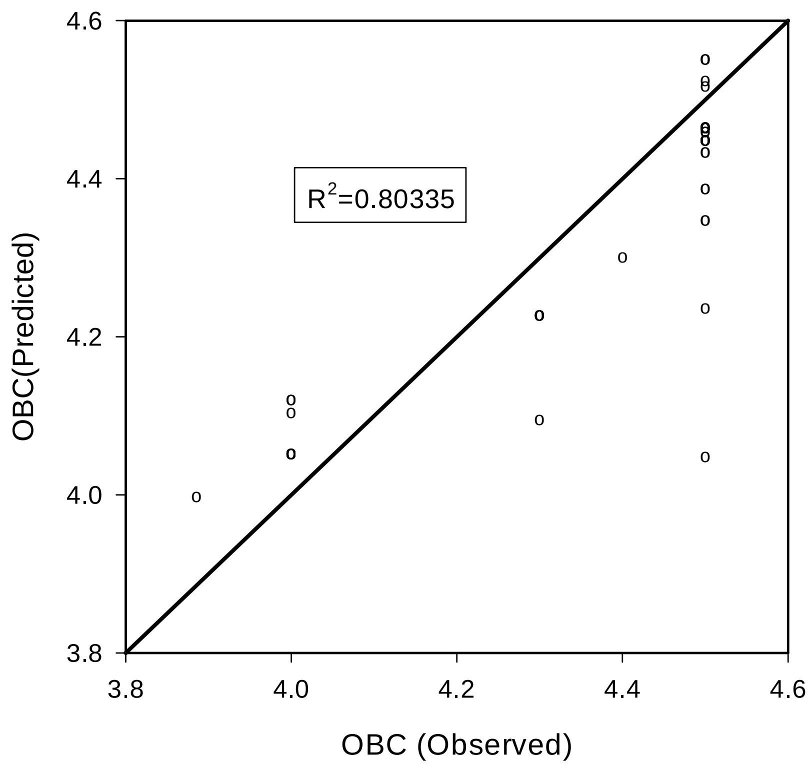

Figure 5 The Correlation of Predicted to Observed OBC for Asphalt-Concrete

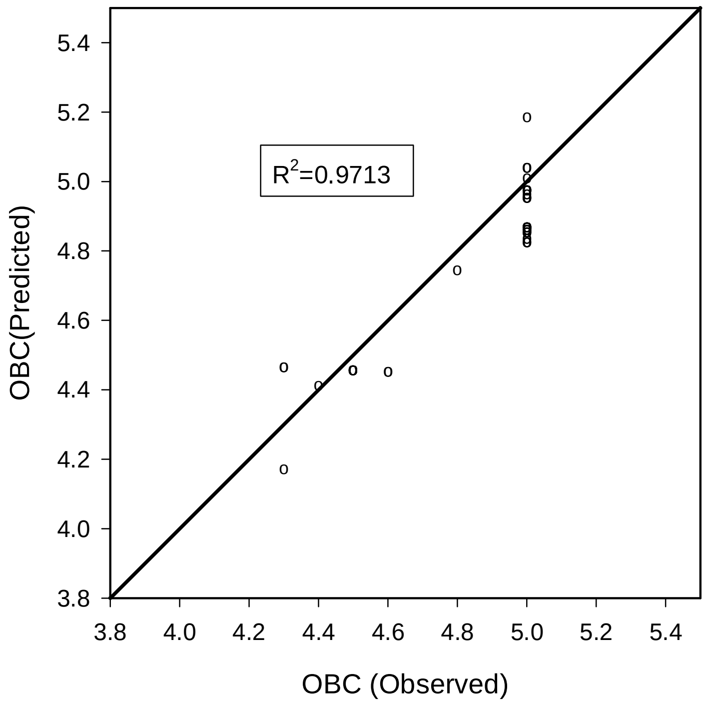

Figure 6 The Correlation of Predicted to Observed OBC for Asphalt-Concrete Type III

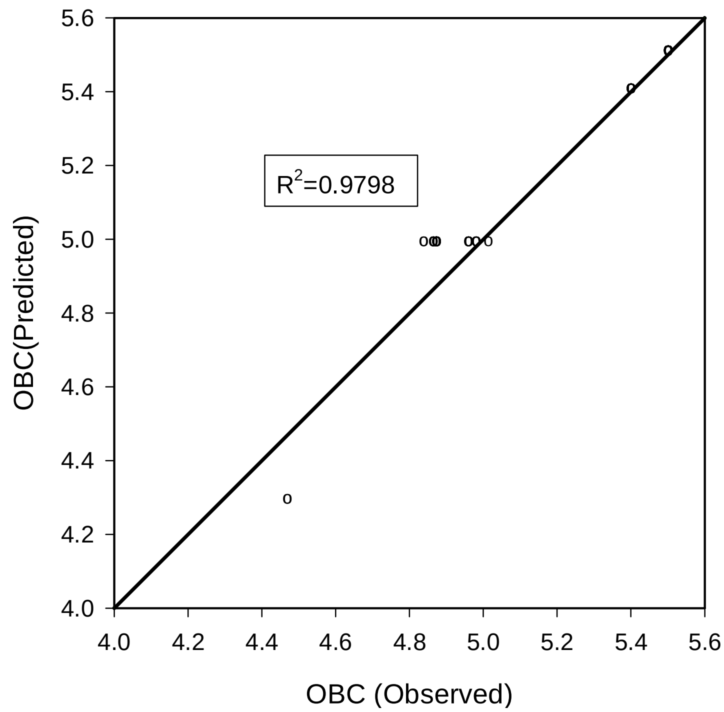

Figure 7 The Correlation of Predicted to Observed OBC for Asphalt-Concrete

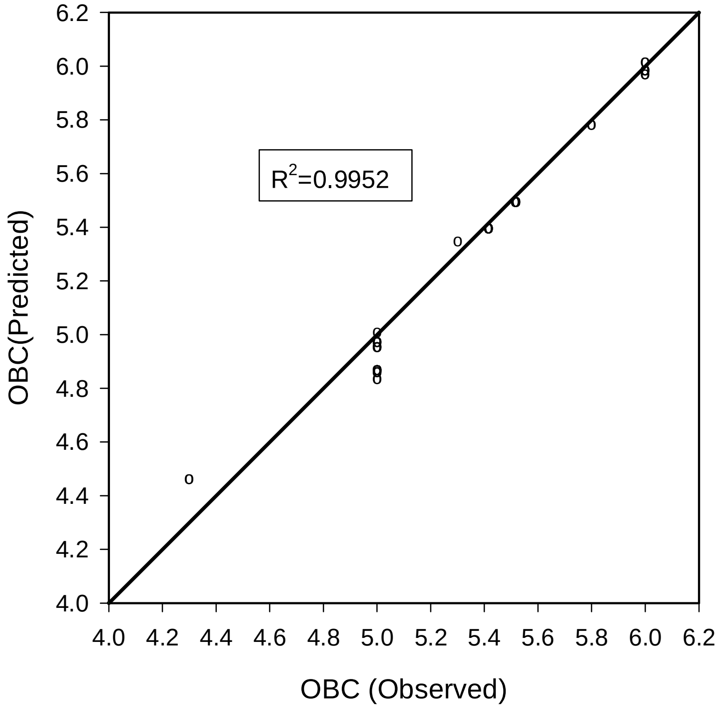

Figure 8 The Correlation of Predicted to Observed OBC for Asphalt-Concrete

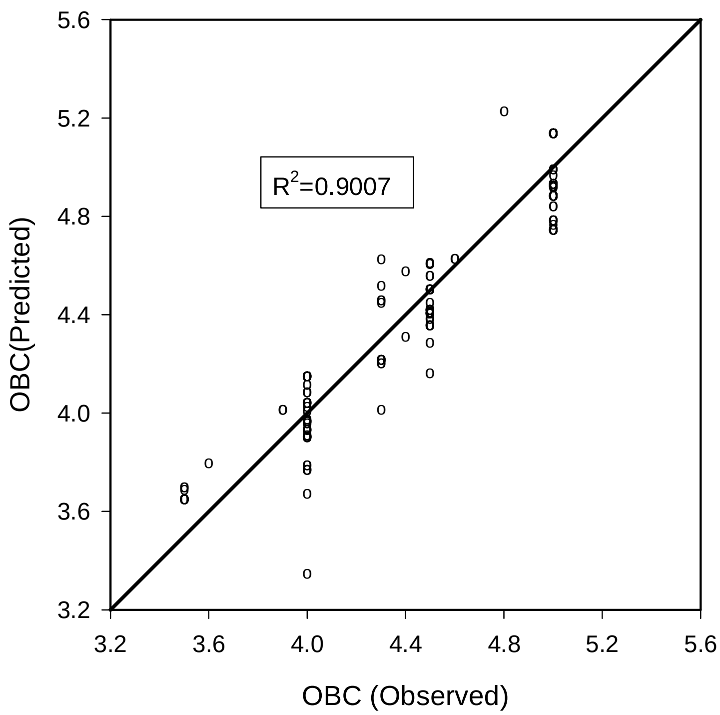

Figure 9 The Correlation of Predicted to Observed OBC for Combined Asphalt-Concrete Types I, II, III, and IV

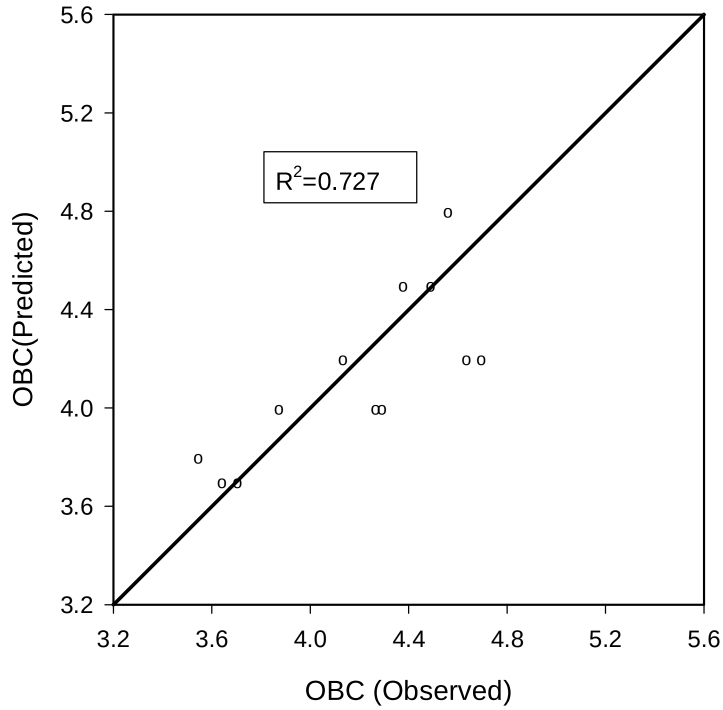

Figure 10 Results of Model Validation for Combined Asphalt-Concrete Mix Types I, II, III, and IV

3.2.10 VISCOSITY TEST FOR BITUMEN

- Clean the oil tube with a solvent, such as benzene, and remove excess solvent from the gallery. Pass the entire material through a 150 micron wire strainer before introducing into the oil tube.
- After the tube is cleaned, pour into the tube a quantity of the material to be tested, sufficient to wet the entire surface of the tube. Allow to drain out.
- The plunger commonly supplied with the viscometer shall never be used on instruments maintained as standards. Insert the cork stopper not less than 6.0 mm and not more than 9.5 mm into the lower end of the air chamber at the bottom of the oil tube, taking care that the cork fits tightly enough to prevent the escape of air, as tested by the absence of oil on the cork after it is withdrawn.
- If the test temperature is above that of the room, heat the material to not more than 1.5^0C below the temperature of test.
- Pour the material into the oil tube until it ceases to overflow into the gallery. Keep it well stirred with the oil tube thermometer, care being taken to avoid touching the outflow tube. Adjust the bath temperature until the temperature of the material remains constant.

- After thermal equilibrium has been attained, no further adjustment shall be made in the bath temperature. The test results shall be discarded if the indicated bath temperature varies by more than $+0.03^0$C.

- After the temperature of the material in the oil tube has remained constant within +0.02^{0}C of the desired temperature for one minute with constant stirring, withdraw the oil tube thermometer and remove the surplus liquid quickly from the gallery by means of the withdrawal tube so that the level of the material in the gallery is below the level in the oil tube proper. Insert the tip of the withdrawal tube at one point in the gallery.
- The test shall be started over again if the tip of the withdrawal tube touches the overflow rim. Under no condition shall the excess liquid be removed by rotating the withdrawal tube around the gallery.
- Place the receiving flask in position so that the stream of liquid from outlet tube strikes the neck of the flask, care being taken that the graduation mark on the receiving flask is not less than 10cm, not more than 13cm, from the bottom of the bath. Snap the cork from its position and at the same instant start the timer. Stop the timer when the bottom of the meniscus of the liquid reaches the mark on the neck of the receiving flask.
- Time in seconds as determined by the prescribed procedure, with the proper calibration correction, is the Saybolt Furol viscosity of the material at the temperature at which the test is made.
- Report the results to the nearest 0.1 second for viscosity values below 200 seconds and to the nearest whole second for values 200 seconds or above.

3.2.10.1 REPORTING OF RESULT

- Time in seconds as determined by the above described procedure, with the proper calibration correction, is the Saybolt Furol Viscosity of the material at the temperature at which the test is made.

- Report the results to the nearest 0.1 s for viscosity values below 200s and to the nearest whole second for values 200s or above.

CHAPTER -4

FUTURE WORK

According to the methodology, which I have shown in the methodology chapter above, will help me in performing experiments based on the aggregates like Marshall tests, sieve analysis, etc., bituminous like flash and fire point, penetration tests, etc. and supportive check performed by the filler mixed with bituminous.

There will be many locations after examining the conditions of the roads made so far, which are damaged and due to which reasons.

These reasons for the damage of the roads and their cause will definitely help me in enhancing the roads properties by the help of the iron slag as a filler, which I am using in this research.

CHAPTER-5

CONCLUSION

For the construction of the roads the only the bitumen is not defined and cannot attain the required strength and different properties, along with them filler and aggregates even plays a vital role as strength provider. This is very common, that filler like cement, fly ass, calcium oxide, slag of iron and copper are used. Iron slag was used in the research as filler. By using the iron slag values have been improved. So that the thickness of the pavement has been reduced and it is benefit to the contractor. In this process damage to the environment is negligible and the benefits to the environment are more. The problem facing by the most of the industries is deposition of the iron slag produced as waste in the industry. This problem can be completely avoided by this use of iron slag in the bitumen on the bitumen mix design.

The layer being used in this research is BM (wearing course), on the partial replacement of cement from the bitumen and adding the iron slag, the surface will get enough strength and give performance to the skid resistance and proper holding of the layer with a water proofing quality and great life span.

The blast furnace slag being used are the waste of the industries and is used in the proper manner.

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