OPTIMIZATION AND INVESTIGATION OF MOULD MAKING PROCESS BY RAPID PROTOTYPING AND NICKEL ELECTROFORMING

M.TECH DISSERTATION

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OPTIMIZATION AND INVESTIGATION OF MOULD MAKING PROCESS BY RAPID PROTOTYPING AND NICKLE ELECTROFORMING

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CERTIFICATE

I hereby certify that the work which is being presented in dissertation entitled "**OPTIMIZATION AND INVESTIGATION OF MOULD MAKING PROCESS BY RAPID PROTOTYPING AND NICKLE ELECTROFORMING**," for partial fulfillment of the requirement for the award of degree of **MASTER OF TECHNOLOGY** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried during period of Dissertation under the supervision of **Mr. Gurpreet Singh Phull**, Associate Professor, Dept. of Mechanical engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation is the result of my original investigation and study. No part the dissertation proposal has ever been submitted for any other degree or diploma.

Date: (**VidhataMehta)**

The dissertation proposal is fit for the submission and partial fulfillment of the conditions for the award of degree of M.Tech Mechanical Engineering.

Date: **(Mr. Gurpreet Singh Phull)**

Supervisor

The M.Tech Dissertation examination of Vidhata Mehta, has been held on _____________

Signature of Examiner

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ABSTRACT

In the present work, experimental investigations have been made to develop permanent mould making process, with the use of fused deposition modelling and nickel electroforming. The experiments are designed by Design of Experiments technique using Taguchi L9 orthogonal array .A series of experiments with Rapid Protptyping patterns were conducted. Relationship between pH, Temperature and time and their effect on thickness, surface finish and other parameters has been deduced by using Taguchi technique L9 orthogonal arrays. The optimized process parameters are established for thickness and surface finish and their percentage contribution is calculated using Analysis of Variance (ANOVA) technique. The whole experimental study indicates that how current, PH and temperature change affects the thickness and surface finish of ABS component. Results are concluded on the basis of plating thickness inspection with destructive test meter and surface roughness tester

Keywords: Electroforming, Fused Deposition Modeling, Acrylonitrile Butadiene Styrene (ABS), Design of Experiments (DOE), ANOVA, Taguchis orthogonal array.

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LIST OF ABBREVIATIONS

FDM	Fused Deposition Modeling
RP	Rapid Prototyping
RT	rapid Tooling
ABS	Acrylonitrile Buta-diene Styrene
EDM	Electric Discharge Machining
CAD	Computer Aided Design
ANOVA	Analysis of Variance Analysis
DOE	Design of Experiments
DC	Direct Current
PH	pH
PLT	Plating thickness test
AMP	Ampere
µ	Microns
mm	Millimeter
gm	Grams
hr	Hours
min	Minutes
l	Litres

1. INTRODUCTION TO ELECTROFORMING

In this 21st century consumers want better quality and better product, so for that company needs better components with best quality. Tooling and mould making is a vital area in manufacturing process. As the increase in complexity of component has resulted in a corresponding increase in time and cost required to develop such component. The most important challenge with which modern industry comes across is to offer the consumer better products with outstanding variety Rapid prototyping (RP) is one of the modern manufacturing techniques, which uses computer aided design (CAD) based automated additive manufacturing process to construct parts; that are used directly as finished products or components Earlier moulds were made by subtractive manufacturing or we can say by metal removal processes, which consumes lot of time and money but in this research we have tried to develop a new method of making mould by additive manufacturing using fused deposition modeling and nickel electroforming.[1]

1.1 Types of Manufacturing

Manufacturing is defined as the transformation of raw material in to finished products. And for producing finished products we need to do some operations. Manufacturing processes are mainly categories into two categories. Primary manufacturing processes and Secondary manufacturing processes. Basic size and shape to the raw material is provided by primary manufacturing processes according to the designer's design, Forming, Casting, etc are some examples of it. The final shape and size with good dimensional accuracy, fine surface characteristics etc is provided by Secondary manufacturing processes. Most of the Material removal processes are the secondary manufacturing processes or also know as subtractive manufacturing.[3]

Subtractive manufacturing is that manufacturing process in which metal is removed or cut from the piece. It is divided into mainly two groups and they are "Conventional Machining Processes" and "Non-Traditional Manufacturing Processes". Conventional machining methods are those in which sharp cutting tools are used to mechanically remove the material by direct interface of tool & work piece. In non-conventional machining method the materials is removed by using electrical, chemical, thermal or mechanical energy without sharp cutting tools.

As removing of material of material to create a shape is costly process also it waste lot of energy and material for the production of the product. Last few decades has witnessed a note dimension of manufacturing development rapidly is additive manufacturing. This work has tried to explore one such dimension of additive manufacturing by combining rapid prototyping and electroforming methods. In today's world products and materials are very complex and to make them by non-conventional method, which should be easy to handle and economical. Conventional machining uses mechanical (motion) energy for its operations and Non-conventional machining usually use other forms of energy.

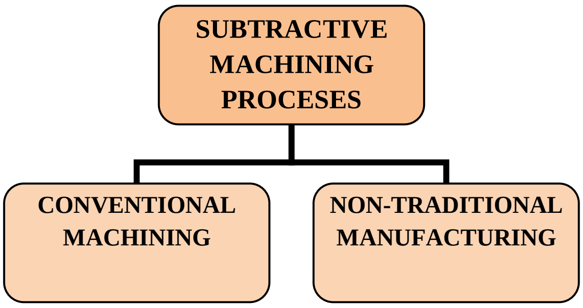

Figure 1 Types of machining

1.2 Overview of Electroforming

ASTM B 83 93 describe it simply and concisely as follow: Electroforming is the production or reproduction of articles by electro-deposition of metal upon a mandrel that is subsequently separated from the deposit." It is, therefore, a method of fabricating parts that are usually free standing once separated from the mandrel. This definition will satisfy all purists in the technology [4].

1.2.1 TYPES OF ELECTROFORMING

Electroforming is basically defined as electrochemical process where metal ions are transferred from a solution and are deposits thick layer on the surface of a cathode. To achieve uniform coatings during electro-forming of metals and plastics deposition of metals such as copper, nickel, silver or palladium on the surface of a variety of materials by means of an electrolytic bath. But electroforming is also of two types.

1) Electroforming of metal on Conductive material

2) Electroforming on metal on Non-Conductive material

- Electroforming of metal on Conductive Materials: In this metal ions are transferred from solution and ions are deposited as a thick layer on the metal surface of cathode. In this cathode part is also a metal like stainless steel and forming is done on it. Stainless steel is used as conductive mandrel because of its property of easily detachability from electroformed part [5] as shown in fig.

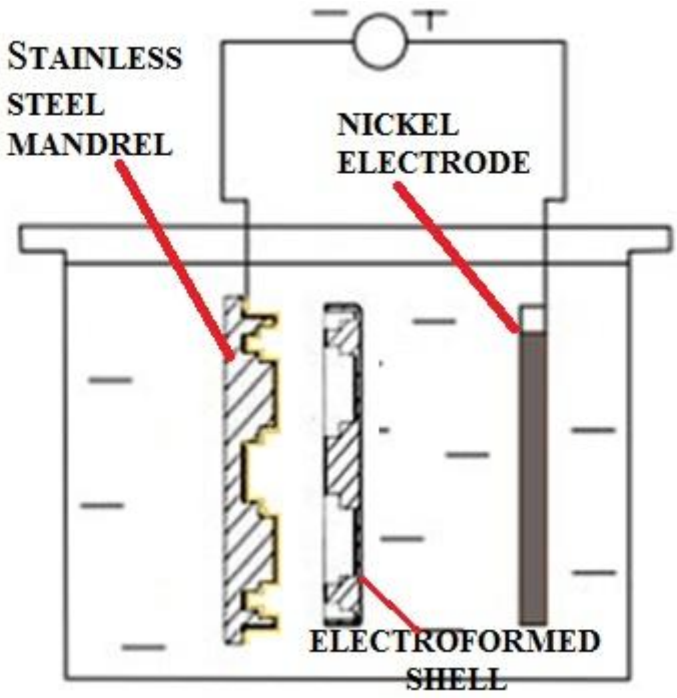

Figure 2 Electroforming of metal on metal

3) Electroforming of metal on Non-Conductive Materials0: In this metal ions are transferred from a solution and are deposited as solid layer onto non-conductive surface of a cathode. In this work cathode part is an ABS plastic and forming is done on it as shown in fig.3. But as ABS is a non conductive so it is required to make it conductive and for that cleaning and activation are very necessary. Cleaning and activation develops conductive characteristics in ABS and makes it conductive for copper electroplating so that nickel electroforming can be done. The use of the electroforming methodology describes the various phases to cleanse, etch, pre-activation and activate the ABS components so that they are ready for electroforming.

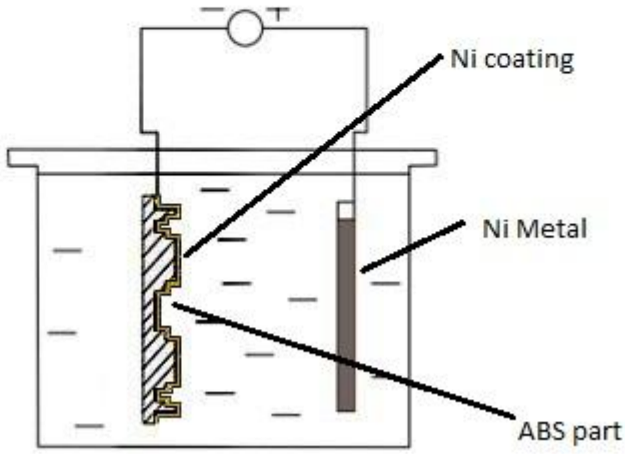

Figure 3 Electroforming on metal on plastic

1.3 Fundamental components of Electroforming Process

Electroforming is a metal forming process that grows metal through electroplating process. The process create an electroform piece through electro deposition of base form in a plating bath. An electrolytic bath is used in this process to deposit metal (Copper) onto a conductive surface. The difference between electroforming and electroplating is the thickness of the plating, with electroforming the plating is thicker and self-supporting.

Basic Components of electroforming process: Basically electroforming process has three major components described as follows:

1.3.1 Electrolyte – An electroforming tank filled with distilled water and salt of the metal (which is to be coated on the cathode) and certain amount of acid or alkali added to improve its conductivity. The tanks or baths used for electroforming are either acid bath or alkaline bath depending upon the acid or basic chemicals used in the bath. Mainly copper and nickel bath is made as electrolyte.

1.3.2 Anode (positive electrode) – Usually this is made of electroforming metal (Cu, Ni), which is to be coated on the object. Anode is eaten away in the electroforming process and equivalent eaten away metal is deposited on cathode.

1.3.3 Cathode (negative electrode) –It is made of the ABS on which metal is to be deposited from anode. Cathode is the negative electrode Figure 4, shows the basic components of plating.[6]

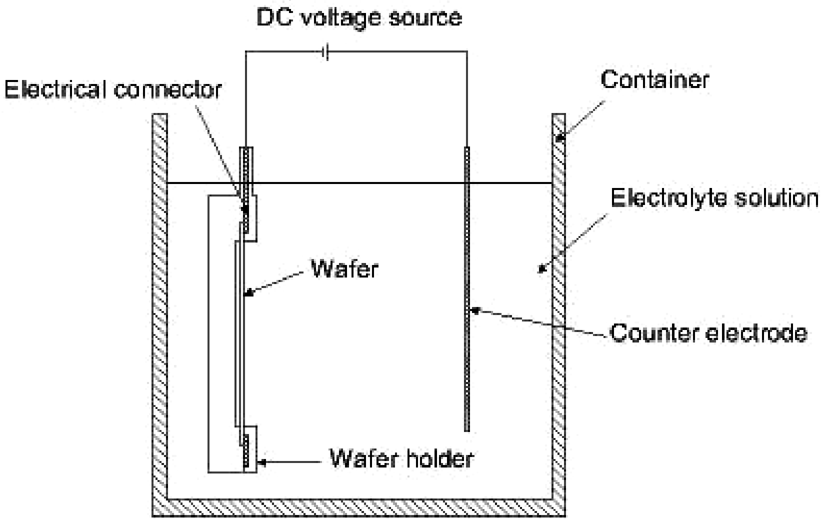

Figure 4 Showing basic components of Electroforming

1.4 Principle of Electroforming

In this work, the ABS component is made to be negative and the nickel electrode is made to be positive, ABS component is to be plated with copper. For power supply a device called rectifier is used which converts AC to DC, which flow only in one direction. Negative terminal of rectifier is connected to the ABS component on which electroforming is to be done, which is called Cathode and positive terminal is attached to the nickel electrode. [7]

Then electrolyte is formed with the help of nickel sulphamate, distilled water and small amount of sulphuric acid and small pinch of HCL. And cathode and anode are dipped in it. The object which is to be plated is made cathode i.e negatively charged and it attracts positively charged Nickel cations. And nickel metal is made anode i.e positive charged. At the cathode electrons are removed from nickel metal, oxidizing it to the nickel cations. Thus the nickel metal is dissolves as ions into the solution and Nickel is plated to the ABS component.

In this section reaction during electrode deposition is explained and case of nickel forming is demonstrated. The setup is made of direct current circuit, work piece (ABS) is made of cathode and metal (like Nickel) is made anode, an electrolytic bath is used to deposit Nickel metals onto a conductive patterned surface. The process involves the reduction of metal ions from electrolyte. Electrons are supplied to cations which are drift to anode. Here M^{n+} (n is the valiancy of the metal ion, n=2 for Nickel plating) combines with the ne^- to form metal M Therefore, reaction at cathode follows: DC circuit with an anode and a cathode sitting in a bath of solution that has the metal ions necessary for coating. .

Reaction on cathode as follows

$M^{n+} + ne^- \rightarrow M$ (Reduction reaction = Reduction of metal)

At anode, electrons are supplied to anions which drift towards to anode. Here M gives the M^{n+} and ne^- .

The reaction at anode as follows:

$M \rightarrow M^{n+} + ne^-$ (Oxidation reaction = Dissolution of metal) [2]

We want to plate ABS with copper and then electroformed with nickel. But before that we need proper cleaning and activation process, which is also known as surface preparation process.

1.5 Surface Preparation

In surface preparation of ABS, firstly course the surface to allow metals to adhere so that electroplating and electroforming can be done over the surface of ABS Plastic. This process is bit complicated, it includes a long chain of applications of chemicals such as zinc plate 452, hydrochloric+442, chromic acid, sulphuric acid etc. Plastic sample is treated several times with different chemicals so that its surface will become free from dirt and these chemicals also helps in making the surface of ABS course or rough at micro level, so that conductive paint can be applied. So that electroplating can be performed.

Surface pre-treatment by chemical is very important in the case of preparations for electroplating surface Preparation is designed to ensure good adhesion to the surface. In our surface treatment we cleaned the ABS specimen surface, usually this includes employing of hot soap degreasing, solvents, acid cleaners like H_2SO_4 dip, abrasive materials and water. Hot soap degreasing and H_2SO_4 dip will do modification of surface

Figure 5 Surface preparations for electroforming

That includes change in surface attribute and after that rinsed it with tap water or washed off with water. Now our ABS part is ready for Etching process. For etching of plastic part rinsed it with water several times after each step to clear away the dust and dirt from its surface.The Etch is a solution of chromic acid and sulphuric acid at elevated temperatures. Typical concentrations range from 300-500 g/l of chromic acid and 300-500 g/l of sulphuric acid with small amounts of wetting agents to allow the viscous solution to enter small grooves and depressions. Temperature ranges are usually 65° - 75 ^{o}C (149 – 167 ^{o}F).[8]

1.6 Parameters of Electroforming Process

The following parameters are most commonly considered as the input variables that can be easily varied to achieve the desired output.

1.6.1 PH

PH tells the acidic and basic character of the solution. It tells the acidic or alkalinity (basic character) of the chemical solution on a logarithmic scale on which 7 is neutral, values less than 7 are acid and values more then 7 are basic or alkaline. The mathematical formula of pH is $-\log_{10}$ c, where c is the hydrogen ion concentration in moles per liter.

1.6.2 Temperature

It is the degree of internal heat of the solution or the body .The degree or intensity of heat present in a substance or object.

1.6.3 Current

Current is defined as the flow of electric charge. Its SI units is Amperes.

1.7 Applications of Electroforming

- Electroforming process is widely used in production of moulds used to produce body and interior components for automotive and aerospace applications.
- It is a well established process in jewelry making.
- Its major use is in the production of thin metal foils. The range of applications is in the production of printed circuit boards, solar heating panels.
- It is widely employed in manufacture of tooling that requires good surface finish and tight tolerance.
- Electroforming can be used in rapid tooling techniques such as producing electrodes, cores or patterns etc. for complex geometries.[9]

1.8 Advantages of Electroforming

- Precise reproduction of surface detail.
- Production of complex-shapes.
- High dimensional precision.
- Many different substrate materials are possible.
- Mass production.

1.9 Disadvantages of Electroforming

- Maximum dimensions depend on the size of the available bath.
- Labour intensive.
- Costs are relatively high.
- Some non-uniform thickness.

2 INTRODUCTION TO RAPID PROTOTYPING

2.1 OVERVIEW AND METHODOLOGY OF RAPID PROTOTYPING

Rapid prototyping (most recently, broadly classified as additive manufacturing) is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three dimensional computer aided design(CAD) data. The term rapid prototyping (RP) refers to a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data. The main advantage of the system is that almost any shape can be produced. Time and money saving vary from 50-90% compared to conventional systems.

The essential part of product development and manufacturing cycle is to assess the form, fit and functionality of design before investment in tooling is termed as Prototyping and rapid prototyping is the making prototypes of the components but in a fast manner using 3D computer aided design (CAD) data.The main advantage of this system is that any shape can be formed very easily. It quickly manufacture the physical model using CAD data. Now days RP is used in every field even in biomedical sciences and Aerospace industry. Prof. Deepa Yagnik experimented about the use of RPT in Aerospace industry. She says aerospace industries are employing FDM technology for so many applications as it gives most flexibility with a variety of thermoplastics designed for aerospace applications. Aerospace icons like NASA & Piper Aircraft employ the most exciting FDM (3D printing) applications in the world. But problem with FDM is it produces ABS parts which are non-conductive .Non-conductive materials like ABS (Acrylonitrile Butadiene Styrene) with electroforming can be used to produce electrodes for spark machine. But before knowing about electroforming we should understand the term electroplating.[10]

Rapid prototyping technologies currently available include including Stereo lithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), Solid Ground Curing (SGC), and Ink Jet printing techniques.

2.2 Methodology of Rapid Prototyping

The procedural work of Rapid Prototyping can be understood as under:-

- Firstly, the CAD model is prepared using available CAD software packages such as Pro-Engineer, Creo-Parametric, Solid Works, CATIA, etc.
- Then, the CAD model is converted to Sliced Thin Layer (STL) format.

- The SLT format file is fed into the software interface of the prototyping machine.
- Afterwards the required scaling and orientation is set and the final commands are given.
- Machine software analyzes the model and converts the data into machine hardware language, determining the tool motion path.
- The tool then moves as according to the tool motion path, adding the material layer upon layer to produce actual physical model from the CAD data.[11]

2.3 WHY RAPID PROTOTYPING:

- Extend product lifetime by adding necessary features.
- Minimizes sustaining engineering changes.
- Decrease costly mistakes.
- Decrease development time.
- Additive manufacturing.
- Easy and approachable.

2.4 BENEFITS OF RAPID PROTOTYPING

- User friendly technology
- Easy to use and approachable
- Complex shapes can be made very easily

3 FUSED DEPOSITION MODELING

3.1 OVERVIEW:

FDM is generally used for 3D printing and additive manufacturing technology used for prototyping and modelling. It is additive manufacturing because it lays down material layer by layer. This process uses production grade thermoplastic material to produce both prototype and end-use parts. The thermoplastic material includes ABS, PC-ISO poly carbonate and Ultem-9085 for high temperature applications.[11]

3.2 WORKING OF FDM:

Firstly a CAD model of the desired component is made on Pro-e software and it was converted in to STL format for fabrication of the work piece via FDM in 3D printer. The Acrylonitrile Butadiene Styrene (non-conductive) plastic part is fabricated using 3D printer. The underlying technique used in 3D printer is additive manufacturing. 3D printer fabricates three dimensional work pieces from STL digital file, which is achieved by placing continual layers over the object till whole of it is shaped. When the desired object is fabricated by 3D printer then Supports are removed. The surface of the model is then finished and cleaned.[12]

Figure 6 Fabbster Kit 11-1(3D printer)

FDM technology 3D printers make the object in layer by layer form it uses additive manufacturing, in which material is added in layer by layer form. ABS is supplied to the extruder and extruder extruding thermoplastic filament and forms the desired object according to the CAD design.

FDM works in 3 steps :

1. Pre-processing- in this we supply CAD design to machine and machine calculates a path to extrude thermoplastic and any necessary support material.

2. Production: - 3D printer heats the ABS to a semi liquid state and deposits it in ultrafine beads along the extrusion path and makes the object in layer by layer form.

3: Post-processing – the user breaks away support materials and the part is ready to use.

.3.3 Advantages of FDM

- Quiet and works without noise
- Fast for small, thin shapes.
- Produces strong parts.
- Cost-effective.
- Able to produce multicolored parts using colored ABS.
- Intrinsic shapes can be made easy.
- The technology is clean, simple to use and office friendly.
- Supported production grade thermoplastic are mechanically and environmentally stable.
- Complex geometries and cavities become practical with FDM technology.
- Nontoxic and easy to use.
- User friendly, we can make CAD file in any designing software.
- Heating temperature is between 200 to 300^{o}C

3.4 Disadvantages of FDM

- Slow when making large cross-sectional areas

4 INTRODUCTION TO ABS

The most widely used plastic substrate for decorative electroplating throughout the world is ABS. ABS is the polymerization of Acrylonitrile, Butadiene, Styrene monomers chemically this thermoplastic family of plastics is called “terpolymers”, in which they involve the combination of 3 different monomers to form a single material that draws from the properties of all three. ABS, hard tough heat resistance engineering plastic that is widely used in appliances housing, pipe fittings and automotive interior parts. ABS is an acronym for the amorphous terpolymer Polyacrylonitrile-Polybutadiene- Polystyrene. The key to this polymer is the Butadiene molecule, 1, 3-Butadiene, which becomes polymerized and chemically bonded**.**

Figure 7 ABS Plastic Part

Acrylonitrile is colorless liquid characterized by strong order, its boiling point is 77.3 ^{o}C and its freezing point is approx. -83.55 ^{o}C. In general ABS plastic exhibits good durability and resilience, as well as mechanical strength in addition this thermoplastic polymers demonstrates a favorable combination of thermoelectrically and mechanical properties.[13]

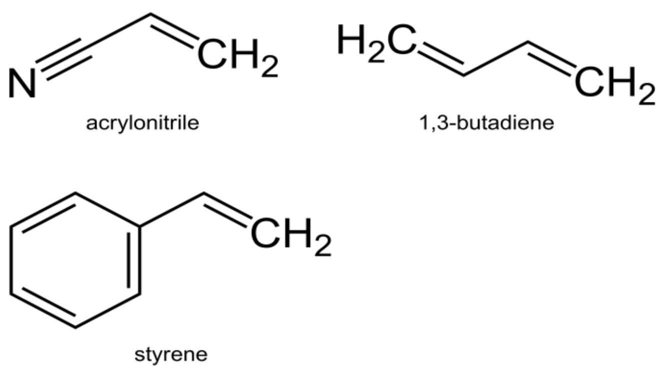

Figure 8 Chemical formula of ABS

4 LITERATURE REVIEW

The literature review deals with the summary of few selected papers which describes the work done by researchers related to Electroforming and combining with additive manufacture.

M.V Kulkarni et al [14] in this paper author explains the procedure of activation of Nylone6 by conductive paint method. They used Nylon6 material for copper electroplating. Nylon6 is difficult to plate because it is hygroscopic materials so conductive painting method has been adopted for electroplating them. Activation of plastic by paint method is used in this research paper. And it also explains the proper parameters for electroplating like chemical composition of bath, temperature and PH.

L.M Galantucci et al [15] done their research on improving the surface finish of FDM parts by performing chemical dipping based on immersion in di-methyl-ketone water solution. The results given by them are verified by testing an FDM produced marine turbine blade. They conclude that by this treatment flexural strength is improved and also surface finish is improved. With no loss of mechanical properties surface roughness is reduced and slso greater ductility is found.

Vidhata Mehta et al [16] this paper author explains the procedure of activation of ABS plastic by conductive paint method and by chemical method. He explains the comparision of both the methods and also explains the best parameters of activation.

Vipul Sharma et al [17] in this paper experimental investigations have been made to develop macro-model of silicon moulding process for fabrication of plastic components. Cad model was made in catia software and Taguchi technique L9 orthogonal arrays used for mathematical modelling.

Prasad K.D.V. et al [18] conducted their research on development of RT techniques for production of sheet metal drawing tooling by combining stereolithography with nickel electroforming process. Two types of prototype tools were manufactured by them first the stereolithography pattern using aluminium filled epoxy resin and the second is stereolithography technique with nickel electroforming process. They concluded that performance of tools manufactured by them was reasonably good in forming of 0.5 and 0.8 mm aluminium sheet. So, RP technology is much efficient in saving of time and cost.

Herandez [19] conducted several experiments to precisely improve the thickness uniformity of the electroforming process. The main disadvantage of the electroforming process is the non uniformity of the copper plating. To reduce this non-uniformity they introduce, a tool which consists of a software application for analysis and simulation of the electroforming process and a device for the orientation of the work piece model, which is programmed and controlled by the application. They also proposed some solution in order to solve the difficulty of uniformity of the copper deposition and they are: use of additives to improve the capability of the bath, utilizing a pulse current source with precise control over the output waveform and it can program the pulsating cycles and can reverse the polarity.

J.A. Mc Geough [20] describes us the various application of electroforming in traditional/macro and micro manufacturing, which includes tooling, mould making, fabrication of microelectromechanical system, micro optics and medicine. Electroforming can be used in wide range to produce thin foils of copper which can be used in production of printed circuit boards, for production of moulds and dies. Tools that require good surface finish and tight tolerance can be produced using electroforming. It can be used in polyurethane molding, injection molding, slush molding, rotational molding and compression molding.

Anoop Kumar Sood [21] had done his experimental work to improve the dimensional accuracy of fused deposition modeling produced part. He influences the interaction of various parameters viz., layer thickness, part orientation, angle, air gap and width on dimensional accuracy of parts produced. He concludes that shrinkage is the predominant factor. Shrinkage along length and width both are attributed to the development of internal stresses. Stress accumulation also increases with layer thickness.

Mohd. Hasbullah Idris [22] investigated ABS pattern produced from FDM for use as a pattern for investment casting process. They produced a solid and a hollow pattern using ABS. Their conclusion expressed that hollow pattern have better dimensional accuracy when compared to solid pattern. The surface quality of upper surface is much better than lower surface when compared. Hollow pattern shows no mould cracking at burning temperature. In general, ABS is found feasible to use as investment casting pattern material.

Pranjal Jaina, A. M. Kutheb aIndian [23] used Rapid Prototyping technique for making a prototype or pattern for casting a product. FDM is used as a rapid prototyping technique. They produced a disc using both investment casting technique and sand casting technique and both methods were compared. They concluded that when design pattern is very complicated it is feasible to use sand casting technique to make a new pattern which can be used for mass production. On the other hand, when one has to produce a new product only with his description, Investment casting by lost RP process comes into action.

Yasser A. Hosni et al [24] developed the process for customizing implants which helps in minimizing the bone removal. They integrate technologies of CT, Image processing, Stereolithography, FEA and investment casting in design and fabrication of an optimal fit between patient bone and implant component. They conclude that load distribution even more than standard design can be produced. It is expected that in future parts will be designed which can directly be used as implants by using RP technology.

Prasad K.D.V. Yarlagadda et al [25] conducted their work on producing EDM electrodes with the help of rapid prototyping and electroforming. Since tooling is very much important aspect from manufacturing point of view. Therefore, increase in complexity may lead to increase in cost and time also. So with the help of rapid prototyping and EDM process using silicon rubber casting and electroforming author described a new method of producing electrodes, which after backing with suitable material can be used as EDM electrodes. From results, it is concluded that copper electrodes show a good potential for EDM electrodes.

Rahmati Sadegh et al [26] in this author made a rapid wax injection tool of a gearbox shift fork was designed, simulated, and manufactured using rapid prototyping and rapid tooling technology.He used CAE simulation software. He compared the results with conventional wax model production methods. He also compared the time, cost, and other related characteristics, which resulted in saving of 50% in time and 60% in cost.

Wang Gui-xia et al [27] in this paper the processes of direct copper plating on ABS plastics were explained and investigated. In this paper author used many techniques (likes the atomic force microscopy, ultraviolet–visible absorption spectrometry (UV–vis) and X-ray fluorescence spectroscopy (XRF) techniques) for determining the direct copper plating on ABS plastics. He concluded that new etching process can give birth to some polar group which is essential for absorption more Pd from colloids solution**.** Even the particles in copper plating was uniform and good.

Munish Chhabra et al [28] in this paper author reviewed the industrial applications of state-of-the-art additive manufacturing (AM) techniques in metal casting technology. An extensive survey of concepts, techniques, approaches and suitability of various commercialised rapid casting (RC) solutions with traditional casting methods is presented.

Sivadasan M et al [29] this paper tells the study of investment casting with RP and it explored the applicability of FDM generated ABS pattern suitability for Investment casting . This work focused on thermal cracking tendency of IC shell. In this work pattern are modelled on rapid prototyping machine. During the ceramic shell preparation cracking is reported. The investigation indicates the possibility of 63% reduction in thermal expansion of the pattern, which is very encouraging**.**

Chua et al [30] explains the whole process of FDM from CAD model conversion to physical production of the prototype including formation and removal of supports. They explains the beginning of FDM as a software process in which the CAD model of prototype is converted to sliced thin layer(STL) format. They also explains the process of STL conversion as mathematical layering and orientation of the model for the purpose of building. About support structures, they tells that the support structures are generated within STL model and the machine dispenses multiple materials to achieve prototyping with support structures. They explains that the model is produced by extruding small beads of thermoplastic material to form layers as the material to form layers as as the materials hardens immediately after extrusion from the nozzle. About motion and feeding they explains that the plastic filament or metal wire is pushed into the extruder nozzle typically by a worm drive at a controlled rate and stepper motors/servo motors are deployed to relocate the extrusion head.

D.T Pham et al [31] in their work, gives the detailed information about the construction and the working principle of fused deposition Modelling Technique. Along with this, they explains the working conditions of FDM including the build material heating temperature and solidification and adhesion criterion. They also explains the motion control of the extruder nozzle as numerically controlled mechanism.

Pulak M.Pandey et al [32] this paper provides the brief overview idea of Rapid prototyping technology and this paper also gives brief idea about the different types of Rapid prototyping techniques with model building. Factors of consideration before part deposition in Rapid prototyping technology can be inferred from the paper.

Dong Ho Kang and Jin Chul Choi et al [33] this this paper author developed a new etching process for ABS Plastic by chemical forming which is an alternative to the di-chromic acid etching process. This new etching process is quite simple and more environments friendly. Even adhesion test was conducted by cross cutting method and results revealed good adhesion strength.

Yasser A. Hosni et al [34] developed the process for customizing implants which helps in minimizing the bone removal. They integrate technologies of CT, Image processing, Stereolithography, FEA and investment casting in design and fabrication of an optimal fit between patient bone and implant component. They conclude that load distribution even more than standard design can be produced. It is expected that in future parts will be designed which can directly be used as implants by using RP technology.

Jose M. Arenas et al [35] conducted their research on redesigning a method of construction by assembling parts with structural adhesives produced by FDM. It is because of the reason that FDM joints exhibits low level of surface finishing and low consistency. Also cantilever elements need large material structures to be supported. In their work, they proposed the use of cyanoacrylate, which values combined and mechanical benefits and adaption to FDM manufactured components. Since FDM provides components with a reasonable strength in plastic materials which are made by ABS and have low environmental impact.

C. Y. Hsu et al [36] investigates an effective method for manufacturing electrical discharge machining (EDM) electrodes using the rapid prototyping (RP) system based on electroless plating and electroforming. To shorten the electrode manufacturing process, decrease the manufacturing duration as well as the cost of electrodes this method was developed. Electroless plating was then performed to introduce electric conductivity onto the gypsum electrode surface, followed by copper electroforming of the thickness about 1 mm to obtain the EDM electrode. At the end they conclude that no cracks were found on the electrode and that the electrical discharge machining effects were very much promising. Also there were no remarkable damages observed in the micro view of the weave from an electrode after tests for die sinking electrical discharge.

Jian-Ming Yang et al [37] developed an experimental system to electroform the thin-walled revolving parts. They employed some measures to improve the uniformity of deposition distribution, such as conformal anode, cathode shield and high-frequency pulse current. The profile of the conformal anode is precisely designed by using the function of electric field analysis of ANSYS software, so as to reduce the experimental works and increase the application effect of conformal anode. The deposition thickness, alloy composition and micro hardness of the electroforms are measured to reveal the actual deposition distribution. By their research they conclude that deposition distribution depends, to a great extent, on the current density distribution. The current densities are larger at the protuberances of the cathode while smaller at recesses.

Frederic Gillot et al [38] they concluded from their research work to manufacturing electrodes by direct electroplating of copper on positive shape resulting from an RP process is extremely attractive, especially regarding the manufacturing time. However electrodes accuracy has proved to be badly damaged by non uniformity of the copper layer. Sharp angles showed serious covering anomalies. It necessary to take into account the dimensional accuracy of the part used to support the plate copper, as well as dimensional accuracy of the pre-metallization layer used if the support is non conductive.

Mario D. Monzon et al [39] proposed their work on electroforming to make cores for plastics injection molds. Shells are obtained from models manufactured through rapid prototyping using the FDM system. They analyze the mechanical features of electroformed nickel shells, studying different aspects related to their metallographic structure, hardness, internal stresses and possible failures, by relating these features to the parameters of production of the shells with electroforming equipment. After testing in different conditions they conclude the nickel sulfate bath, with the utilized additives has allowed obtaining nickel shells with some mechanical properties that are during application such as good reproducibility, high level of hardness and good mechanical resistance in terms of the resultant laminar structure.

Yang, Ming C. Leu et al [40] has integrated Solid freeform fabrication with electroforming for the generation of metal molds and EDM electrodes is presented in this paper. A part built by stereolithography is metalized by electroless plating and then placed in an electroplating solution where metal is deposited upon the part by electrolysis. After the desired thickness of metal has been reached, the part is removed from the metal shell by heating. The shell is then backed with other materials to form a mold cavity or an EDM electrode. It is concluded that electroforming thickness affects the mechanical properties and dimensional accuracy of the mold. Thermal deformations caused by burning out the SL masters and backfilling the electroformed metal shell with molten metal are identified as the major sources of inaccuracy.

D. King et al [41] proposed different materials for producing prototypes of very complex part geometry directly from three-dimensional CAD software such as polymer, wax, and paper without the benefit of specially designed tooling. The SLS process is used which fuses, or sinters, the powder to form the mould geometry, which is then filled with bronze to form a metal matrix. The tools are tested to confirm design accuracy for form, fit and functional testing, turnaround times, and for marketing evaluation. By the results it is concluded that modular tool inserts offer a fast low cost alternative to prototype aluminium mould tooling. The parts produced are very accurate and there is no finishing required and no mould cooling is required. The machining is also very faster compared to aluminium.

M. Monzon et al [42] did the research on validation electrical discharge machining electrodes made with rapid tooling technology finally they concluded from this research the electroformed electrodes can work with same parameters and conditions as a conventional electrodes except for the strong works intensity, a high VDI that is rarely uses in conventional electrodes for industrial applications. The roughness value achieved suggest that in general, electroformed electrodes produced cavities with a roughness lightly above that obtained with conventional electrodes. However they are industrially acceptable this allows them to be a new proposal for economic and rapid manufacturing. Also at low VDI values the electroformed electrodes are more efficient than the conventional ones because the quality of the surface is slightly better.

Zeng-Wei Zhu et al [43] done a research on electroforming of revolving parts with near-polished surface and uniform thickness, finally they concluded from this study, revolving thin wall part with complex profile was successfully produced by a new electroforming technology, in which isolating hard particles filed the space between the cathode and anode. During electroforming the particles were driven to do compound movements and polish the surface of cathode continuously. It was found that the polishing of the particles can significantly smoothen the deposit surface by removing the pits and nodules, level the micro-profiles of deposit by improving the mass transfer to the micro-depressions and inhibit the growth of micro-peaks.

Prasad K.D.V. Yarlagadda et al [44] conducted their work on producing EDM electrodes with the help of rapid prototyping and electroforming. Since tooling is very much important aspect from manufacturing point of view. Therefore, Increase in complexity may lead to increase in cost and time also. so with the help of rapid prototyping and EDM process using silicon rubber casting and electroforming author described a new method of producing electrodes, which after backing with suitable material can be used as EDM electrodes. From results, it is concluded that copper electrodes show a good potential for EDM electrodes.

Pei-Chi Yen et al [45] discussed a new method for improving the activation treatment before deposition of copper on ABS**. "**Etched ABS plastic was dipped directly into PdS04 solution instead of the usual sensitization followed by activation. Experimental results show that the Pd2+ ions from PdS04 solution are coordinated to the polar groups (i.e. -COOH, -S03H. t., etc.) on the surface of the etched ABS, resulting in the formation of ABS-Pd2+ complex. In an electroless copper bath containing a formaldehyde (HCHO) reducing agent, the ABS-Pd2+ complex is reduced to product Pd^0 atoms, which then act as catalysts and initiate the deposition of copper metal. Initially, the copper deposition rate was slow; however, it rose to that for conventional methods in about 10 min."

John Kechagias et al[46] conducted their research on producing a Electric discharge machining tool using Rapid tooling technology which uses Rapid prototyping models to reduce the time and cost of manufacture. They concluded from their work that to produce parts which are large in size can be better produced by laminated object manufacturing, accuracy of delicate parts with stereolithography and testing of the parts were done with fused deposition modeling. Also, for uniform deposition during copper electroforming the current value must be $10mA/cm^2$. By using this, an electroplated copper shell of 0.6 mm can be achieved in near about 24 hr, which is capable of eroding a 6 mm deep cavity.

Allan E.W.Rennie et al [47] have conducted their initial work by using stereolithography models deposition of copper shells. They applied current density of near about 20mA/cm2. Shell thickness of range between 0.6 and 3.0 mm were produced. In their experiment, they have reported that some areas achieve a greater thickness and some areas achieve lower thickness. It was also concluded that separation of erosion faces is also occurring from side walls. After removal of electroform machining was conducted using EDM machine. During machining, 50 mm3/min of MRR was achieved at initial stage and 5mm3/min was achieved at final stage.

Qian Ma et al [48] in this paper author developed a substitute for conventional chromic acid etching solutions. He developed an environmentally friendly etching system containing MnO2–H3PO4–H2SO4 colloid was used to check the surface etching for PC/ABS as a substitute for conventional chromic acid etching solutions. In order to obtain a good etching performance, a swelling system, containing tetramethylammonium hydroxide (TMAH), and 1-Methyl-2-pyrrolidinone (NMP), was used to investigate the surface swelling for PC/ABS resin. Then the effects of H_2SO_4 concentration, and etching time on the surface topographies and surface contact angle were investigated.

Zengnian Shu et al [49] in this paper author developed an environment-friendly Pd free surface activation techniques for acrylo nitrile–butadiene–styrene (ABS) surface. This technique is a replacement for conventional chromic acid etching bath and palladium catalyst. The effects of CuSO4 concentration, (CH3)2NHBH3 conc., reduction temperature and reduction time on the adhesion strength between the ABS surface and the electroless copper film were investigated. And the average adhesion strengths reached 1.31 kN m−1, which is near the values (1.19 kN m−1) obtained by SnCl2/PdCl2 colloid.

Harpinder Singh Sandhu et al [50], in this paper author tells the new way to machine super alloy like INCONEL 718, which is very important for making vessels of Cryogenic fluids etc. In this research work experimental investigations have been made to find the machining characteristics of high density ultra fine graphite and Inconel 718 superalloy.

5 SCOPE OF THE STUDY

Electroforming is one of the most promising techniques in the field of manufacturing which can used to manufacture electrodes, tools, dies, molds and patterns. The deposition in the process of electroforming depends on various parameters. In industrial arena these parameters are set by the technician based on his experience. As in our study we are varying three parameters PH, Temperature and current according to a particular manner we are providing 4 hours time for plating a part and optimizing the various effects on thickness and surface finish of component. So, various parameters can be set according to various manners and a particular set of data can be established to achieve a particular thickness and a better surface finish.

The research in this area combines the rapid prototyping technique using FDM process and then to perform electroforming process on ABS component. The possibility of making it an viable production process & is still in its early phase.

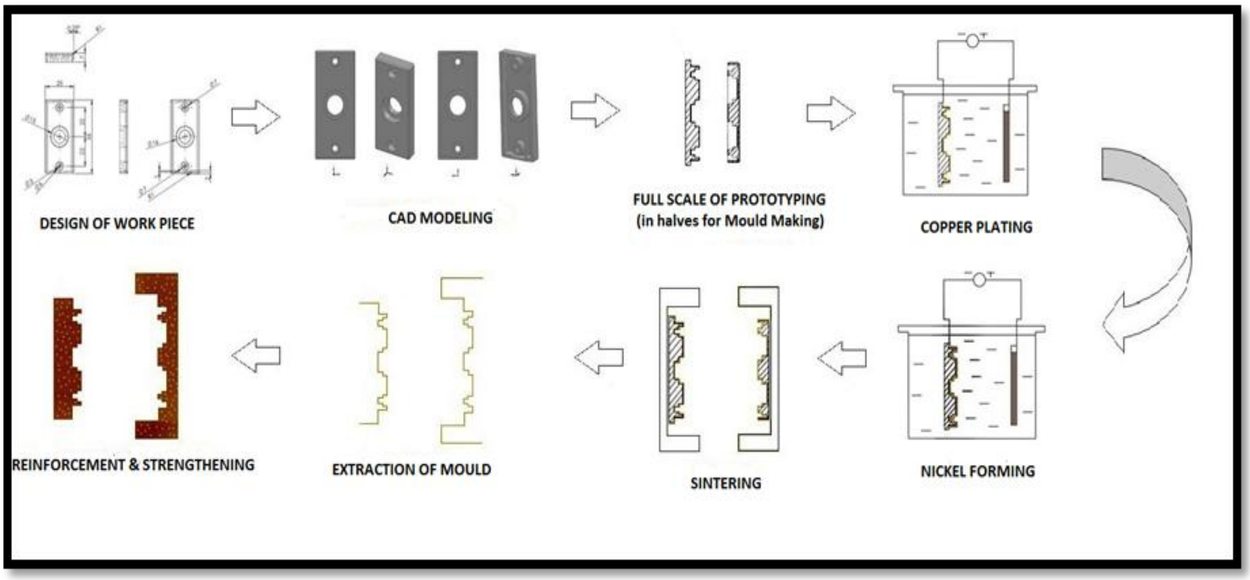

Figure 9 Objective of Thesis

6 HYPOTHESIS OF THE STUDY

6.1 Problem Formulation

Manufacturing of electrodes, molds, cores and pattern may be difficult by using various conventional machining methods which includes machining, pressing, welding etc. which also requires a lot of time and also experience. Electroforming process along with rapid prototyping offers a good alternative method for manufacturing similar kind of tool in a short period of time. The parameters that are mainly affecting thickness and surface finish are voltage, concentration and time. This work aims at the optimization of various process parameters of electroforming process for different variables and establishing a relation between them.

6.2 Objective of the study

To establish the complete setup for electroforming process and going to study the various parameters (PH, Temperature and current) affecting the rate of deposition on the ABS specimen produced by FDM. The main objective is to achieve desired thickness and optimization of process.

The procedure to be followed is as follows:

- Experimental set-up to perform electro-deposition process on ABS specimen
- To achieve desired thickness with better surface finish.
- Optimization of various results achieved by using ANOVA technique and Validation of process

6.3 Parameter Selection

For this experimental work, three parameters are chosen as they can be monitored easily:

1) PH (3 to 4.5)
2) Temperature (in range of 45 to 58 ^{o}C)
3) Current (2.5 to 3.5 amp)

Various levels of the above three input machining parameters were taken and further L9 orthogonal array of Taguchi experimental design was chosen to conduct the experiments.

1. PH: ph)
    a. 3.0 pH L1
    b. 3.5 ph L2
    c. 4.0 ph L3
2. Temperature (^{o}C)
    a. 45 ^{o}C L1
    b. 50 ^{o}C L2
    c. 55 ^{o}C L3
3. Current : (Amp)
    a. 2.5 amp L1
    b. 3.0 amp L2
    c. 3.5 amp L3

6.4 Response parameters

Out parameters are:

1) Thickness
2) Surface Roughnes

7 METHODOLOGY

In this section a brief description of the Electroforming set-up used to perform the experiments, material (copper anodes) and the workpiece (ABS) used in this work are given. A brief description used in the calculation of output responses has also been covered in this section. The experimental procedure to be undertaken during the research study to validate above hypothesis is as follows:-

PHASE-I

- Preparation of CAD model of pattern and conversion to STL(Sliced Thin Layer) format.
- Printing of full scaled solid model in three dimensional coordinated using Fused Deposition Modeling.
- Removal of dust and dirt (Surface treatment of ABS pattern)

PHASE- II

- Activation of sample by Silver conductive Paint of SUGANDHA CORPORATION.
- Electroplating of Copper on the ABS pattern, so that nickel forming can be done.

PHASE-III

- Electroforming of Nickel on the ABS pattern.
- Sintering of the nickel formed sample.
- Extraction of Mould.
- Reinforcement and strengthening by epoxy filling.
- Interference evaluation of thickness and roughness.
- Evaluation and Optimization of Process.

7.1 ELECTROFORMING SET UP

The electroforming set up includes a tank in which solution for the electroforming process is prepared and a rectifier which provides DC supply for the process. The material used for manufacturing the tank is stainless steel. The experimental set up is as shown in the figure.

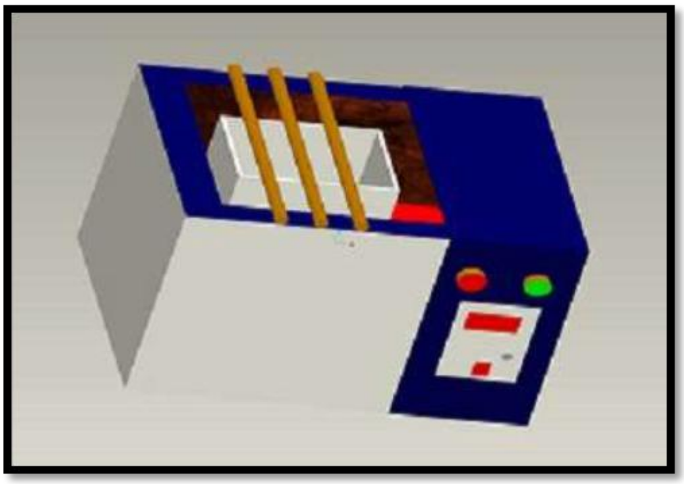

Figure 10 Nickel Electroforming Tank

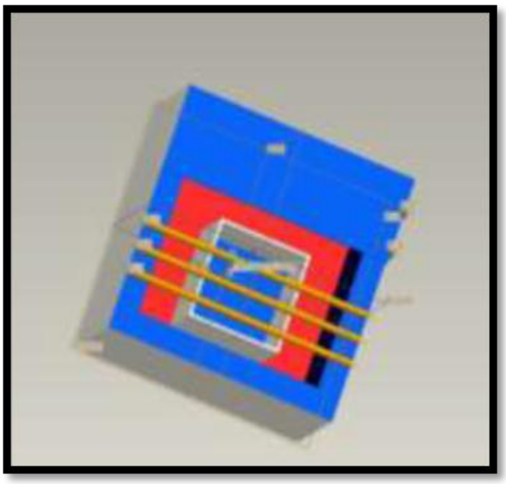

Figure 11 Nickel Electroforming Tank Inner View

For the experiment design is made in PRO-E model of tank and Take 5 stainless steel plates of dimensions 30*30 inches and thickness 3.5 mm and done welding on the corners to join it. Tank made of stainless steel is used to avoid rusting due to chemicals. A motor was used to stirrer hot water in outer tank to circulate water for the regulation of temperature in water bath. Heater is also attached in outer tank for heating of water bath. For Nickel electroforming a similar model of inner tank of Teflon glass with dimensions 12*12 inches and thickness 8 mm is made. Teflon glass is joined with adhesive silicon gum. To regulate solution in inside glass tank. Aquarium pump is used to regulate ions in electrolyte solution. Installation of digital pH meter to maintain the pH of an electrolytic solution at constant. Rectifier is attached externally to electrodes for the constant DC current supply. P type (PT-100 meter) thermostat is attached for senescing the temperature with RTD auto cut to maintain water bath.

The machine is provided with an air agitation system for proper flow of electrons. Filtration process is done manually so that no dust or any other impurities can affect the deposition rate. The bath or the solution for electroforming process is prepared using triple ionized water. Rectifier used has a voltage range of 0-5 V and current range of 0-5 Amp, Titanium coated grills are used for hanging purpose of Nickel electrodes each weighing 500 g and copper rods are fitted at top of tank to hang component to provide better conductivity to electroformed parts and the electrodes.

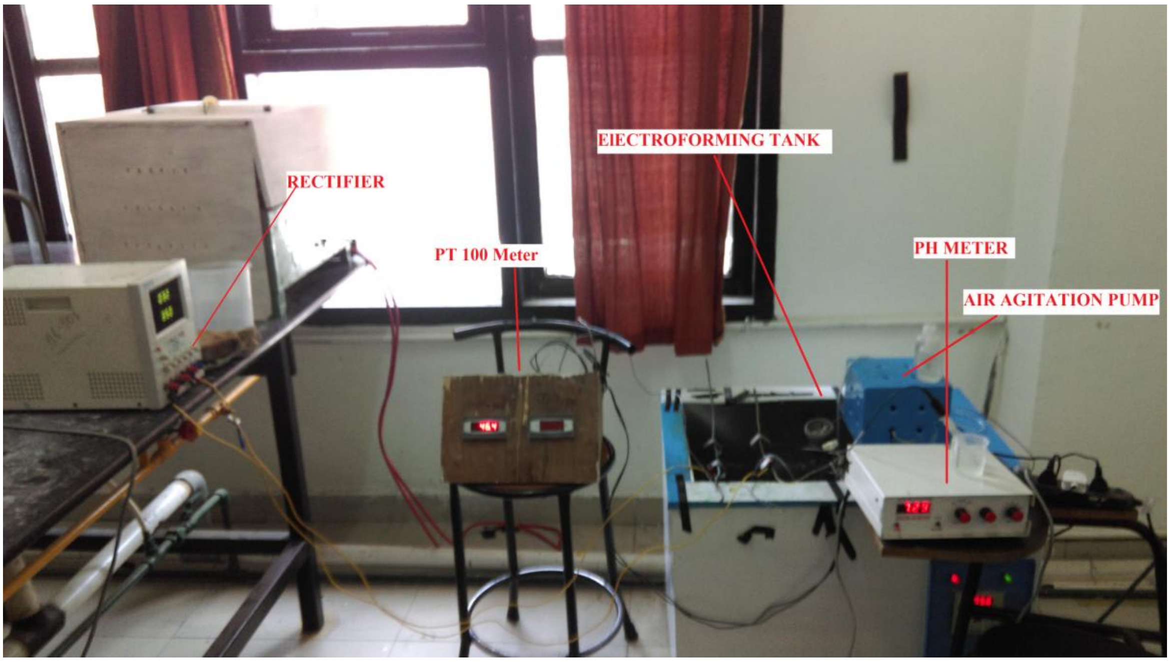

Figure 12 Experimental set-up used for electroforming process

Epoxy for Strengthening of Mould

Epoxy resin is a thermo set plastic reinforced with composite material, it is characterized by certain mechanical properties such as strength, stiffness and hardness. In this experiment, epoxy used is BASF Master Brace SAT 4500 formally known as saturant. Epoxy comes into two parts that is base and hardener. This is epoxy is used in this experiments because it has high strength, high viscosity and it can be cured at room temperature. As per BASF datasheet or catalogue ratio for hardener and base is 100:40 by weight and it should be stirred at 600 rpm for its proper mixing. Before pouring into the mould a whole time of 5 min should be given to avoid bubble interrupts

7.2 Work piece configuration

For the present work, work piece manufactured using FDM as rapid prototyping technique. The various parameters of workpiece are:

Volume = 4287.38 mm^3 ; Mass = 2.0 gm

Surface area = 5290.06 mm^2

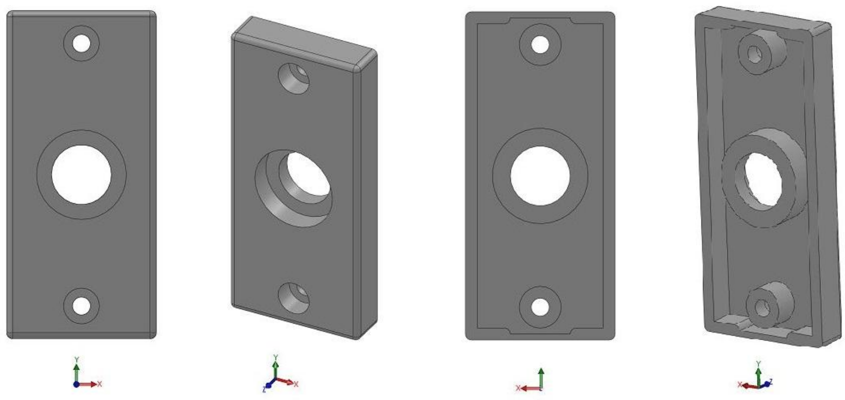

Figure 13 Model used for Electroforming process

7.3 Taguchi design experiments in MINITAB

Design of experiments is the series of tests in which purposeful changes are made to the input variables of a process so that we may observe and identify corresponding change in the output response. In the present work, 3 factors each at 3 different levels are selected for the experimentation. The 3 factors and its levels are tabulated as below:

Table 1 Factors and Levels finalized for the experimentation

	Level 1	Level 2	Level 3
PH (ph)	3.0	3.5	4.0
Temperature (^oC)	45	50	55
Current (amp)	2.5	3.0	3.5

MINITAB [17] provides solution for static and dynamic problems. MINITAB determines o/p tables and plot main effects. The experiments are framed according to the L9 orthogonal array. The Taguchi method is applied in four steps as follows

- Brainstorming the excellence character and design parameters that are significant to the process.
- We have to design and conduct the experiments.
- Then analyze the results to determine the optimum conditions.
- After doing all above steps run a confirmatory test using the optimum conditions.

The Taguchi's L9 orthogonal array with 3 factors and 3 levels selected is as shown in the table.

Table 2 Design of Experiments using Taguchis L9 orthogonal array

Expt. No.	PH	TEMP	CURRENT
1	3	45	2.5
2	3	50	3.0
3	3	55	3.5
4	3.5	45	3.0
5	3.5	50	3.5
6	3.5	55	2.5
7	4.0	45	3.5
8	4.0	50	2.5
9	4.0	55	3.0

7.3.1 Taguchi experimental design and analysis

Taguchi method simplifies and standardizes the fractional design by introducing orthogonal array (OA) for constructing or laying out the design of experiments. It also suggests a standard method for the analysis of results. These OA are generalized Graeco- Latin squares. Any two columns of an OA make a 2-factor complete factorial design. Therefore whatever is happening to all the other parameters at one level of parameter being studied is also happening in the same way at other levels being studied. The effect of one parameter under study is separable from the effect of other parameters. Thus the combination and optimum level of each factor can be determined. The second feature is that OA experiments minimize the number of experiments. A factorial experiment with 3 parameters each at three levels would require (3^3=27) test runs whereas Taguchi L9 OA would require only 9 trial runs for providing same information. In the

Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives:

1. To establish the best or the optimum condition for a product and/or process.
2. To estimate the contribution of individual variables and their interactions.
3. To estimate the response under optimum conditions.

The optimum conditions are identified by studying the main effect of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of the contribution of individual parameter plays an important role in deciding the nature of control to be established on a production process.

7.3.2 ANOVA (Analysis of Variance)

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate, tool wear and surface roughness. Based on the ANOVA the relative importance of the machining parameters with respect to Tool Wear Rate, Surface Roughness and Radial Overcut is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. Within treatment variability.
2. Observation to observation variability.

So ANOVA helps us to compare variability within experimental data. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the mean squared error of Y about its target T. The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance due to the use of Fisher's F-distribution as part of the test of statistical significance.

The advantages of design experiments are given below:-

1. Identification of important decision variables, which control and improve the performance of the product or the process.
2. Number of trials is significantly reduced.
3. Optimal settings of the parameter can be found out.
4. Inference regarding the effect of process parameters on the performance characteristics can be made.

7.4 Operational Procedure of Electroforming process

Specimen or Sample piece that is to be electroformed has to go through a variety of different processes which includes surface preparation so that metal can adhere. The main purpose of surface pre-treatment is to remove the dust and films from substrate surface. [51]

- Cleaning- The methods of should be so appropriate that all contaminants, dust should remove properly and no surface damage should occur. Here we are using zinc plate 452 cleaner to remove all the surface contaminants. Temperature should be maintained at 60-65·C during the process and time consumption will be about 5-10 minutes.
- Water Rinsing- After cleaning the surface, water rinse is necessary so that no chemical should adhere to the surface of specimen.
- The third step is to dip the specimen in sulphuric acid solution at room temperature.
- Water rinsing
- The next step is conditioning. Solution of chromic acid + sulphuric acid should have to be prepared and specimen should have to be dipped for about 30minutes. Temperature requirement is 60-65·C during the process.
- Apply silver conductive paint.

Now, At this stage our specimen becomes conductive and it is ready for copper deposition.

- Now, we will do acid copper plating by preparing a solution of copper sulfate + sulphuric acid. The process will have to be done at room temperature. A schematic flow of typical electroforming process is as follow

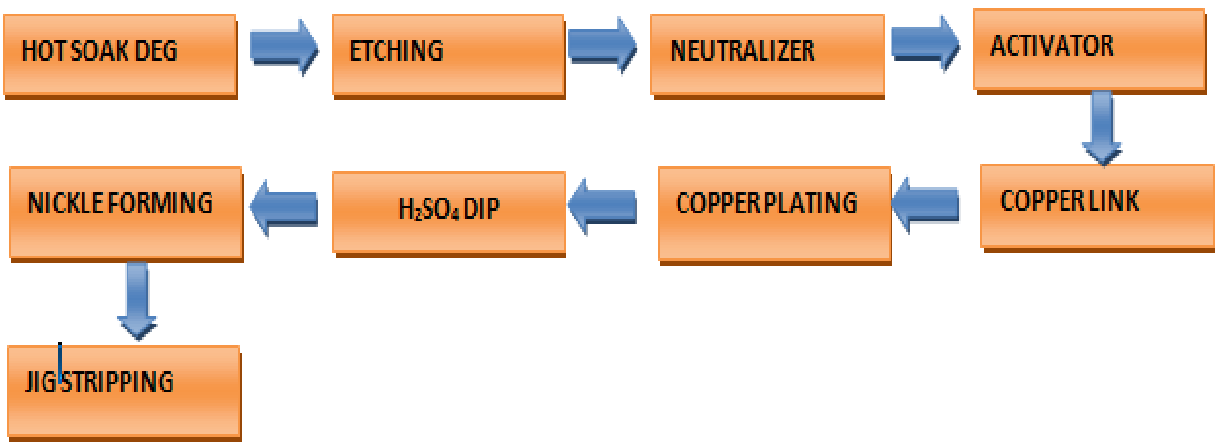

Figure 14 Flow Diagram of Electroforming process

Various parameters to be maintained during process are described below (note that before every step, water rinsing is necessary):

Table 3 Parameters during Electroforming process

S.NO	PROCESSES	CHEMICALS	TEMP (˙C)	TIME(MIN)
1	Cleaning	Zinc plate 452	60-65	5-10
2	Dipping	Sulphuric acid		1-2
3	Conditioning	Chromic acid + Sulphuric acid	60-65	30
4	Acivation	Using silver conductive paint	----	3 layers
4	Acid copper plating	Copper sulfate + Sulphuric acid	Room temp	20-25
5	Chromic Acid Bath	Chromic acid (10ml in 100ml)	Room temp	2
6	Nickle Forming	Nickle Sulphamate+Nickle chloride+ Boric Acid	45-60	________

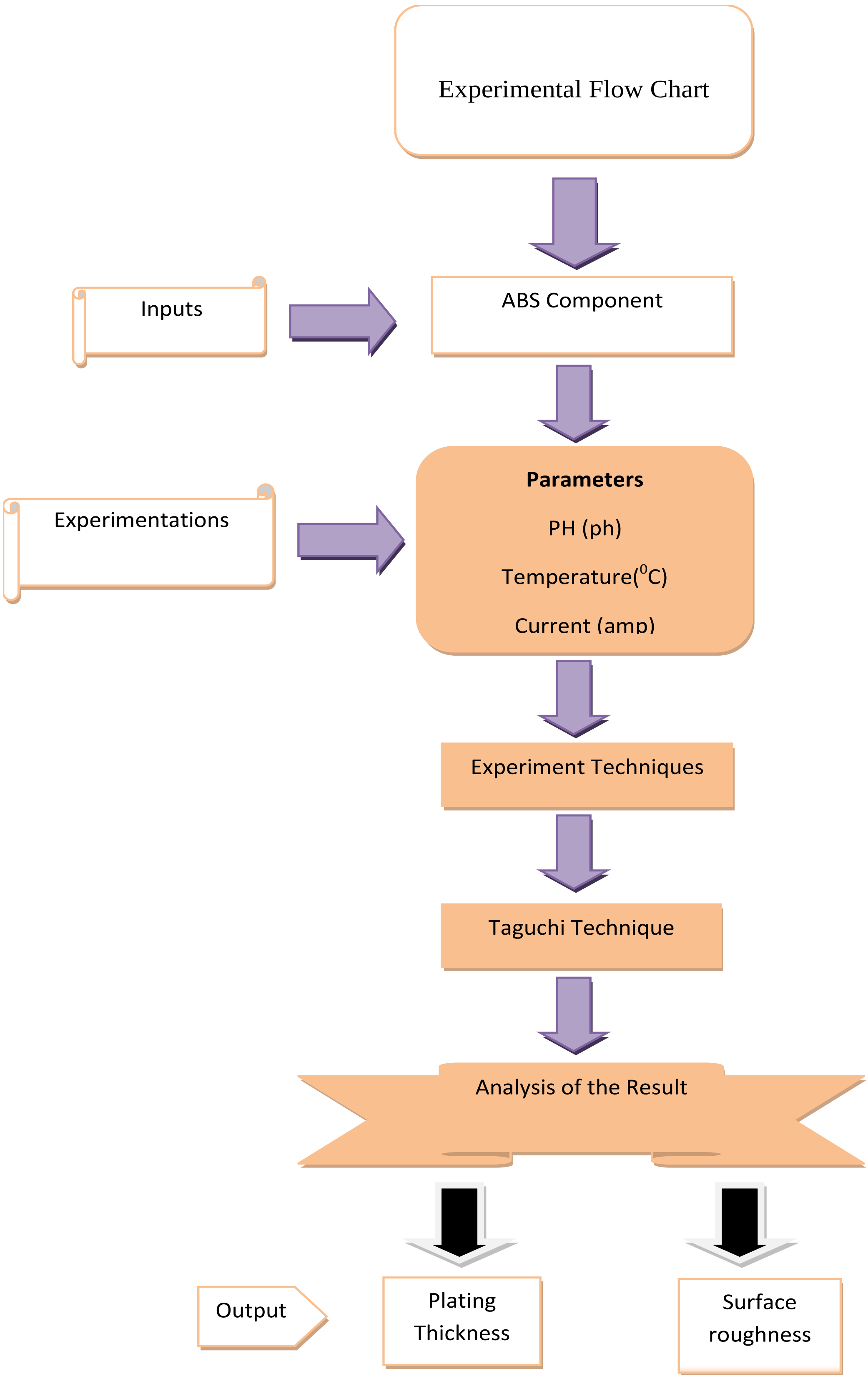

Figure 15 Flow chart of Methodology

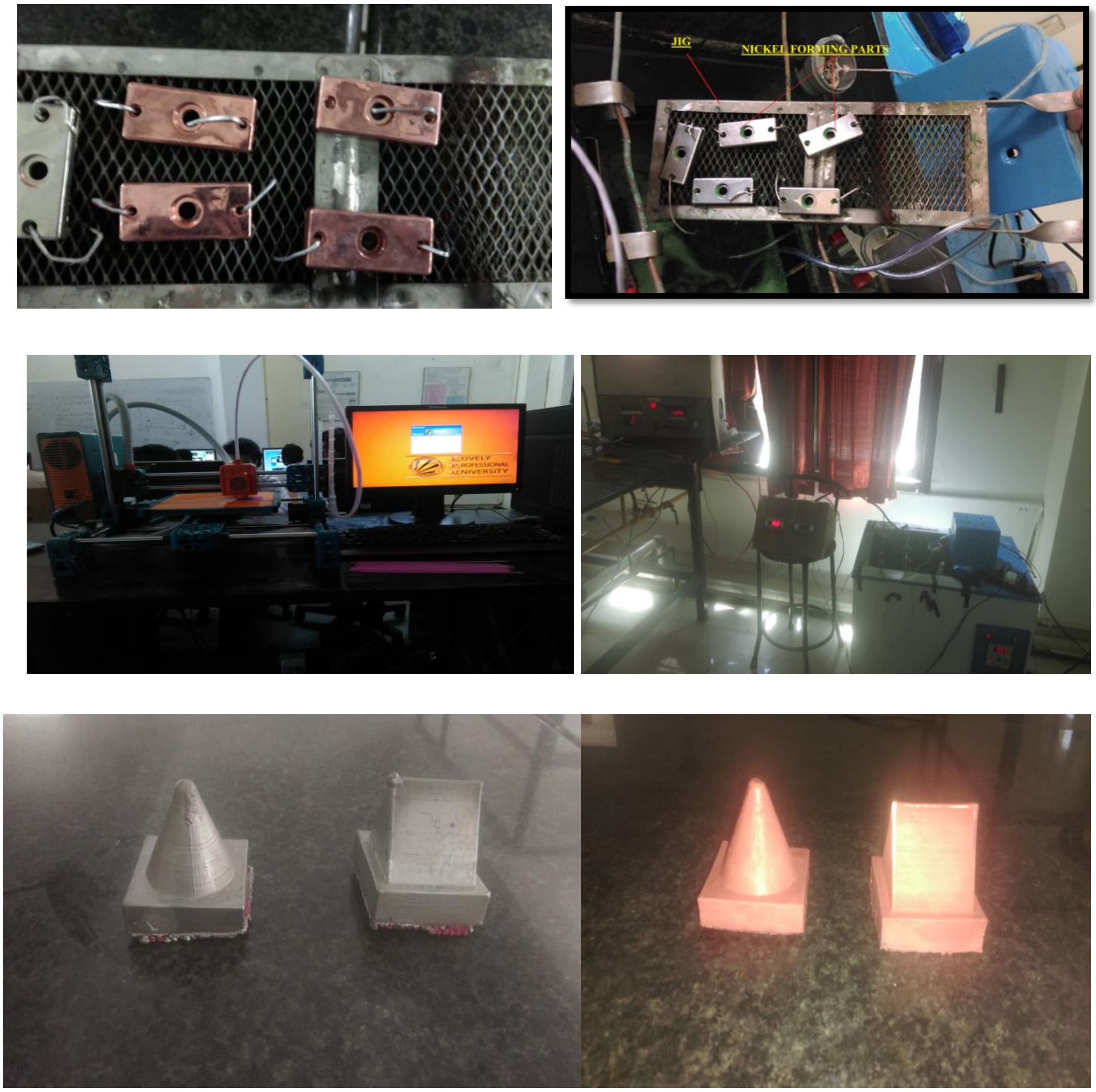

Figure 16 Pictures during electroforming process

7.5 Evaluation of Thickness

The thickness can be calculate by plating thickness test (PLT Test). PLT thickness test was used to measure the approximate thickness. For various experimental results.

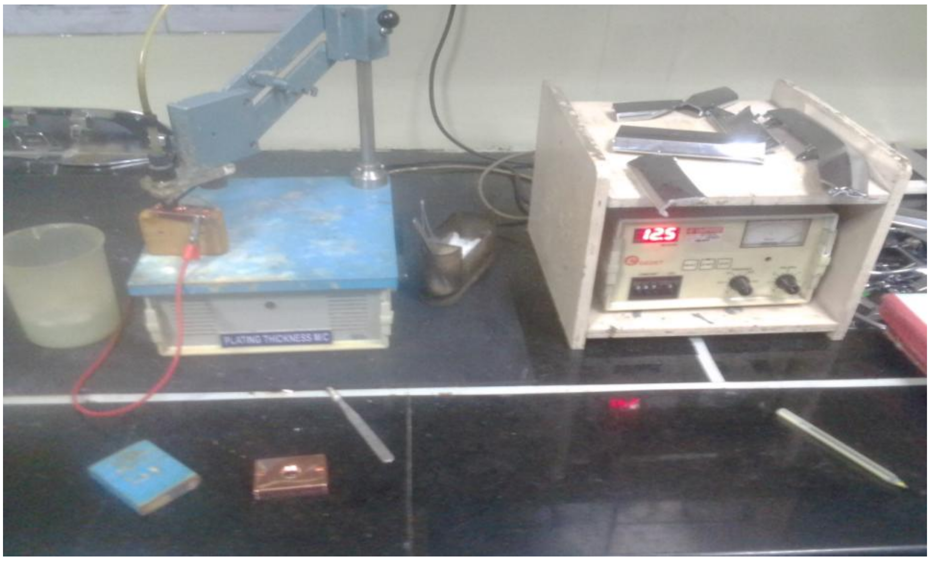

Figure 17 Plating thickness Meter

7.6 Evaluation of Surface roughness

Surface roughness is very important parameter in evaluating quality and accuracy of the product. It was measured using the surface roughness testing machine, model MITUTOYO SJ-201P. This equipment uses the stylus method of measurement; it has the profile resolution of 12 nm and measure the roughness up to 100µm. It uses tracing length of 4.0mm for analysis.

Figure 18 Measurement of Surface Roughness using Talysurf

7.7 Evaluation of Rust

Environment test was designed to check the rusting of sample. In this test temperature was decided to vary from -25^{o}C to 80^{o}C. In this test specimen was kept for 3 hours at room temperature then it was kept at -25 ^{o}C for next 3 hours. Then it was kept at 80 ^{o}C for next 3hours. Like this 2 cycles will conduct in 24 hours. Rust was observed on the sample. Temperature was maintained in this in ENVIRONMENT TEST MACHINE shown in fig.19. In this machine we can set the temperature according to our requirement. Varying of the temperature is done from -25^{O}C to 80^{o}C, to check the feasibility of rust in nickel electroformed Sample.

Figure 19 ENVIRONMENT TEST MACHINE

8 RESULTS AND DISCUSSIONS

In this chapter effect of individual process parameters on the selected response/quality characteristics has been discussed. The standard procedure suggested by Taguchi is employed. The mean or the average values and interaction plot of the response/quality characteristics for each parameter at different levels have been calculated from experimental data. ANOVA of the experimental data has been done to calculate the contribution of each factor in each response and to check the significance of the model. The most favorable conditions (optimal settings) of process parameters in terms of mean response of characteristic have been established by analyzing response curves.

The main effects indicate the general trends of influence of each parameter. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control. Results are divided into three sections on the basis of the three measured output responses.

- Thickness
- Surface Roughness

Figure 20 Nickel Electroformed Samples

8.1 Thickness: In this section the effect of process parameters that are current, ph and temperature on thickness has been discussed and the experimental results are tabulated below.

Table 4 Results for thickness on ABS after Electroforming Process

Ex. No .	PH(ph)	TEMPERATURE(°C)	CURRENT (amp)	CURRENT DENSITY(amp/cm^2)	Weight theoratical	ACTUAL WEIGHT	Efficiency	THICKNESS (microns)
1	3.0	45	2.5	0.04795	10.947	8.12	74%	58.750
2	3.0	50	3.0	0.01438	13.368	11.54	86.70%	63.280
3	3.0	55	3.5	0.01678	15.326	12.41	80.90%	69.170
4	3.5	45	3.0	0.01438	13.368	11.28	84%	72.180
+	3.5	50	3.5	0.01678	15.127	12.47	93%	78.250
6	3.5	55	2.5	0.04795	10.947	9.127	83.30%	69.920
7	4.0	45	3.5	0.01678	15.326	12.65	82.53%	83.250
8	4.0	50	2.5	0.04795	10.947	8.62	78.74%	79.280
9	4.0	55	3.0	0.01438	13.368	12.02	89.90%	81.175

Faraday's law indicates that the weight of the metal deposited in an electrolytic process is proportional to the current, plating time and its chemical equivalent.[52]

Thus:

$$\mathbf{W = Ite}$$

where W = weight (in grams) of metal deposited,

I = current (A),

t = time in (secs) and

e = chemical equivalent.

The product of current and time (It), is the quantity of electricity passed. For a given coulomb, the weight of an element discharged is proportional to its chemical equivalent. One Faraday (F) deposits a gram-equivalent of an element of atomic weight, A. F = Faraday (an electricity to deposit 1 gram equivalent of metal = 96500 Coulomb or 26.8 ampere – hour), C = Coulomb, n = valence of the element, A= atomic weight. Thus:

$$\mathbf{W = ItA/nF} \qquad \mathbf{(1)}$$

We also know the deposition thickness, D (cm), can be solved by:

$$\mathbf{D = W/\ d.Sa} \qquad \mathbf{(2)}$$

where 'd' is the density of the metal (g/cm3) and 'Sa' is the area of deposition (cm2).

Using equation (1) and (2), we have:

$$\mathbf{D = ItA/n.f\ .d.Sa} \qquad \mathbf{(3)}$$

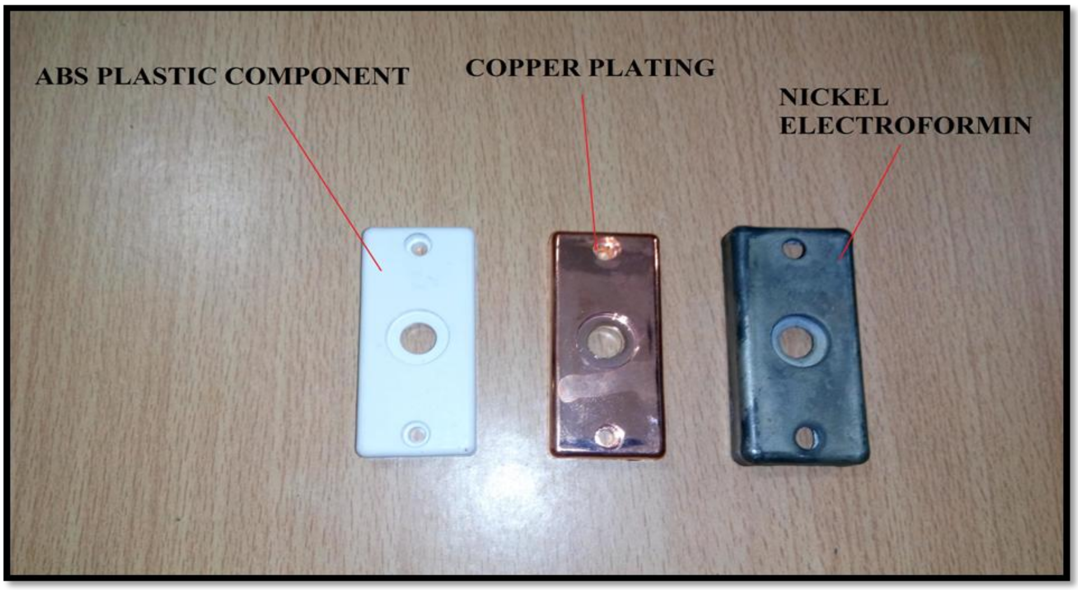

Figure 21 Deposition after electroforming on ABS surface

In this experiment I got Highest theoretical weight 15.326g at 4.0 PH when the temperature was 45 ^{o}C and current was 3.5 amp and I also got max actual weight at same parameter 12.658 g.And cu

Current efficiency = WAct=W_{ACT}/W_{theo} **4**

Current efficiency depicts the experimental results satisfies theoretical results.

By using the MINITAB software the main effects and the interaction effects of the means are evaluated and the results are represented graphically as follows:

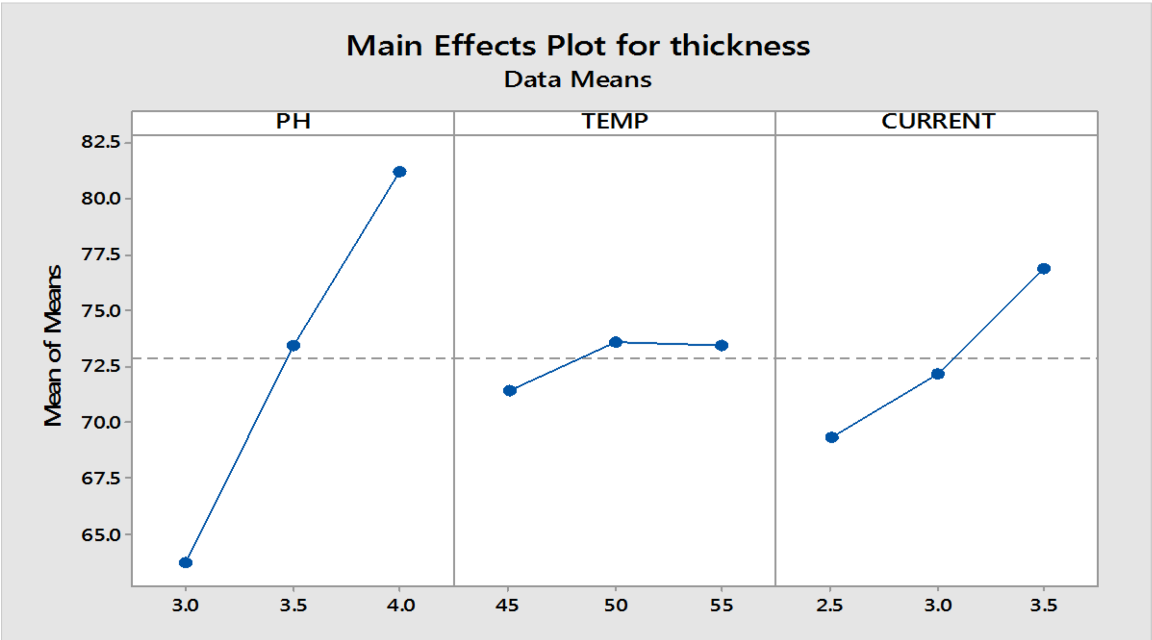

Figure 22 Main Effect Plot for Thickness of ABS Component

It was observed that when the PH was 3.0 the thickness was less and with the increase of PH value of thickness also increased .From the main effects plot it is interpreted that the thickness is increasing as the pH increases, with increase in current, whereas temperature plays a minor role in thickness, firstly it increase and then become constant as predicted by mean graph.. According to response table first rank parameter is pH and it is affecting the experiment most followed by current and temperature. Response table for mean for thickness is mentioned below.

Table 5 Respone Table for Means for Thickness

Level	pH	Temperature	Current
1	63.73	71.39	69.32
2	73.45	73.60	72.21
3	81.23	73.42	76.89
Delta	17.50	2.21	7.57
Rank	1	3	2

According to response table first rank parameter is PH and it is affecting the experiment most followed by current and temperature.

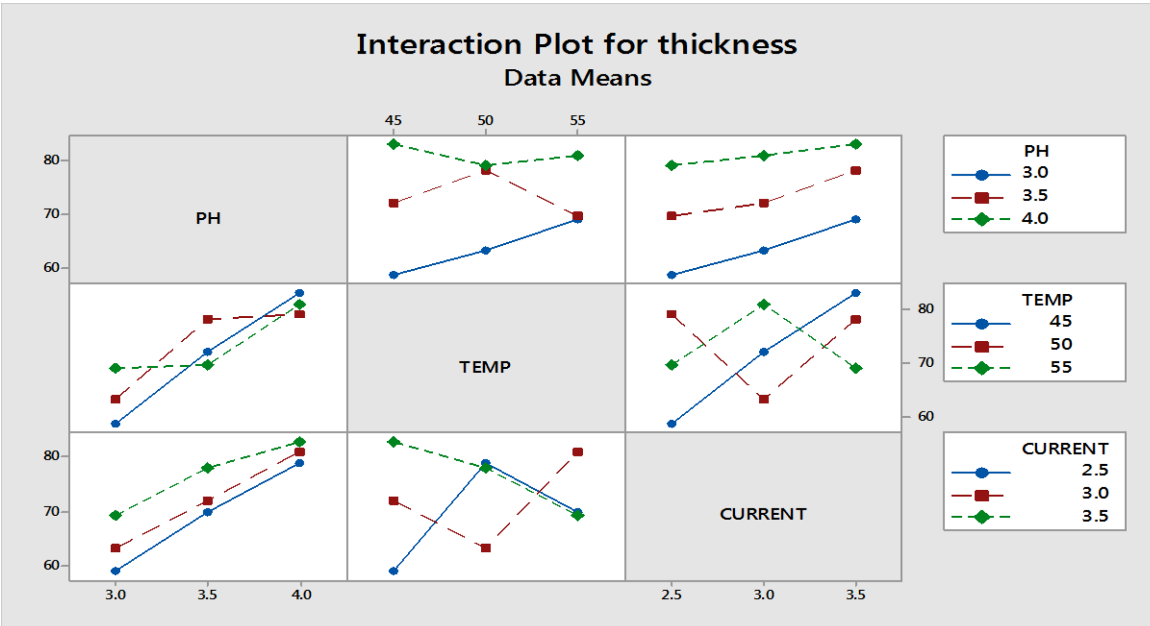

Figure 23Interaction effect plot for thickness of ABS component.

Firstly draw the optimized parameters for all the input variables with respect to other variables which give the more detailed information. From the interaction plot of means of thickness it can be interpreted that there is a significant interaction between all the factors as there are very few parallel lines in the entire interaction plot. This implies that one factor is dependent upon another factor. The experimental data is analyzed by ANOVA at 95% confidence level and the contribution of each factor to the output response has been determined and the results are as shown below:

Table 6 Analysis of varience for thickness, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	F	P
PH	2	461.328	461.328	156.83	0.006
TEMP	2	9.031	9.031	3.07	0.246
CURRENT	2	87.623	87.623	29.79	0.032
RESIDUAL ERROR	2	2.942	2.942		
TOTAL	8	560.924			

S = 0.1924   R-Sq = 99.1%   R-Sq(adj) = 96.5%
DF-degrees of freedom, SS-sum of squares, MS-mean squares (Variance) F-ratio of variance of a source to variance of error, P < 0.05 determines significance of a factor at 95% confidence level

The variation data for each factor and their interactions were F-tested to find significance of each. The principle of the F-test is that the larger the F values for a particular parameter the greater the effect on the performance characteristic due to the change in that process parameter. From table 6 it is clearly seen that Thickness is mostly affected by PH and current.. The parameter R-sq (amount of variation) = 99.1%, R-Sq (adj) = 96.5%, and the standard deviation of error in the modeling S= 0.1924 and by comparing the value it can be concluded that which effect is significant and which is not. The Residual plot implies us about the variation with respect to each contributing factor. It should me minimum enough or should close to mean line of graph, which implies that there is least variation in our experimental work with the input parameters which are PH, temperature and current

The maximum thickness is observed at the 4.0 Ph when current was 3.5 amp and temperature was 45^0C. By increasing the current thickness increases rapidly but excess current also cause burring as shown in fig below.

Figure 24 Burning of samples due to High Current

In order to effectively study the effect of the each parameter with respect to other parameters the interaction effects has been plotted and is as follows:

The Residual plot implies about the variation with respect to each contributing factor. It should be minimum enough or should close to mean line of graph, which implies that there is least variation in our experimental work with the input parameters which are pH, Temperature and Current. The residual plot for thickness of ABS component is as follows:

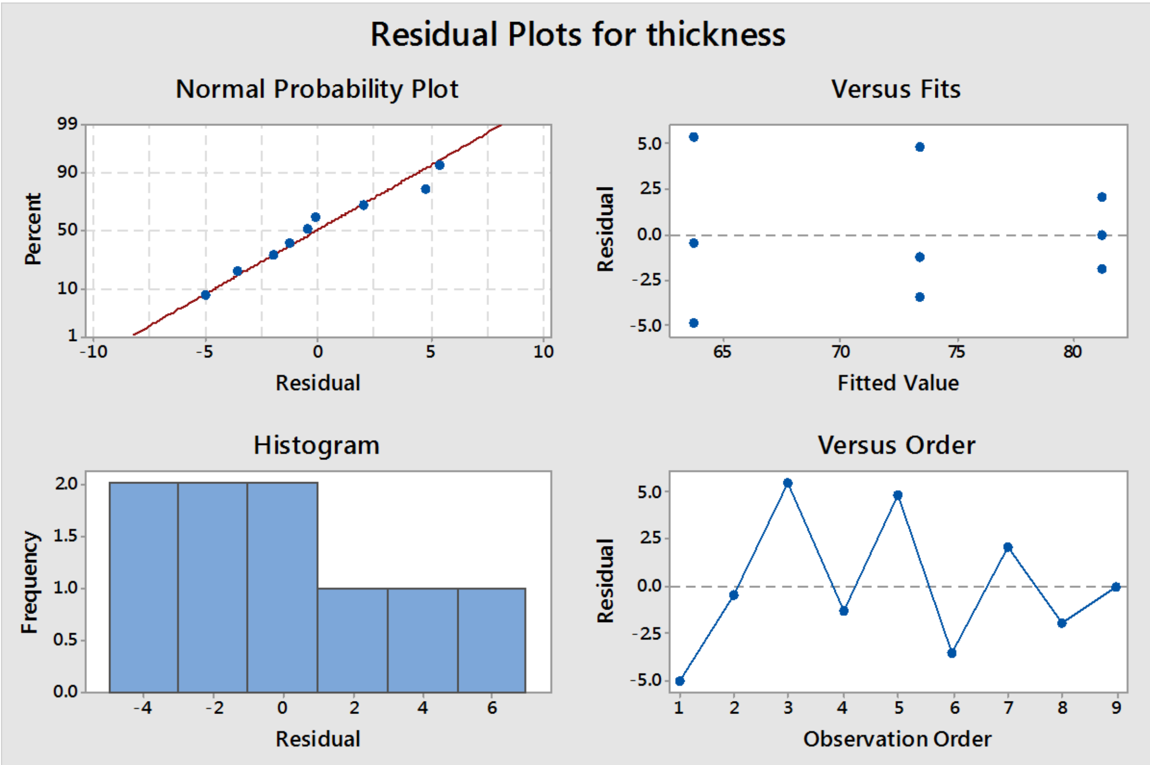

Figure 25 Residual plots for thickness of ABS component

8.2 Surface roughness:

In this section effect of various parameters that are voltage, concentration and time on surface roughness has been discussed. The surface roughness of electroformed component is measured using the Talysurf with least count 0.01µm. The surface roughness of the electroformed component is evaluated and the experimental values are tabulated.

Table 7 Results for surface roughness of ABS component

Expt. No.	PH(ph)	TEMPERATURE(°C)	CURRENT(amp)	ROUGHNESS (µm)
1	3.0	45	2.5	0.71
2	3.0	50	3.0	0.67
3	3.0	55	3.5	0.74
4	3.5	45	3.0	0.52
5	3.5	50	3.5	0.36
6	3.5	55	2.5	0.43
7	4.0	45	3.5	0.21
8	4.0	50	2.5	0.29
9	4.0	55	3.0	0.31

The surface roughness showed a small difference from almost 0.21 µm to 0.71 µm. So the effects of the input parameters are to be analyzed and main effect plot for the surface roughness of electroformed ABS component is as follows:

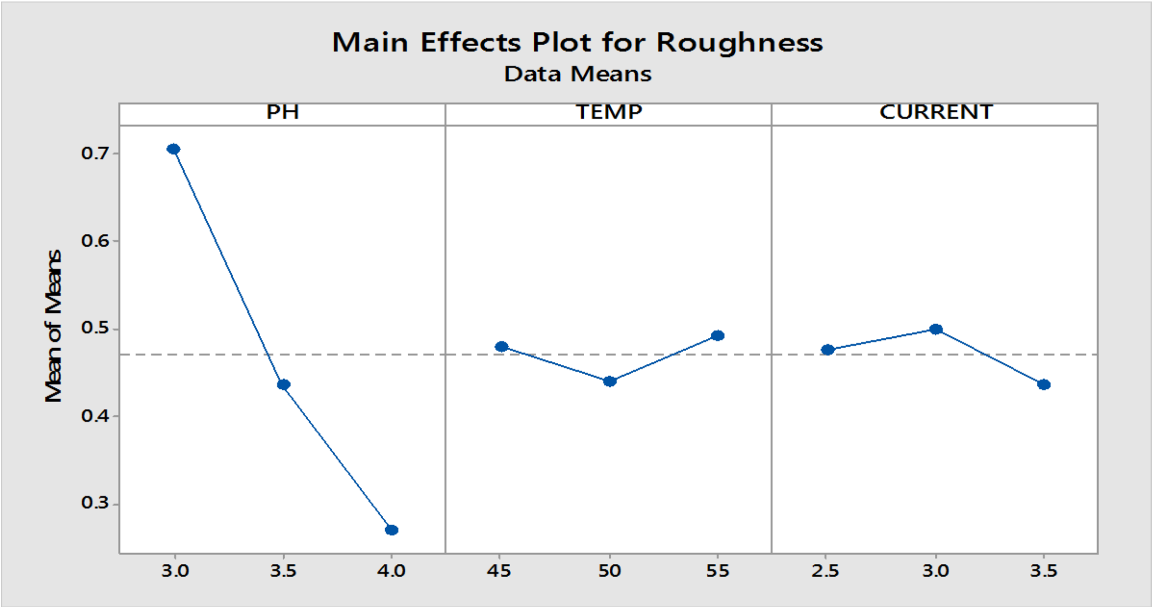

Figure 26 Main effect Plot for SR of ABS sample

From the main effect plot it is observed that the with increase in pH surface roughness decreases and the surface roughness showed an inverse relation at all levels. From above figure it is clear that in case of temperature surface roughness firstly decreases and then increases with increase in Temperature.. It is also observed that the increase in surface roughness is particularly high in between at 3 ph value. The best surface finish is obtained at 4 PH, when Temperature was 45 ^{o}C and current was 3.5 amp.

The Interaction plot for surface roughness of electroformed ABS surface is as follows:

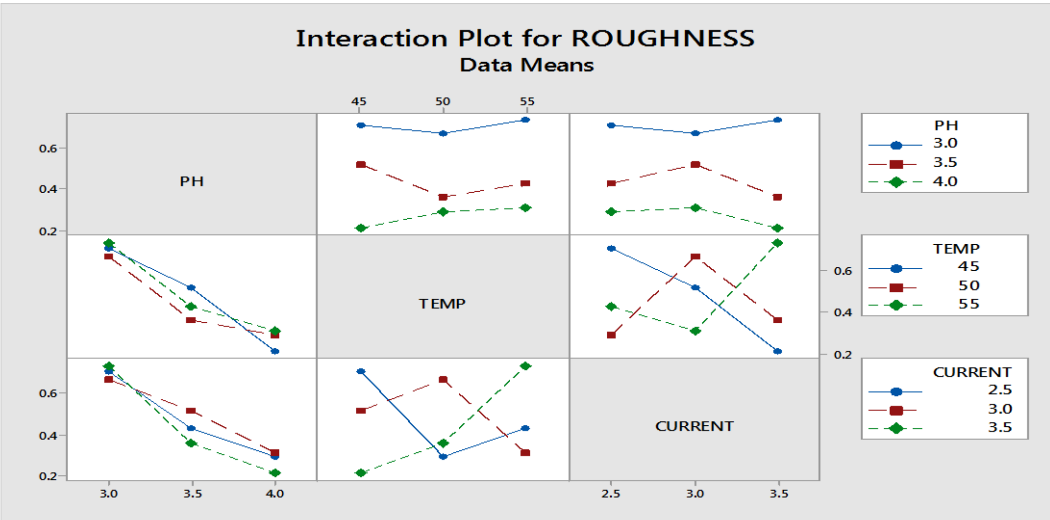

Figure 27 Interaction plot for surface roughness of ABS component

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From the interaction effect plot we can draw the optimized parameters for all the input variables with respect to other variables which give the more detailed information. Form the interaction plot of means of thickness it can be interpreted that there is a significant interaction between all the factors as there are very few parallel lines in the entire interaction plot.The optimized setting for surface roughness of electroformed ABS surface is obtained at 4 PH, when temperature was 45 ^{o}C and current was 3.5 amp

The experimental data is analyzed by ANOVA at 95% confidence level and the contribution of each factor to the out response has been determined and the results are as shown below:

Table 8 Analysis of variance for surface roughness, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	F	P
PH	6	0.302133	0.0500356	9.92	0.094
TEMP	2	0.291356	0.145678	28.69	0.034
CURRENT	2	0.004622	0.002311	0.46	0.687
ERROR	2	0.010156	0.003078	0.61	0.623
TOTAL	8	0.312289			

S = 0.0712585 R-Sq = 96.75% R-Sq(adj) = 86.99%
DF-degrees of freedom, SS-sum of squares, MS-mean squares (Variance) F-ratio of variance of a source to variance of error, P < 0.05 determines significance of a factor at 95% confidence level

From above table, it can be clearly seen that surface roughness is mostly affected by PH followed by current and temperature. It implies that to achieve better surface finish, we have to choose the best Ph and Current factor. As main effect plot indicates surface roughness of electroformed ABS surface is obtained at 4 PH, when temperature was 45 ^{o}C and current was 3.5 amp. .

The parameter R2 (amount of variation) = 96.75%, R-Sq(adj) 34.15%, and the standard deviation of error in the modeling S= 0.0712585 and by comparing the value it can be concluded that which effect is significant and which is not.

The residual plot for Surface roughness of ABS component is as follows:

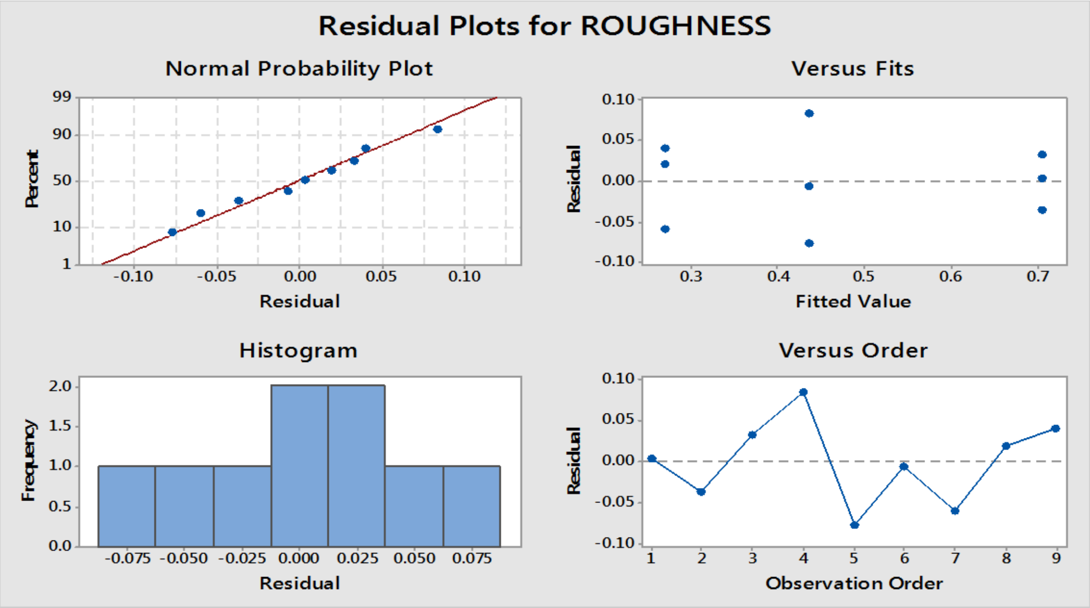

Figure 28 Residual plots for surface roughness of ABS component

The Residual plot implies us about the variation with respect to each contributing factor. It should me minimum enough or should close to mean line of graph, which implies that there is least variation in our experimental work with the input parameters which are PH, Current and Temperature.

8.3 Environment test

Environment test was also conducted in which temperature varied from -25^{O}C to 80^{o}C. In this test specimen was kept for 3 hours at room temperature then it was kept at -25 ^{o}C for next 3 hours. Then it was kept at 80 ^{o}C for next 3hours. Like this 2 cycles conducted in 24 hours. No change was observed at negative temperature but by varing the temperature from negative to positive some rust was observed on the sample. To avoid the rust one coating of crome plating is suggested at final stage.

Figure 29 ENVIRONMENT TEST

9 CONCLUSION

In this study the experiment was conducted by considering three variable parameters namely PH, Temperature and Current. Elecforming of ABS was governed by chemical method and silver conductive paint method. Brass conductive paint as coated onto ABS plastic to create base layer for Cu surfaces onto which Nickel readily deposited for giving strength to the sample piece. The objective was to find the Thickness & Surface Roughness and to study the effects of the variable parameters on these characteristics. The Material used for electroforming is ABS and Nickel anodes were used. Using the Taguchi method an L_9 orthogonal array was created and the experiments were performed accordingly. The following conclusions were drawn:

In Plating thickness inspection with destructive test meter, it is known that rate of deposition is directly proportional to current density. So if we increase the current deposition rate will increase and thickness will increase. But it is to be noted that any slight variation in PH and current density would lead to improper plating and Forming. Thickness inspection with destructive test meter we used SN9 & SN5 for Cu, and Ni .Thickness of copper, and nickel .It was also observed that decrease of PH and the increase high Current cause burning in ABS sample and causes improper plating.

Figure 30 Comparision of sintered Temperatures

Sintering temperature also plays a vital role in better finishing of mould as in experiment observed, when the samples after nickel forming was sintered about 150°C at that time quality of extracted piece was good. Surface finish and even shining was observed but when the sample was sintered above 500°C, dullness and poor quality was observed. So it was concluded maximum temperature range for sintering the nickel is 200 °C above this quality of sample is affected.

The optimized parameters for Electroforming process for Nickel plating on FDM produced ABS component are 4 PH, 3.5 amp current and 45°C temperature.

- Significant increase in pH and Current affects the deposition rate. Some roughness and improper plating takes place at the edges of workpiece with increase in current.
- It was also observed that copper plating also affects the nickel forming. Better is the copper plating better will be the nickel forming.
- There was some problem observed in plating of copper in paint method especially at the sharp edges. Coating was not good at sharp edges .So it is advised to do some changes in CAD model to cure this problem like by providing rounds or fillets at the corners.
- Surface finish is better achieved at low current and smoothness can be easily verified by naked eyes or by touching the surface.
- According to response table first rank parameter is pH, that it is affecting most followed by current and temperature
- According to the ANOVA table most effecting parameter I were also pH, followed by Current and Temperature. . It implies that to obtain better surface finish current should be in range of 3 to 5 amp and PH should kept between 4 to 4.5
- Sintering temperature should not be more that 200°C for good finishing.

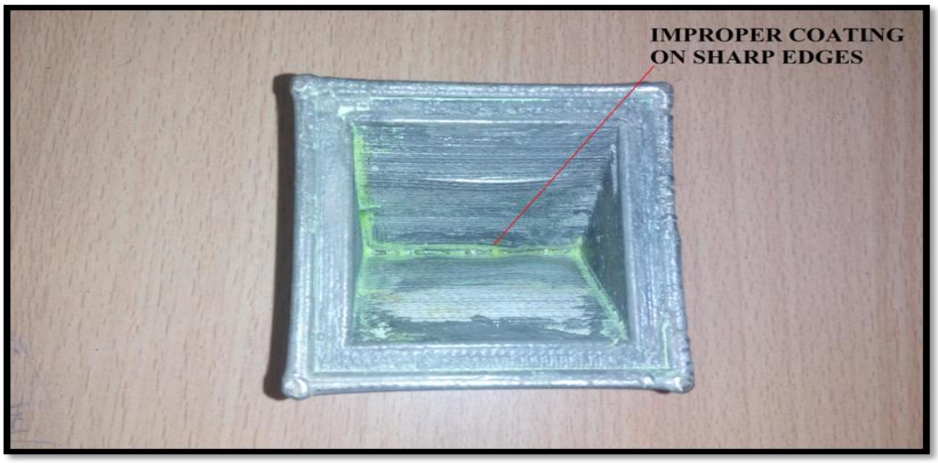

Figure 31 Problem with Sharp Edges

10 FUTURE SCOPE

- This technology can be used in every field like Bio medical science, military, marine etc.
- By varying various parameters a particular approach can be decided to achieve a proper thickness and a better surface finish.
- Any type of shape can be made in FDM and even we can make full assembly of products and after that nickel forming can produce same metal part.
- Mould prepared with Additive manufacturing should be Comparied with the mould prepared by subtractive manufacturing.
- Nickle tools and electrodes can also be made with this technology.
- Different techniques of rapid prototyping such as stereolithography, Selective laser sintering, laminated object manufacturing can be used to manufacture various shapes to be electroformed and the effects of various parameters can be distinguished.
- Various materials such as acrylate, polyvinyl carbide, poly acrylonitile etc. can be used to manufacture different shapes of specimen to be electroformed and their effect on surface finish can be verified easily.
- In range of application to use electroformed components as an EDM electrode can be done by using various materials and their cutting parameters can be varied to achieve better machining.
- Some more study is required for the use of epoxy in the mould. Even metal chips can be used as reinforcement and strengthening of mould.
- This technique can also be used to produce parts in many industries.
- After extracting the mould one coat of chrome plating can also be given to protect it from rust.
- Forming of alloys can also we done.

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