Feasibility of RP-Assisted SILICONE Rubber Moulding Based on Cost & Surface Roughness Parameters

A Major Project Report

Submitted in Partial Fulfillment for the Award of the Degree of

Master of Technology

In

Mechanical Engineering

With specialization in

PRODUCTION ENGINEERING

By

JITENDER DHANGER
(Roll No. 2K12/PRD/08)

Under the guidance of

Sh. K. SRINIVAS (Assistant Professor)

Department of Mechanical Engineering

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

DELHI-110042

SESSION 2012-14

STUDENT'S DECLARATION

This is to certify that the project entitled "**Feasibility of RP-Assisted SILICONE Rubber Moulding Based on Cost & Surface Roughness Parameters**" being submitted by me, is a bonafide record of my own work carried by me under the guidance and supervision of **Sh. K. SRINIVAS (Assistant Professor)** in partial fulfillment of requirements for the award of the Degree of Master of Technology (Production Engineering) in Mechanical Engineering, from Delhi Technological University, Delhi.

The matter embodied in this project has not been submitted for the award of any other degree.

JITENDER DHANGER

University Roll No: 2K12/PRD/08

CERTIFICATE

The project titled "**Feasibility of RP-Assisted SILICONE Rubber Moulding Based on Cost & Surface Roughness Parameters**" submitted by **JITENDER DHANGER** for the award of degree of Master of Technology in Production engineering, has been carried out under my supervision at the Department of Mechanical Engineering of DELHI TECHNOLOGICAL UNIVERSITY, DTU. The work is comprehensive, complete and fit for evaluation.

Sh. K. SRINIVAS
(Assistant Professor)

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
DELHI-110042
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JITENDER DHANGER
2K12/PRD/08

ABSTRACT

This thesis renders a synergistic approach, rapid prototyping and process for rapid development of investment castings tool and analyzes the defects during tool development and provides a solution in order to minimize them. Rapid Prototyping technique is employed in order to make feasibility of manufacturing of customized part which is not possible by using wax in conventional investment casting process. The entire approach is illustrated and validated through experimental studies in order to have the mould with-in no time and minimum defects and cost.

Rapid manufacturing is one of the pre-requisite in order to meet the demand of the modern generation and thus RP and its various techniques has fast become an indispensable part of modern manufacturing. Use of Rapid Prototyping (RP) for Rapid Manufacturing (RM) is one of the important areas of research today. Fused deposition modelling (FDM) process of rapid prototyping is very easy to use and maintain as it is non laser based technique .The technique is used to get the physical part of ABS polymer with lower lead time and using this part to develop the silicone rubber mould. The mould is then used as a tool of investment casting. Feasibility of manufacturing the tool for a customized part is the main focus of this project.

Metallic products can be manufactured easily if the tool for the part is manufactured with less time consumption and material cost, this tool is obtained with the help of ABS part from FDM and preparing the wax pattern easily which is followed by conventional investment casting process. The experimentation is carried in order to obtain the rubber mould and to use the mould to have the wax pattern

.

Practical implication of this research aim to address the issue of manufacturing cost effective, defect free customized part. RP has proved to be a cost-effective and time-efficient approach for development of RT, thereby ensuring possibility for technology transfer in casting industries. This has lot of significance in automobile industries in manufacturing of mechanical component & also for orthopaedic medical implants in medical application.

LIST OF FIGURES

NOMENCLATURE

RP-	rapid prototyping
RM-	rapid manufacturing
FDM-	fused deposition modelling
ABS-	acrylonitrile butadiene styrene
RT-	rapid tooling
DOE-	design of experiment
IC-	investment casting
Stl-	standard tessellation language
CAD-	computer aided design
CAM-	computer aided manufacturing
SL-	stereo lithography
HES-	hydrolyzed ethyl silicates
LOM-	laminated object manufacturing
SLS-	selective laser sintering

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CHAPTER 1   INTRODUCTION

1.1 INTRODUCTION

The design and development paradigm, product development in casting is shifting from traditional trial and error in workshop to simulation based virtual realization up-front design process. Due to which it appears quite cumbersome to use the method of trial and error but it appears easier to understand for a single product to understand this approach.

Auto CAST-X software or a number of simulation software on casting are available, which models the entire casting system and imitates the dynamic behaviours of the system in work conditions, provides complete design information for generation, verification, validation and optimisation of design for the entire casting process via simulation.

The design information provided helps to reveal and predict the final product output in terms of product defects, quality and properties in such a way that the optimal design solution is possible to determine. In this the modelling of the casting processes is first articulated and associatively between the casting processes, modelling, simulation is presented.

Today’s era is quite competitive and consumer-centric. Market demand is possible to get changed within a short span of time and in order to meet the demand of the product, product need to be produced as per the demand and as per the required quality. Starting from a small scale industry for fulfillment of a local markets need like glass marbles they need to change the colour at regular interval in order to attract kids for their sale, to enlarge industry of an automobile in which most of the models have the same features and even after that some companies have higher sale than the other which is made possible by providing special features in addition to the base parts with the minimum possible expenses.

Indirectly, one can easily interpret that which one is more customers oriented and tries it’s best to satisfy the individuals demand. Earlier day’s manufacturer manufacture the product and force the customer to buy it, but now a day’s customer have a lot of choice in the market and his expectations are increasing day by day. Therefore, manufacturer is manufacturing the product according to customer needs due to this product variation formed because different customers have different expectations. Customers get their product as per their need and quality.

Investment casting is a manufacturing process that has gone through several changes, out of these Rapid prototyping has the highest impact on it and thus affected it in many ways. The design of the Process for Lost RP Pattern evolved new research in the design by use of Block mould Investment Casting. The Process developed includes nonlinear shape sample of ABS pattern, liquid silicone rubber mould, biosint, water, muffle furnace. The shape which is almost impossible to machine in other hardware manufacturing setup has found the feasibility for that complicated shape with the help of RP process.

Although CAD/CAM systems are widely used in new product design and manufacturing, and specific commercial CAD/CAM systems that are customized for new intricate shape product in which applications are also available. The aim of this research is to develop an intelligent RP approach which is feasible with investment casting.

The main aim of this work is to provide a method to use the ABS pattern for making several wax patterns from silicone rubber mould. It will help to cast the intricate shapes with the help of wax pattern without making the conventional tool which is of higher value and also not making use of ABS pattern (destructively) in order to reduce the cost of product. It also aims that casting should be of minimum rejection.

The idea of using RP machines for the manufacture of products in high or medium volumes seems unrealistic as the cycle times, material cost and capital equipment. In metal casting processes, conventionally, the developments of pattern and core boxes account for more than 70% lead time and greatly influence cost and dimensional quality of product. Study revealed that the sand cast components manufactured using RP patterns shown better results for dimensions and surface finish (Ingole et al., 2006).

Basically the sand casting practice is not suitable for manufacturing small and intricate parts due to many reasons.

i. Small sized patterns are not easy to prepare with the conventional process.
ii. Perfection in producing contoured patterns is always the problem.
iii. Metal patterns require more finishing time and cost but Wooden patterns are dimensionally unstable.

iv. Accuracy is the major problem for the parts produced with sand casting.

v. Parts produced with conventional patterns require further finishing.

1.2 METHODOLOGY

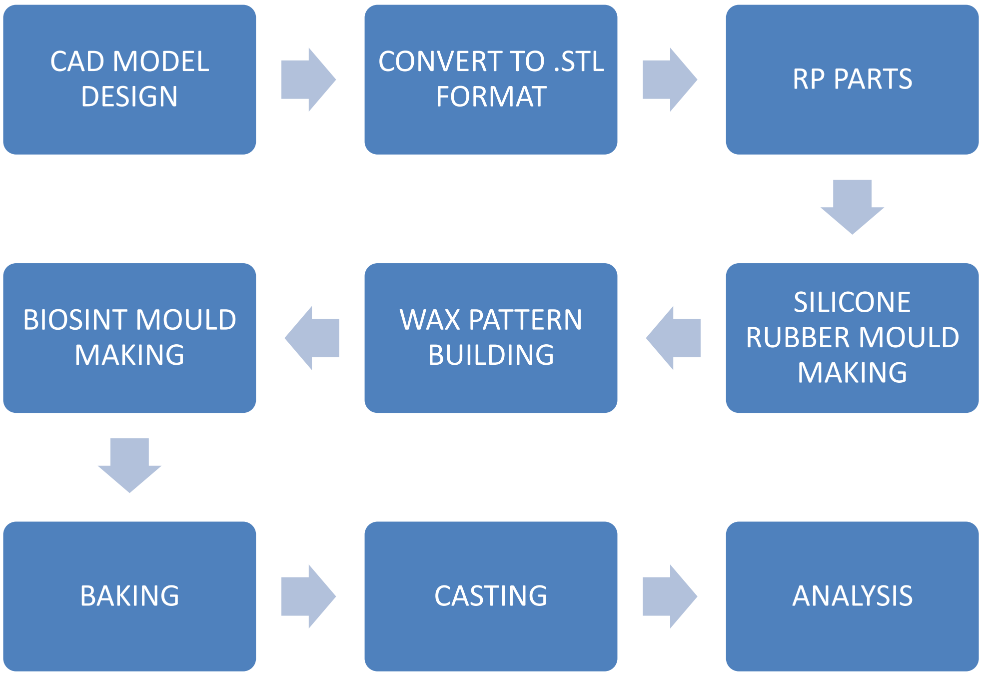


Figure1.1 Flow Diagram of Methodology

CHAPTER 2 LITERATURE REVIEW

2.1 LITERATURE REVIEW

Colin Gouldsen [1999], this research presents the result of the IC evaluation program for shell mould to both FDM customers and IC foundries. It serves as a guideline that takes into account the different variables in the product building process and the foundry business, for Stratasys FDM users who want to produce ABS patterns for making metal castings and also for foundries which produce on small scale and have little or no experience, it provides information about the process to serve as a basic process plan for using ABS parts or IC patterns. In this literature, Tests were conducted on FDM ABS samples to determine the characteristics during typical foundry processes. Samples were sent to six laboratories which provided relevant data to the pattern burn-out process. Each foundry had experience of using different RP parts. Feasibility and expertise were established over nine month, using three test geometries. These tests included typical expansion and thermal decomposition and ash content under air & argon environment. After testing, the burn-out procedure varies with different foundries. In general, the furnace is preheated to about 871 °C then loaded with the shells. The temperature is ramped up to 1066–1120 °C and held for the time ranging from 50 minutes to 2 hours, depending on the foundry capability.

It is meant to be a guideline that takes into account the different variables in the part build process and the foundry business. For Stratasys FDM users who want to produce ABS patterns for making metal castings, the document outlines guidelines and provides fundamental procedures. For foundries experienced in rapid prototyping, it can serve as a guide for tuning their process for materials other than epoxy, polycarbonate, laminated paper or other RP produced material. Finally, for foundries that have little or no experience, it provides process information to serve as a general guide for using ABS parts or IC patterns.
Biomet is a medical company located in Warsaw, Indiana. Biomet designs and manufactures joint replacement devices including knees, hips, etc. It has utilized ABS patterns to generate IC since the second quarter of 1997. To date they produce over 50 castings a month of cobalt chrome or 17-4 stainless steel materials in a company-

owned foundry. Cycle times have resulted in a reduction to two weeks to produce these preproduction castings, at an annualized cost savings of $120,000. figure 1 and 2, shown on the following page, demonstrate several of their parts.

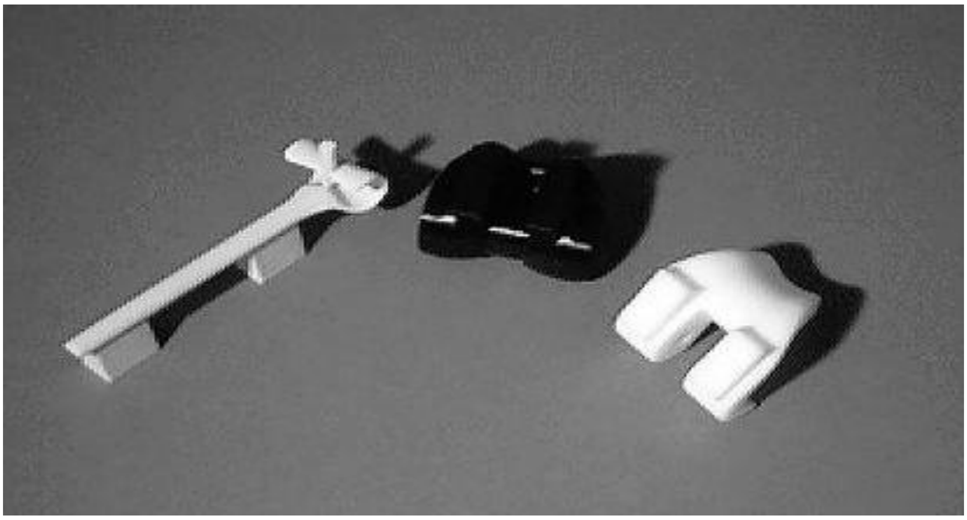


Figure 2.1ABS IC pattern for an elbow (with gating) and two knees (Biomet))

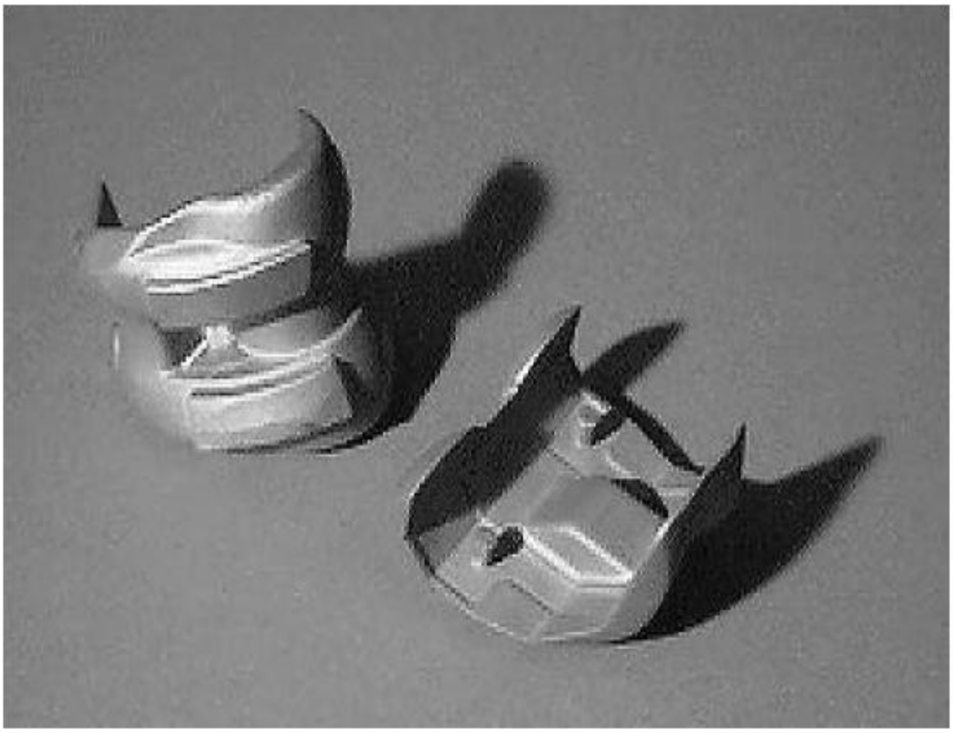


Figure 2.2 Two cobalt chrome knee implant investment castings (Biomet
).

Table 2.1 Advantages &Disadvantages of Patterns Made from FDM ABS, FDM Wax and Wax from Tooling

	FDM ABS	FDM Wax	Wax from Tooling
ADVANTAGES	• Parts are strong and able to withstand the rigors of transportation • Thin-walled parts can be created • Surface finish is better than RP wax • Parts can be post-finished without fear of breakage • Users are more experienced at building accurate parts in this material	• Foundries prefer to use wax • There is no change in the foundry process when using the wax	• Large quantities can be produced economically • Consistency of dimensions • Good surface finish
DISADVANTAGES	• Only a few foundries, at this time, have experience using ABS • Foundries that have no experience, need time to become proficient	• Any wax part is fragile, and transportation to a foundry could yield multiple parts • The softening point is 170 °F (77 °C), which can be reached in the hot sun	• High tooling cost that may exceed $50,000 • Long lead times of up to 12 weeks

Results from various industries helps to conclude that Patterns built from ABS offer a number of quality advantages over patterns made by other RP processes: Clean burn-out, robustness, the ability of the part to be handled without damage, dimensional stability and ease of pattern preparation. Surface finish preparation of the pattern is important to achieve the best results.

Nagahanumaiah et al [2003]. The paper suggests different alternates for developing the pattern (expendable) and different tooling techniques for the investment casting. Integration of RP with IC suggests a significant number of paths for tool generation. Some paths that are available have technical limitations and some can be process specific. Main challenge while using rapid tooling requires the strength, accuracy and cost effectiveness along with surface finish. In this paper an attempt is made to quantify the process capabilities from technical and business point of view. The issues associated with different tooling routes are described along with few industrial examples and identified the directions for future research. The main advantage of these tool paths in developing rapid hard tooling for injection moulding and pressure die-casting is also discussed.

Chil-chyuan-kuo*et al [2012] undertaken a project to manufacture the wax pattern of cylinder head with the help of silicone rubber. During the work, surface roughness proves out to be an important criterion and to improve this hand finishing is done to improve the surface finish. Silicone rubber is chosen as the material of an elastomeric mould due the properties of elasticity and surface energy. Also, as the no. of components increased the assembly precision decreased. First step is to produce the silicone mould and then assembling the mould. After this wax patterns are prepared or the engine is replicated and removed from the mould. It was found that the thermal shrinkage of length, width, height, diameter, and length of a square hole is about 1.12%, 1.07%, 2.19%, 0.47% and 0.86% respectively. The proposed method is able to develop the sophisticated geometry over a short period of time and at a lower cost in the motorcycle industry because the cylinder head is one of the challenging and most complicated parts of the engine and costly too.
Therefore, a technique is proposed to manufacture the high precision part like cylinder head is possible with wax pattern of cylinder head. Surface finish replicated to wax pattern from the silicone mould is satisfactory for investment casting. Results reported by the process can be helpful in development of a new cylinder head in the motorcycle industry.

J.MALE et al [1996] This research is for a comparison of various parameters like time, cost and accuracy of soft tooling for investment casting. On time basis the SL part took more time when compared with the resin die and silicone rubber die, the product on which it was experimented was having the same dimensions for all. As the same location and clamping system was used as the epoxy resin tool, the sand/resin backing of each piece also had to be done sequentially, adding more time to the process. While using the SL faced tool, the tool failed, meaning that no wax pieces were produced using it. It may be due to either the pressure of the moulding machine holding it clamping the tool together, or due to the pressure of the wax injection.
The resin tool took approximately half the time to build than the hybrid tool, but also

took almost twice the time of the silicon robber tool. The reduction in time over the hybrid tool is due to eliminating the lengthy CAD and SL work involved. Therefore, the increase in time is primarily due to the part needing a four part tool.

Soft tools were cost effective only when the no. of parts produced was more than five and it was due to the high cost of the stereo-lithography part. Pattern when produced from wax were found to be more accurate than that produced from resin tool.

From the results it was concluded that hybrid SL/epoxy mould is not effective in reducing times and costs for this test part. This is due to the size of the part, which made building the pieces in SL time consuming. Silicon rubber mould was the fastest mould to make and the number of parts of the tool does not significantly increase the time required. The resin tool was successful in producing waxes for use in investment casting. The tool was robust enough for the wax injection process with no visible damage to the tool.

David A Ford [2008] in this research, complex external structure of gas turbine or other machineries and internal geometries are easily possible by means of Investment casting process. Since it is unlikely that alloy development will produce less expensive materials, it is the responsibility of the investment caster to improve and develop the process to optimise raw materials and reduce overall manufacturing costs. Environmental concerns and fuel costs give added pressure to develop the manufacturing capability to optimize the turbine’s thermal efficiency with complex and accurate geometries and to reduce the engine weight with thin section components. Shell Moulds: The environmental protection act of 1990 for the control of air pollution was a major concern for UK foundries using the hydrolyzed ethyl silicate (HES) process since both the alcohol and ammonia used in the process were emitted to atmosphere. An alternative process was necessary and both foundries and suppliers were engaged in extensive work to evaluate new systems. There was little choice other than to use silica sol as the replacement binder but there were three problems to overcome:

(i) To prevent shell cracking during de-wax.

(ii) To produce a shell with equivalent dimensional consistency to HES moulds.

(iii) To produce a shell which did not induce casting defects such as cracks, inclusions or surface finish issues.

These problems were eventually overcome by the development of polymer additions to give green strength and by controlled drying using a combination of humidity, airflow and temperature in specially constructed drying tunnels. Early trials identified that shell drying caused the temperature of the wax pattern to drop by several degrees, the subsequent warming of the shell after drying caused the wax to expand and crack the shell. The process developed was to ensure that the shell drying was controlled so as to prevent the harmful temperature excursions. Over 100,000 patterns were produced in the USA by rapid prototyping in 2007 of which 50% were for production standard castings. This represents $250M worth of cast products. The technology has matured over the last 10 years and there is a number of established processes e.g. Stereo lithography, Selective Laser Sintering (SLS), Thermo jet, Solids cape etc. Of these the most popular in Europe is a wax impregnated SLS marketed as Cast form‘. Rapid Prototyping has also been used for direct core manufacture and proprietary trials are underway to produce integrated shells direct from rapid prototyping.

P.M.Dickens et al [1995] the problems associated in using the RP patterns as the sacrificial pattern is investigated along with the properties like suface finish and accuracy of the models and the casting in order to make a comparison. One can review it as the merging of the oldest manufacturing process with the modern one (RP technology).

It is found to be an ideal match for both the processes as both has the potential of producing the complex parts. They produce the wax pattern directly from the wax parts directly from two processes i.e. FDM and SLS but the main difficulty of using the wax pattern is during its transportation as it is too brittle. The main work is that they have used the sacrificial wax pattern for IC process. It results in a serious defect due to the expansion of wax while phase change and distorting the product and thus also give a direction for research work in surface finish of the pattern and using it with conventional wax.

The project showed the need of the experience of using the rapid prototype in casting and thus foundries having the experience can only convert the part into casting with accuracy. The wax patterns from the FDM are brittle so it need to be considered while transporting it to foundries,

The results of the project helps one to conclude that work is need to done on surface finish while using the RP for the process and FDM pattern should be handled with care while transporting to foundry. However, it also gives clue about the work going on the process to have better accuracy and the stability of the models.

C. W. Lee et al [2004] the author through this research paper demonstrated that the manufacturing of complex shaped metal parts is economical with the help of Investment casting. High tooling cost and lead time associated with the IC process can be easily overcome by the usage of RP technique. In this project fused deposition modelling is used for creating the sacrificial patterns. In addition to the above the patterns possibility of using the FDM pattern to produce the silicone rubber mould is investigated and its cost and lead time are calculated which is then compared with conventional method of tooling. A list of criteria is used in this benchmark are as follows:

1. Cost of RP fabrication.
2. Surface finishing of the RP part.
3. Time taken for part building.
4. Dimensional stability of RP part.

From the above study it is very much clear that the residual ash content is lowered from the actual IC process using the ABS pattern as sacrificial pattern. A surface roughness test was conducted and it was found that the pattern with the surface finish had improved surface but the casting obtained from the pattern were not of that surface finish as that obtained from the IC process.

Dr. B.Ravi [2011] the research work aids the tooling (dies) processes with computer aided design which is followed by simulation. It helps to give the better and faster insight of the optimisation of the design of feeder and gating design. Both dispensable and permanent mould processes can be simulated. The usage of CAD imposes several difficulties for the first time users. Study also helps those users to use any of the approach proposed by it. One is casting simulation clinics and the other is web based telesimulation are described in such a way that it is being disseminated to even small foundries. The design method includes cores, feeder and the gating system. By adopting the non-value added time during casting can be minimised apart from this simulation technology and intelligent methodology are also helpful in this minimisation. This has been successfully developed and demonstrated on industrial casting.

CHAPTER 3 RAPID PROTOTYPING APPROACH

3.1 RAPID PROTOTYPING

Rapid Prototyping (RP) is the ability to generate three-dimensional models that need no machining or tooling. RP adds material layer by layer until the desired shape is achieved, instead of cutting away the material by machining. RP allows for more flexibility than machining because the complexity of the model does not give any limitations to its production in case of RP. RP generates 3D models quickly and accurately which can greatly reduce the research and development phase of product development, which results in a lower cost to market**.** Rapid prototyping is the process of generating an object directly from its digital representation in CAD/CAM system by adding material layer by layer. The main benefit of this process is that it reduced the time to produce a prototype, which in turn speeds up the entire development process.

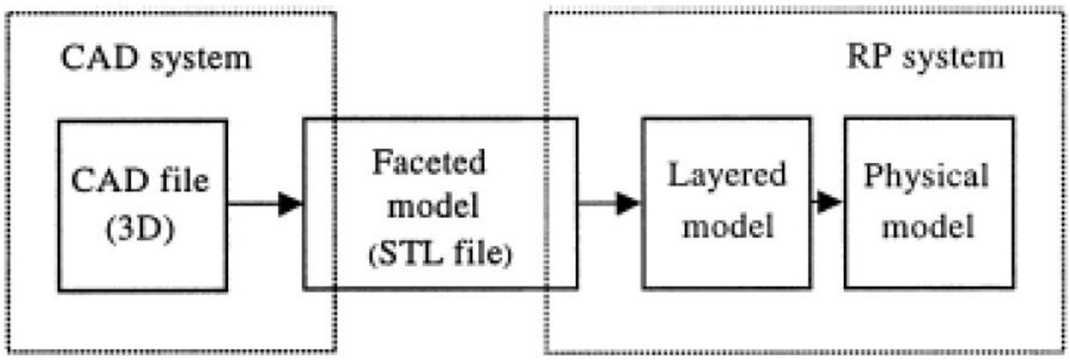


Figure 3.1 Rapid prototype approach

Rapid Prototyping (RP) is a continuation from three-dimensional CAD modelling. RP uses the CAD data to produce layer information that is fed into RP machines to produce a three dimensional solid model from a chosen process and material. Common RP processes include Stereo lithography (SL), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM) and Fused Deposition Modelling (FDM). The majority of RP processes involve the conversion of the CAD data into cross-sectional information and the model is built layer-by-layer.

3.1 WHY TO USE RAPID PROTOTYPING?

i. Objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly.
ii. Objects can be made from multiple materials, or as composites, or materials can even be varied in a controlled fashion at any location in an object.
iii. Additive fabrication systems reduce the construction of complex objects to a manageable, straightforward, and relatively fast process.

3.2 METHODOLOGY OF RAPIDPROTOTYPING:

The basic methodology for all rapid prototyping techniques can be summarized as follows:

i. A CAD model is constructed, and then converted to STL format. The resolution can be set to minimize stair stepping.
ii. The RP machine processes the STL file by creating sliced layers of the model.
iii. The first layer of the physical model is created. The model is then lowered by the thickness of next layer, and the process is then repeated until completion of the model.
iv. The model and any supports are removed. The surface of the model is then finished and cleaned.

3.3 MAJOR RAPIDPROTOTYPING TECHNOLOGIES

Rapid Prototyping operations may be classified as follows:-

3.3.1 Stereo Lithography (SLA)
3.3.2 Selective Laser Sintering (SLS)
3.3.3 Laminated Object Manufacturing (LOM)
3.3.4 Solid Ground Curling
3.3.5 Laser Engineered Net Shaping
3.3.6 Fused Deposition Modelling (FDM)
3.3.7 Inkjets

3.3.1 FUSED DEPOSITION MODELING (FDM)

FDM is the second most widely used rapid prototyping technology, after stereo lithography. A plastic filament, approximately 1/16 inch in diameter, is unwound from a coil (A) and supplies material to an extrusion nozzle (B). Some configurations of the machinery have used plastic pellets fed from a hopper rather than a filament. The nozzle is heated to melt the plastic and is having a mechanism which allows a control over the flow of material and thus shape. The nozzle is mounted to a mechanical stage (C) which can be moved in both horizontal and vertical directions.

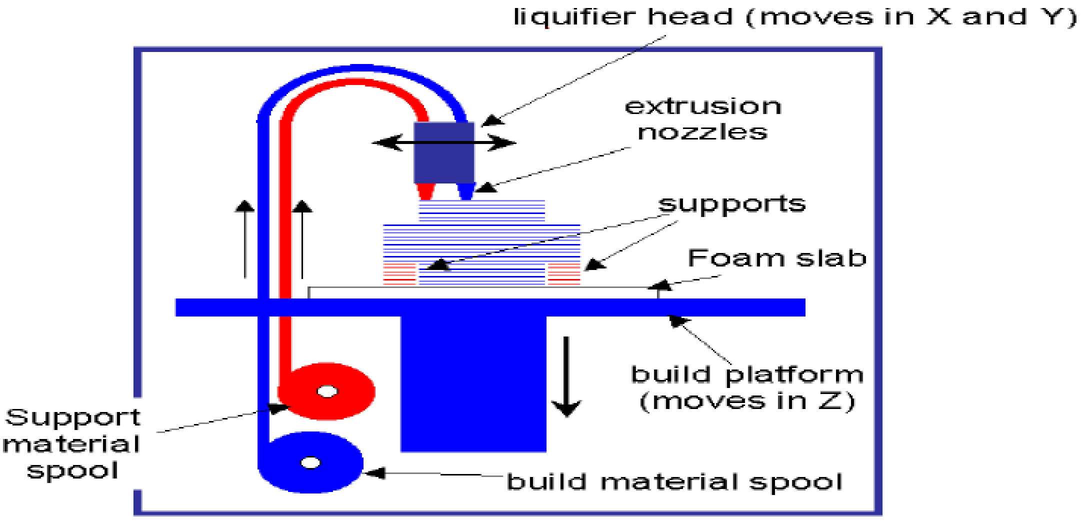


Figure 3.2 Principal of FDM

As the nozzle is moved over the table (D) in the required geometry, it deposits a thin bead of extruded plastic over the table by forming a particular shape layer by layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The temperature is kept just below the melting point of the plastic by placing the entire system in an oven. Thus, only a small amount of additional thermal energy needs to be supplied by the extrusion nozzle to cause the plastic to melt. This provides much better control over the process. Support structures must be designed and fabricated for any overhanging geometries and are later removed in secondary operations. Several materials are available for the process including a nylon-like polymer and both machinable and investment casting waxes. The introduction of ABS plastic material led to much greater commercial support material was introduced at that time which was easily removable by simply breaking it away from the object. Water-soluble support materials have also become available which can be removed simply by washing them away. The recent introduction of polycarbonate and poly (phenyl) sulphate modelling materials have further extended the capabilities of the method in terms of strength and temperature range. Several other polymer systems as well as ceramic and metallic materials are under development. FDM machines are very similar in operation, but they run different materials. The FDM 2000 is usually set up to run standard ABS or Investment Casting Wax (ICW), and the FDM 3000 is almost always set up to run Waterworks‘ ABS, which has a water-soluble support material. The FDM 2000 can also be set up to run Elastomeric Material.

3.3.2 STEREO LITHOGRAPHY

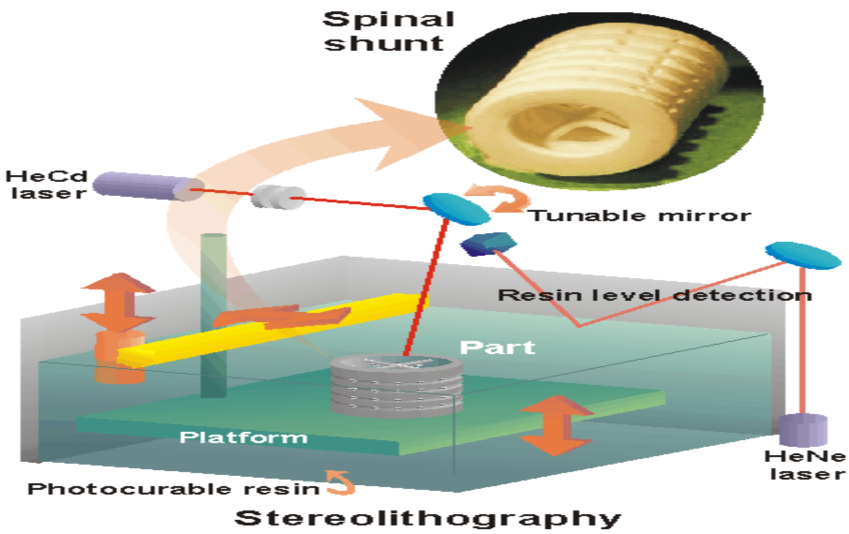


Figure 3.3 Stereolithography

Stereo lithography systems build shapes using light to selectively solidify photo curable resins. It is currently the most widely used RP technology and was first commercialised by the U.S company 3D systems. It creates acrylic or epoxy parts directly from a vat of liquid photo curable polymer by selectively solidifying the polymer with a scanning laser beam. Parts are built up on an elevator platform that incrementally lowers the part by the distance of the thickness of the layer. To build each layer, a laser beam is guided across the surface, drawing a cross-sectional pattern in the X-Y plane to form a solid section. The platform is then lowered into the vat and the next layer is drawn and adhered to the previous layer. These steps are repeated, layer-by-layer, until the complete part is built up. This process uses “deep dipping” recoating, whereby the elevator is first lowered by several millimetres so that the liquid entirely flows over the current upper surface of the part. The elevator is then raised to the desired height and a doctor-blade (wipe arm) traverses the surface to quickly level the viscous material. Features with gradually changing overhangs can be built up without support structures.

3.3.3 SELECTIVE LASER SINTERING

SLS process was originally developed at the University of Texas at Austin and then commercialized by DTM Corporation (U.S.).

In SLS a layer of powdered material is spread out and levelled over the top surface of the growing structure. A laser then selectively scans the layer to fuse those areas defined by the geometry of the cross-section; the laser energy also fuses layers together. The un-fused material remains in place as the support structure. After each layer is deposited, an elevator platform lowers the part by the thickness of the layer, and the next layer of powder is deposited. When the shape is completely built up, the part is separated from the loose supporting powder. Several types of material are in use, including plastics, waxes, and low-melting-temperature metal alloys, as well as polymer coated metals and ceramics for making “green” performs. Any material which can be converted into powders, which can be bound together by fusing them at a reasonably low temperature (350-500°c), can be used for making the parts in this process are nylon, ABS and investment casting wax. Generally tough parts are obtained without any support structure. Less material wastage and ceramic parts can be obtained.

3.3.4 LAMINATED OBJECT MANUFACTURING (LOM)

It can be seen from the figure that firstly slices are cut in required contour from roll of material by using a 25-50 watt CO_2 laser beam. New slice is bonded to previously deposited slice by using a hot roller, which activates a heat sensitive adhesive. Apart from the slice unwanted material is also hatched in rectangles to facilitate its later removal but remains in place during the build to act as supports. Once one slice is completed platform can be lowered and roll of material can be advanced by winding this excess onto a second roller until a fresh area of the sheet lies over the part. After completion of the part they are sealed with a urethane lacquer, silicone fluid or epoxy resin to prevent later distortion of the paper prototype through water absorption.

In this process, materials that are relatively cheaper like paper, plastic roll etc. can be used. Parts of fibre-reinforced glass ceramics can be produced. Large models can be produced and the building speed is 5-10 times as compared to other RP processes. The limitation of the process included fabrication of hollow models with undercuts and re-entrant features. Large amount of scrap is formed.

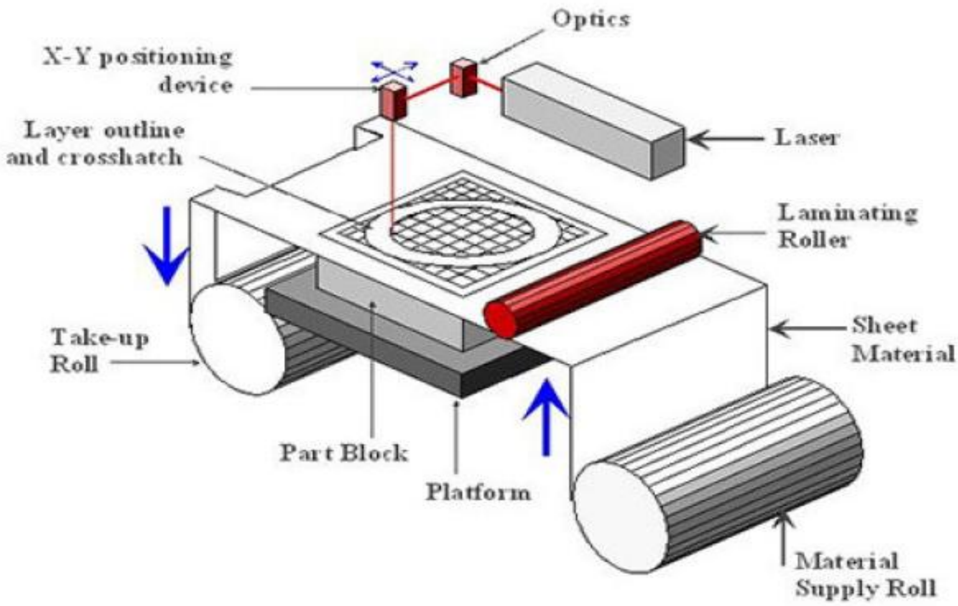


Figure 3.4 Laminated object manufacturing

3.3.5 SOLID GROUND CURING

This approach uses a method in which an image of the entire cross-section in a single operation using photo masks. It was commercialized by cubital (Israel/Germany) and was called SGC.

In SGC, each cross-section is imaged onto an erasable mask plate produced by charging the plate via an iconographic process and then developing the image with an electrostatic toner (like the xerography process). The mask is then positioned over a uniform layer of liquid photopolymer, and an intense pulse of UV light is passed through it to selectively cure the material. Uncured photopolymer is removed from the layer with a vacuum system and replaced with a low-melting-point, water-soluble wax that serves as the sacrificial support. After the wax has cooled, the layer is milled to produce a flat surface. The pattern on the exposed mask is erased by wiping off the toner, and the entire process is repeated. After the part has been completed, the wax is removed by melting

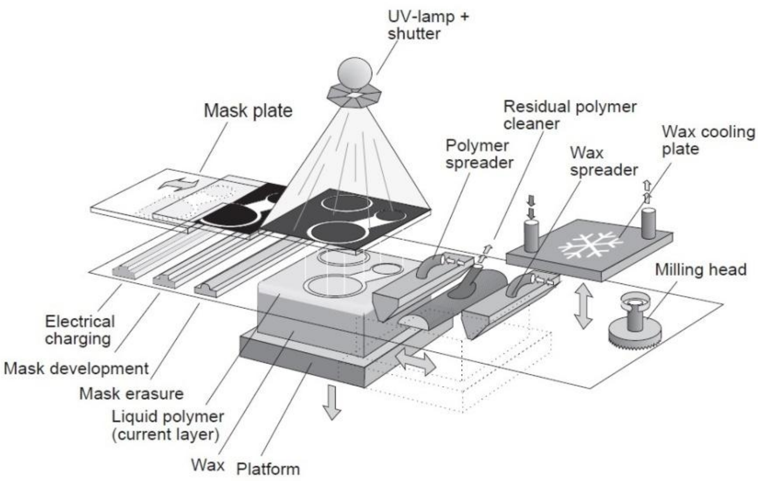


Figure 3.5 Solid ground curing

3.4 ADVANTAGES OF RP

The advantages of the RP are as follows:

i. RP reduces the time required for manufacturing of jig & fixture.
ii. It also consumes less time for building prototype (up to one fifth of conventional machining).
iii. Cost required is also less
iv. Complex geometrical shapes can be manufactured easily.
v. Customised products can be manufactured.

3.5 RAPID MANUFACTURING

Rapid manufacturing (RM) is the use of additive fabrication technology to directly produce useable products or parts. As is the case with rapid prototyping, the field is also known by several other names such as additive manufacturing, direct fabrication and direct digital manufacturing. It may also be referred to by the names of one or more of the several technologies utilized; a number which is continuously growing. RM is one of the three major blossoming outgrowths of rapid prototyping. The others are three-dimensional printing - a lower-cost flavour of RP, and rapid tooling - actually a special case of rapid manufacturing. Today the distinctions among the trunk and branches of the RP tree are not very clear. Moreover, these differences can be expected to continue to blur as the technologies mature and applications, specifications and capabilities of the branches increasingly overlap.

3.5.1 PRESENT STATUS OF RM

What we see today is only a pale outline of the future. A few RP systems specifically aimed at rapid manufacturing applications are just beginning to appear commercially. RM is not yet being practiced at present, at least publicly, in any large way. However, many experiments that adapt existing RP systems to specific RM applications are quietly underway in corporate, government and university laboratories. As technology, materials and other barriers are overcome, additive fabrication will find its way into the mainstream across a broad spectrum of applications. RM will be the branch of the technology that has the most direct impact on people‘s lives. Some observers have liked it to a second industrial revolution. That may be going a little too far, but it‘s a good long-term bet that nearly all facets of life will be impacted in some way by RM – and in many ways which may not be apparent at present.

3.5.2 ADVANTAGES AND DISADVANTAGES OF RM

The fundamental advantages and disadvantages of rapid prototyping carry over to rapid manufacturing. The benefits of RM must be balanced against its substantial limitations today. Unless there is an overwhelming need for a specific advantage that RM provides, the balance most frequently favours a conventional approach. However, as technical problems on many fronts are solved, the balance can be expected to tip in favour of RM with greater frequency. The driving force to solve these problems comes from the early adopters whose present applications already possess an overwhelming balance in favour of additive fabrication. These individuals and companies are providing the foundation upon which further improvements will be based. Rapid manufacturing uses the additive fabrication technology to directly produce useable products or parts, which one is one of the three major blossoming outgrowths of rapid prototyping. RM is being applied to automotive, motors sports, dentistry, turbine making company, orthodontics, medicine and collectibles, in medical application implant fabrication.

3.5.2.1 Geometric Freedom.

3.5.2.2 Materials.

3.5.2.3 Elimination of Tooling.

3.5.2.1 Geometric Freedom

Essentially all additive fabrication technologies provide the ability to fabricate with unbounded geometric freedom. It‘s their most important advantage over subtractive methods and main reason to exist. Geometric freedom comes with several limitations using today‘s technology, however. The speed of fabrication compared to standard manufacturing methods is much slower. By some estimates, existing mass production methods are 10 to 1,000 times faster [6]. The finishes and accuracy are also not on a par with conventional technology. Secondary operations are also required, such as support removal and hand-finishing. In a production situation, where multiple parts are fabricated, secondary operations can add up and become time consuming. There are also part size limitations at present which are more restrictive than those of standard methods.

3.5.2.2 MATERIALS

Additive fabrication has the potential not only to use multiple materials but also to control the local geometric macro- and micro-structures of a part. This means that the functionality of a part can be optimized in ways that are impossible with previously existing manufacturing methods. Materials are selected for their mechanical, thermal, optical or other properties and then can be physically deposited in a manner that optimizes or changes those properties beyond the capability of the intrinsic material itself. On the other hand, the reality today is that the key word here is ―potential. It will be a long time before the choice of materials available to rapid manufacturing is even remotely comparable to those available to standard manufacturing technologies. There are just a few dozen RP/RM materials commercially available today, spread out over all classes of materials such as plastics, metals and ceramics. In contrast, plastic selection databases exist that list a mindboggling 40,000+ active grades of plastic alone [2]. In addition, recycling complex materials may be difficult or impossible.

3.5.2.3 ELIMINATION OF TOOLING

CAD directly drives all additive fabrication processes, making it theoretically possible to avoid the use of tooling altogether. In practice, it may often still not be possible to do that because of process and materials limitations of one kind or another, but complementary rapid prototyping technology might offer a beneficial compromise. When feasible, however, the complete elimination of tooling results in enormous savings in time and money. It makes it possible to fabricate parts and products in small quantities, or using materials and design parameters that might not otherwise be conceivable [2]

CHAPTER 4 INVESTMENT CASTING

4.1 CASTING

Casting is one of the oldest manufacturing processes, and even today it is the first step in the manufacturing of most products. In this process, the material is liquefied by properly heating it in a suitable furnace. Then, the liquid metal is poured into a previously prepared mould cavity where it is allowed to solidify. Subsequently the product is taken out of the cavity, trimmed, and cleaned to shape.

It can be easily understood from the definition of casting that one must have the proper knowledge in the following areas for a successful casting as discussed below:

1. Preparation of moulds and patterns (used to make the mould).
2. Melting and pouring of the liquefied metal.
3. Solidification and further cooling to room temperature.
4. Defects and inspection.

Casting is not only used for liquid metals but also for plastic material or the materials which set on cooling when mixed with materials like epoxy or water setting materials like plaster, concrete. Even the materials which are semi solid when they have moisture and solidified when heated in kiln or furnace can be used (clay).

4.2 INVESTMENT CASTING

Investment casting or lost-wax casting ensures the high quality benefits of repeatability, integrity, versatility and accuracy. Repeatable production is possible with the help of investment casting along with the materials ranging from low temperature usage to higher temperature. Starting from the small size casting to the large size like aircraft's complete door frame. It is suitable for a wide range of shapes and contours in small-size parts, especially those that are made of hard-to-machine materials. It is suitable for excellent surface finish. Here, the mould is made in a single piece and thus have no parting line to leave out fins. So it leads to dimensional accuracy. It has been found very suitable for casting and jet engine parts made of high temperature and high alloy strength.

4.2.1 WHY INVESTMENT CASTING

Investment casting is one the best methods known for producing intricate shapes from metals. It has been used continuously for producing shapes of not only ferrous materials but also for non-ferrous from several years. It is possible to produce net shape parts with the help of investment casting. It is good for the processes requiring low production quantities (10 to 10,000 pieces) or for the products which are required to be changed for design purpose. A wide range of alloys are available for investment casting(nearly 200 ranging from ferrous-stainless steel, tool steel, carbon steel and ductile iron—to non-ferrous—aluminium, copper and brass).machining is also available for such a wide range but machining is not possible to used for complex geometries which is possible with investment casting. It is well suited for the complex geometries because it uses expendable patterns and ceramic blocks. The parts which are not possible to forge, machine or to cast by simple conventional method of casting can be possible with this method of casting. Example includes curved vane of an impeller, internal passage and ports in a valve body and also the cooling channels in a turbine blade. The fundamental hurdle during prototype development and short run production is cost and the time for injection in moulds .This process overcomes all the above stated problems but requires a higher lead time and cost only for small quantities.

Design process for the investment casting needs to be planned by using ABS pattern which is to be created from FDM (Stratasys FDM Rapid prototype (RP)).the die manufacturing step need to re-plan for saving time of manufacturing and cost also.

4.3 RAPID PROTOTYPING

Minimal set-up time which can directly generate three dimensional objects directly from computer based models. It is often called desktop manufacturing. It is a layer by layer addition of the cross-section of the final part. Great competitive advantage can be achieved with RP as it is possible an advanced manufacturing technique having short lead time and to get the tool with in no time as compared with the previous one and ensuring a short time to market. With the help of fused deposition modelling ABS patterns can be easily produced and thus providing a good technological solution to the problem mentioned above.

4.4 RAPID PROTOTYPING –A STARTING STEP FOR INVESTMENT CASTING CONVENTIONAL INVESTMENT CASTING PROCESS

During conventional investment casting first step is to manufacture the tool and then wax patterns are formed on the basis of this tool. After wax pattern gating and riser system is designed so as to form the tree for the coated patterns (pattern are coated from silica binder and fine grained fused silica and coarse grain silica layers).the tree is placed in a chamber having high pressure and superheated steam so that after sometime time the wax melts out leaving a cavity or hollow shell. This process consumes 12 to 14 weeks for only tooling step.

4.4.1 ABS PATTERN FROM RP

RP assisted ABS pattern is formed by making a 2D cross-section on either AUTO-CAD, CATIA etc. and converting it into stl format which is then used for prototyping. After pattern formation this is used for tool formation from which same method of conventional investment casting is to be followed i.e. wax pattern is formed and then it is sunk in a phenolic resin or biosint (CoCr) solution and then rinsed. After rinsing it is further covered with the clay powder so that it perfectly fixed for good surface and then tree is formed for placing it in the muffle furnace. Wax melts down leaving the shell hollow. This process consumes up to 4 weeks.

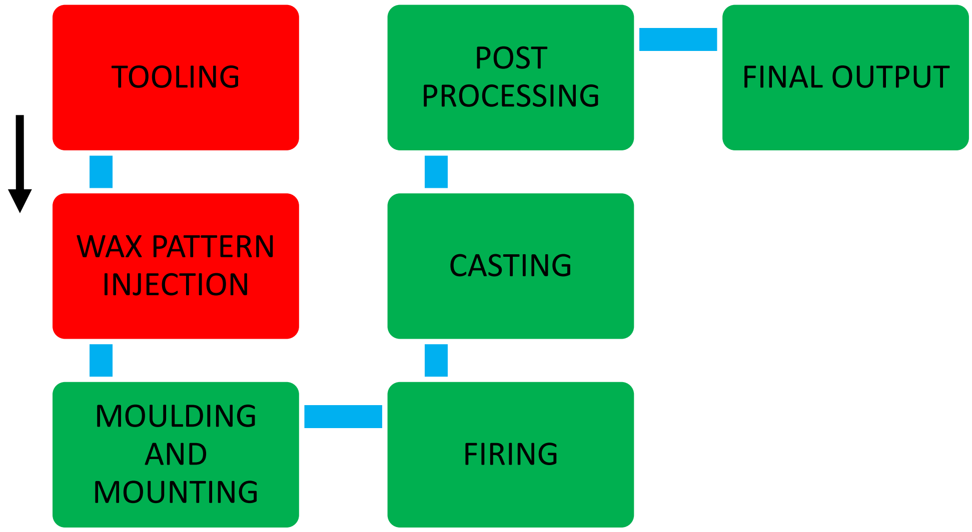


Figure 4.1 Traditional method of Investment casting

(FIRST TWO REQUIRE 6-8 WEEKS FOR COMPLETION WHILE REMAINING STEPS REQUIRE ONLY 4 WEEKS)

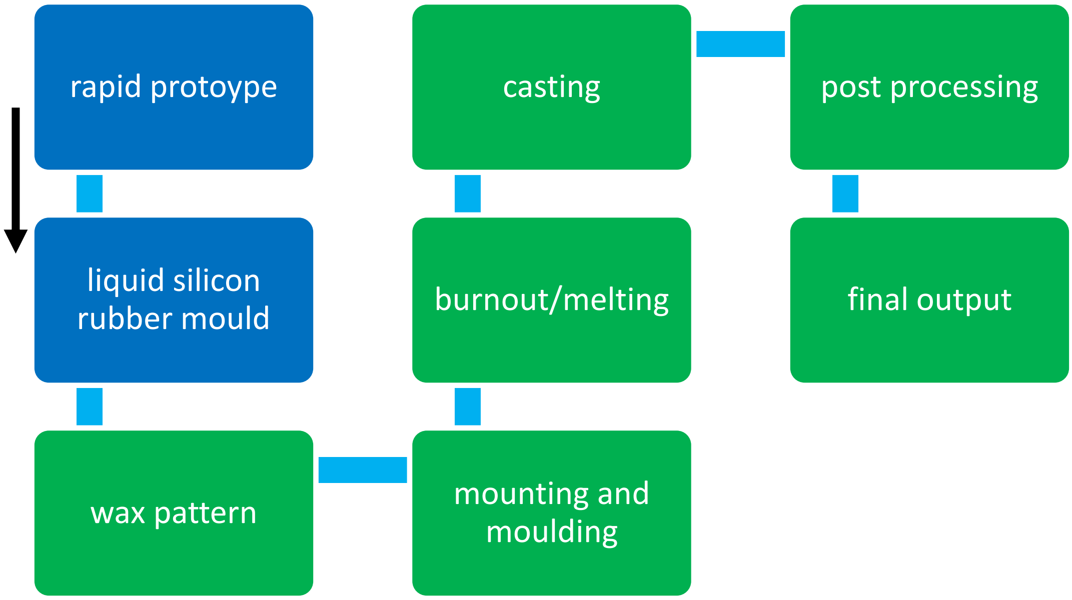


Figure 4.2 RP-Assisted Method

(FIRST TWO REQUIRE 3-4WEEKS FOR COMPLETION WHILE REMAINING STEPS REQUIRE ONLY 4 WEEKS)

4.5 ABS PART FOR BUILDING BLOCK

4.5.1 BLOCK PREPARATION
4.5.2 LIQUID SILICONE RUBBER MOULD
4.5.3 GATING AND VENTING
4.5.4 MODEL TECHNIQUES
4.5.5 PART DESIGN
4.5.6 SHRINKAGE

4.5.1 BLOCK PREPARATION

Thermal expansion experiments (Conducted in literature by Blake) for block IC have shown that ABS expands up to a maximum of 0.35% at approximately 212 °F (100 °C), at which it levels off. After 125c it starts to melt so in order to prepare block what one need to do is either use it with proper care or use this pattern for building tool of silicone rubber.

4.5.2 LIQUID SILICONE RUBBER MOULD

ELASTOSIL® M4511 (RTV-2 silicone rubber) can be cured with different catalyst T-21, T-26, T-51 etc (5 wt %) for different pot life to prepare a mould of silicone rubber so as to have a wax pattern from it. After using any one of the above combination liquid silicone rubber mould is prepared which can handle a temperature range from -5°C to 170°C (it can work for a wider range also).After a curing time of silicone rubber liquid wax can be poured into the mould cavity (wax has melting point of 55°C).after a period of 3 hours one can have the wax pattern ready for usage.

4.5.3 GATING AND VENTING

Gating and venting considerations are very important to the success of the IC casting. For proper combustion to occur, air must get inside the investment through properly placed gates and riser. The gates, feeders or risers and vents are also necessary to provide passages for the ash removal. Therefore proper care should be taken while taking into account the Gating and Venting system.

4.5.4 MODEL TECHNIQUES

This report demonstrates the capability of using liquid silicone rubber for building the wax patterns in short span of time for IC process.

4.5.5 PART DESIGN

All parts that are to be cast require design techniques for manufacturing. This includes working with the foundry to establish part size, wall thickness, minimum feature size, the addition of fillet radii and the elimination of sharp corner and knife-edge.

4.5.6 SHRINKAGE

All ABS patterns must be supplied in a larger size to compensate not only for the metal Shrinkage but also for wax shrinkage. According to literature (Blake) with the foundry practical consideration regarding the specific required shrinkage factor is taken approximate 1.11-1.31 mm (found by conducted case study).

4.6 FINISHING TECHNIQUES OF RP PATTERN

Castings produced from RP part have exact surface reproduction, which is good for its feature replication ability, but likewise a detriment because it captures layer formation and any defects due to the building process. Usually defects are negative, there are imperfections protruding into the part and are captured by the first block coat applied, and is therefore replicated in the casting (by Blake). It is obvious that any RP surface will never be as good as a wax pattern from a mould. Manual intervention is must to provide an acceptable part. The surfaces can be smoothened by filling (patching) and or by removal of marks (sanding).To help, Stratasys has produced a publication called Model Finishing Technique. One can use practically any filler, including wax and spray epoxy.

Option 1: vaporized solvent

Smoothing the surface of the FDM part is possible by sealing the surface by exposing the FDM part to a vaporized solvent for 15 to 30 seconds. Smoothing has been tested on ABS, ABS plus ABS-M30.

Option 2: Solvent Dipping

Solvent dipping, seals the surface by submerging the FDM part in a chemical bath for approximately 15 seconds. The recommended solvent is a Methylene chloride solution, if this is not available, Methyl ethyl Ketone (MEK).

Option 3: Painting

Painting will seal the part as well as fill in the layer lines. Spray the part with sand primer and allow it to dry. Then, sand the part to the desired finish. Repeat as necessary (by Blake).

4.7 FDM AND INVESTMENT CASTING

The key advantage of using FDM (fused deposition modelling) is that it eliminates the need for tooling. Injection moulds for wax patterns range from $3,000 to $30,000, and building the tools can take four to six weeks. With FDM, the tooling cost is eliminated and the lead time for a cast part is slashed to just 10 days on average. This yields a savings of $30,000 and two to four weeks for a typical project, which makes Investment casting viable for prototype quantities. Since FDM is an additive fabrication technology, there is no impact on the investment or delivery schedule as the pattern becomes more complex. Another advantage, which is unique to FDM, is that the soluble support technology allows interior passages to be constructed. Additional time savings also occur in casting design, since FDM patterns can be produced without adding draft angles to the CAD data. A final consideration is the durability of the pattern. Patterns made from foundry moulding wax and other additive fabrication technologies are easily damaged. And, transportation and routine handling can result in broken patterns. The strength and toughness of an ABS part built on a FDM 3D Production System virtually eliminates pattern damage and the delays it can cause. The ABS material is also resistant to distortion from heat, humidity and post curing which can be an issue with other additive fabrication technologies.

4.8 PROCESS OVERVIEW

The investment casting process begins with a pattern. Traditionally, the pattern was injection moulded in foundry wax, but this is replaced by ABS patterns made on a FDM RP system from which the wax pattern are to be built and these wax patterns are fabricated from silicone rubber which acts as a tool, which is a prerequisite for IC. Gates and vents are attached to the pattern, which is then attached to the sprue. After all patterns are mounted to the sprue producing what is called a casting block. At this point the casting block is ready for blocking. The casting blocks self setting to create a hard block that is called the investment. The patterns are then melted out (also called burnout) of the investment by putting on furnace, leaving a cavity in the shape of the part to be cast. A metal alloy is melted, often in an induction furnace, and poured into the preheated investment. After cooling, the block is broken away, the metal parts removed from block and the gates and vents are ground off.

4.9 ABS V/S WAX PATTERNS

The traditional IC process creates wax patterns utilizing a process similar to plastic injection moulding, where wax is injected into an aluminium tool to produce the pattern. Today, this process is well understood and practiced by thousands of IC foundries across the world. The Stratasys FDM process offers an alternative approach of creating a wax pattern from a tool. Patterns may be created directly from either ABS or wax materials. ABS is offered on FDM-P400, FDM 1600, FDM 1650, FDM 2000, FDM 8000 and FDM Quantum machines.

4.9.1 ADVANTAGES OF FDM ABS AND WAX PATTERN

FDM ABS:

i. Parts are strong and able to withstand the rigors (hard) of transportation
ii. Thin-walled parts can be created with accurate dimension.
iii. Surface finish is better than RP wax
iv. Parts can be post finish without fear of breakage
v. Users are more experienced at building accurate parts in this material.
vi. Any complicated and intricate shape part can be manufactured.

WAX FROM TOOLING:

i. Large quantities can be produced economically
ii. Consistency of dimensions
iii. Good surface finish.

4.9.2 DISADVANTAGES OF FDM ABS AND WAX PATTERN

FDM ABS:

Limited foundries, at this time, have experience of using ABS Foundries that have no experience need time to become proficient.

WAX FROM TOOLING:

i. High tooling cost, long lead times of up to 12 weeks- 14 weeks (Major task).
ii. Any wax part is fragile and transportation to a foundry could yield multiple parts.
iii. The melting point is 55 °C, which can be reached in the hot sun.

CHAPTER 5 EXPERIMENTATION

An Experimental Design is the laying out of a detailed experimental plan in advance of doing the experiment. Well chosen experimental designs maximize the amount of "information" that can be obtained for a given amount of experimental effort. The general principles for collecting data for construction of process models using well-planned data collection procedures is often the difference between successful and unsuccessful experiments. Design of experiments (DEX or DOE) is a systematic and rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible and supportable engineering conclusions. All of this is carried out under the constraint of a minimal expenditure of engineering runs, time and money.

The plan is to conduct the experimentation with following objectives:

- To verify the usage of silicone rubber in order to prepare wax pattern, this is to be further used in IC.
- To use the silicone rubber mould for bulk production of wax pattern.

5.1 ASSUMPTIONS

i. Component design (shape and size) of parts are nonlinear and somewhat complex structure.

ii. Wax Pouring Temperature is 55° C.

iii. Process parameters which remain same.

   a. Material Composition

   b. Operator skill

iv. In investment casting there is no need of parting line but still parting line is considered to be horizontal for locating gating system.

5.2 PROCESS

The following are the steps to carry out the experimentation:

i. Create the cad model on solid modelling software like catia, NX, Pro-E.

ii. Convert that cad model into .stl format files.

iii. The layer resolution, part surface quality, part interior style and support style parameters can be set using pre-processing software like Catalyst.
iv. Make the RP part using rapid prototyping machine.
v. Prepare liquid silicone rubber mould with the help of ABS pattern fabricated from FDM.
vi. Pour the liquid wax in this mould in order to have the wax pattern.
vii. After wax pattern, design the gating system for it and produce it.
viii. Mould is prepared using BIOSINT, water.
ix. Bake the mould into the muffle furnace
x. Investment casting.
xi. Analyze the casting result.
xii. Conclusion.

5.3DIFFERENT ABS PARTS FROM FDM PROCESS

Figure 5.1ABS part

Figure 5.2ABS Part (gear)

Figure 5.3ABS Part (femur bone)

5.4 MATERIALS AND ACCESSORIES REQUIRED TO PREPARE THE MOULD

i. Beaker
ii. a stirrer
iii. measuring scale
iv. glue
v. hard cover box or X-Ray film
vi. liquid silicone rubber
vii. RP parts
viii. Sealing wax
ix. Scissors.

5.5 STEPS & CALCULATION FOR USING SILICONE RUBBER

Figure 5.4ABS pattern used in mould preparation

Figure 5.5 Fixing the ABS pattern on a board and enclosing the part in a frame

Figure 5.6 Mixing the silicone rubber

Figure 5.7 Pour the silicone rubber

Figure 5.8 Place the frame for 8-10 hours (curing time)

Figure 5.9 Remove the pattern from the silicone rubber mould

Figure 5.10 Part the mould if required with proper care

Figure 5.11 Arrange the heater and calculate the volume required to be poured

Figure 5.12 Put the wax in a container and heat it to 50-60°c

Figure 5.13 Pour the melted wax directly in the rubber pattern

Figure 5.14 After a solidification time of 2-3 hours remove the wax pattern

From the mould (time depend upon the size of mould)

5.3VARIOUS MOULD OBTAINED FROM DIFFERENT ABS PARTS

Figure 5.15 Mould from pattern A

Figure 5.16 Mould obtained from pattern B

Figure 5.17 Mould obtained from pattern C

Table 5.1 different parts used and their wt.

S.No.	PART	Weight (in grams)	volume	Volume required
1.		**45.38**	**42.412**	**67.859**
2.		**31.16**	**29.121**	**46.594**
3.		**11.85**	**11.074**	**17.718**

5.4 STEPS TAKEN FOR WAX PATTERN BUILDING

i. Calculate the volume required for the tool making.

ii. Select a container that will hold the model and liquid rubber (a paper bucket can be used to contain silicone rubber)

iii. secure model to the base(a glue bead is used at the edges to fix model to the base)

iv. Build a frame so that model is in the center and also secure it to the base.

v. Thoroughly mix the base compound i.e silicon rubber with the curing agent and avoid bubble formation while mixing.

vi. Pour the RTV silicone rubber until the master is completely covered

vii. Avoid any bubble formation while pouring the silicone rubber and if bubbles appears while pouring try to remove these by shaking the the frame or use vibrating machine.finally allow the mould to stand for the specified time .

viii. Once the curing is finished (curing time for elastosil M4511 with T21 is 8-10 hours) remove the mould from the master pattern(RP pattern).
ix. A releasing agent can be used on silicone rubber as per need(Elastosil M4511 needs no releasing agent for wax).
x. Assemble the mould (if in two parts) with hard cover on the sides in order to avoid any leakage from sides (in case of partion of mould).
xi. Arrange wax and electric heater and put the wax in a containar and melt it in order to pour the wax.
xii. Read the temperature of the wax and pour the wax when temperature goes to 50-60°c because higher temperature leads to lower life of mould.
xiii. Pour the wax over the mould and gently place it for solidification (try to use the atmosphere conditions for solidification in less time for large no of production).Setting time is 2 hours.
xiv. After solidification remove the mould from the wax pattern.

5.5 HOW TO DECIDE THE PARTING LINE FOR THE SILICONE RUBBER MOULD WHICH IS OPAQUE

i. Place the master pattern on the gate part and fix it to the base.
ii. Take an image of the set up.
iii. Take a print out of the image and mark a zigzag line in order to equally divide the mould at the time of cutting(with a solid marker)
iv. Paste this image to any of the two opposite side walls and pour the silicone rubber and after curing time remove the frame.
v. Removal of frame from mould results the same line on the mould and cut the mould exactly along this curve with the help of a sharp blade.
vi. After following this line one will find the mould to be cut exactly in the same manner as desired and thus no difficulty while removing the pattern.

In this way even an opaque silicione rubber can be used for intricate shapes and transparent silicone rubber usage can be avoided which is much costly than that used above.

5.6 WAX PATTERNS FROM SILICONE RUBBER MOULDING

Figure 5.18 Wax pattern from ABS part A

Figure 5.19 wax pattern of femur bone

Figure 5.20 wax pattern of femur bone

5.7 BIOSINT MOULD MAKING

i. wax pattern of which mould cavity is to be prepared is placed on surface and around it x-ray film or any other film is placed and fix with packing wax.

Figure 5.21 wax pattern framed in x-ray film

Figure 5.22 wax wires for fixing the X-ray film

ii. Runner and pouring basin can be made with the help of moulding wax.

iii. Biosint (CoCr) powder is be used to prepare shell in investment casting process.

Figure 5.23 bio-sint powder

iv. Powder should be vibrated properly with the help of vibrator machine.

Figure 5.24 powder on vibrator machine

v. Keep the assembly for minimum 40 min. and take out the X-Ray film.

Figure 5.25 Mould after soaking for 40 min.

vi. Insert the model into the furnace for 2 hours and take it out.

Figure 5.26 muffle furnace

Figure 5.27 cured mould after 2 hours

5.7.1 DEFECTS IN BIO-SINT MOULD PREPARATION

i. If time and temperature both are increased then Block becomes more brittle and Crack occurs in mould.
ii. If kept for less temp then residue/half burn of the wax pattern might be there resulting in casting defects.
iii. If block is kept vertical, possibility of choking of basin in bottom position may take place.
iv. If shell thickness reduces, the chance of crack occurs in mould means mould will not wear/sustain the pouring of molten metal.

Therefore, areas which need to be kept in mind while preparing mould are:

i. Time and temperature should be increased step by step and also with-in range in order to have control over the mould strength.
ii. Time and thickness of the shell are also the two important criteria which need to be cared while making the mould or at the initial stages of mould design.

Possible defects in wax pattern building from silicone rubber mould:

i. Cavity on the outer surface is a result of the low temperature of wax while wax is poured.
ii. Wax can distort if some fluid is used to surround it in order to have faster cooling rates (during experiment water is used which distorted the shape, as water is having higher density than wax, so in order to have faster cooling rates a fluid of lower density than wax can be used).
iii. Possibility of pattern damage is also there while removing the wax pattern from the rubber mould.

CHAPTER 6 COST ANALYSIS AND CONCLUSION

6.1 COST ANALYSIS

RP-assisted silicone rubber moulding cost

Cost on RP machine = 700 Rs/Hr

For Implant, Time required is = 2 Hr 14 min.

Cost of ABS Implant = (1400+163.33) =1564 Rs

Silicone rubber mould cost

Silicone rubber cost =980 RS/kg

Amount of silicone rubber required =300 gm

Cost of required silicone rubber =294 Rs

No of silicone rubber moulds possible from ABS pattern =3000

No of wax patterns possible from silicone rubber mould =100

Wax cost =80 Rs/kg

Wax required =187gm

Wax cost =15 Rs

Cost of wax pattern = (1564/3000) + (294/100) + 15

= 18.5 Rs/wax pattern

Conventional method cost

Cost of die (intricate shape) = 20,000 Rs

Patterns of femur bone almost impossible

No. of pattern possible with die = 8000

Cost per pattern = 4Rs

Wax cost = 80 Rs/kg

Wax required =187gm

Cost of wax pattern =2.5+15 =17.5 Rs

Time consumed in wax pattern building

By conventional method = 5-6 weeks

By proposed method = 2-3 weeks

Time saved is almost 2 weeks but cost incurred during proposed method is a little bit larger than the conventional method.

6.2 SURFACE ROUGHNESS TESTING ANALYSIS

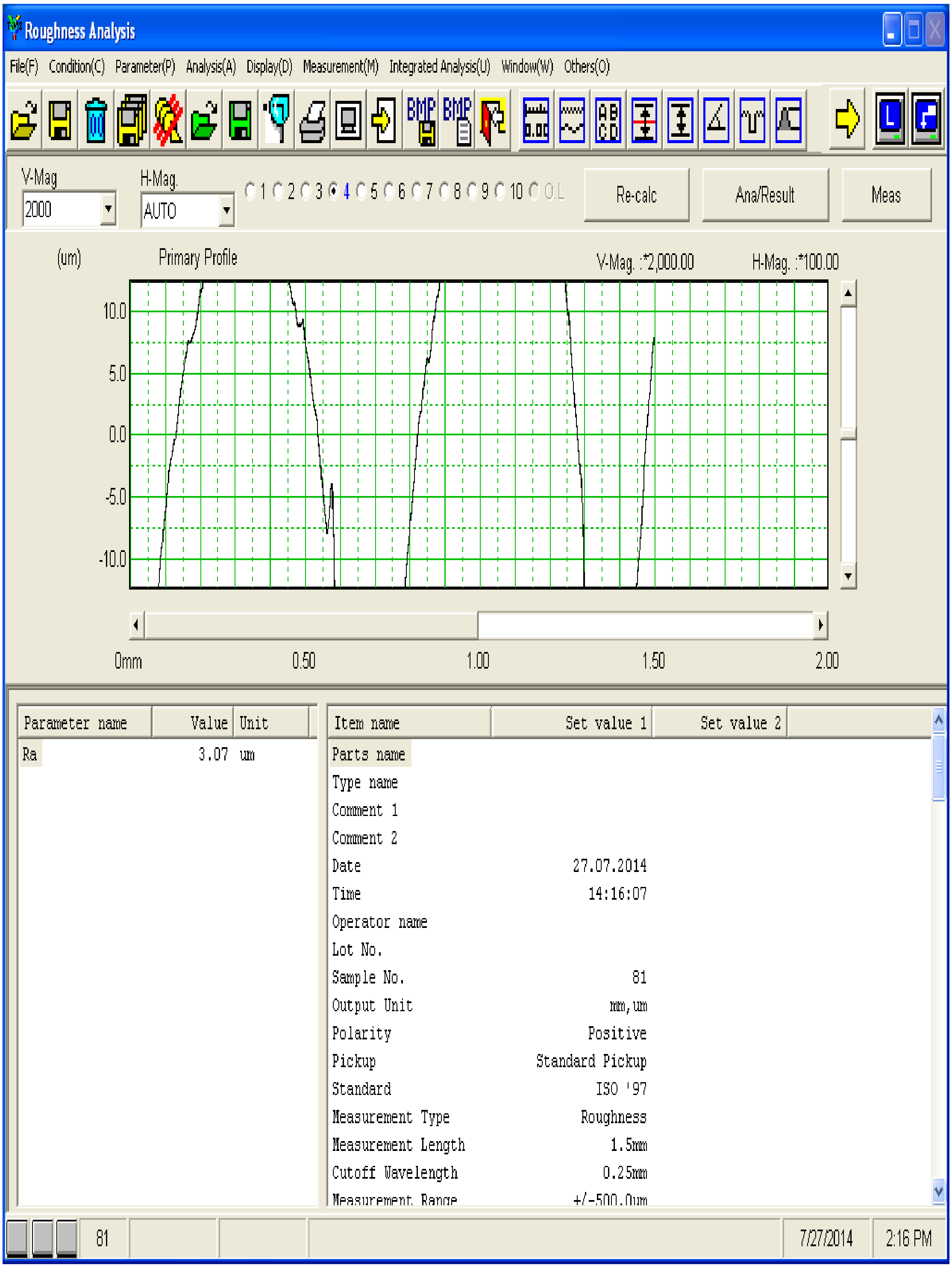


Figure 6.1 ABS 01

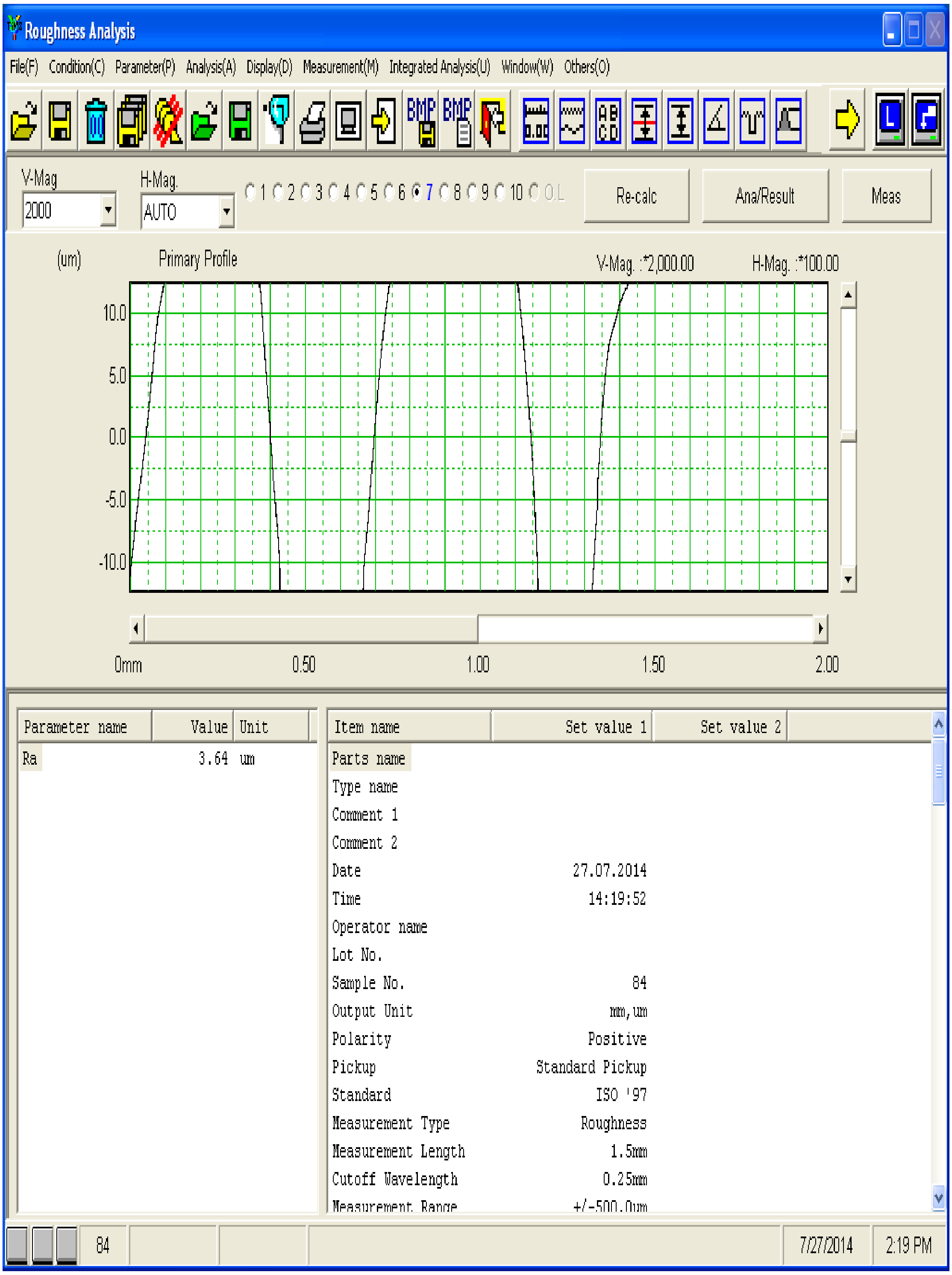


Figure 6.2 WAX 01

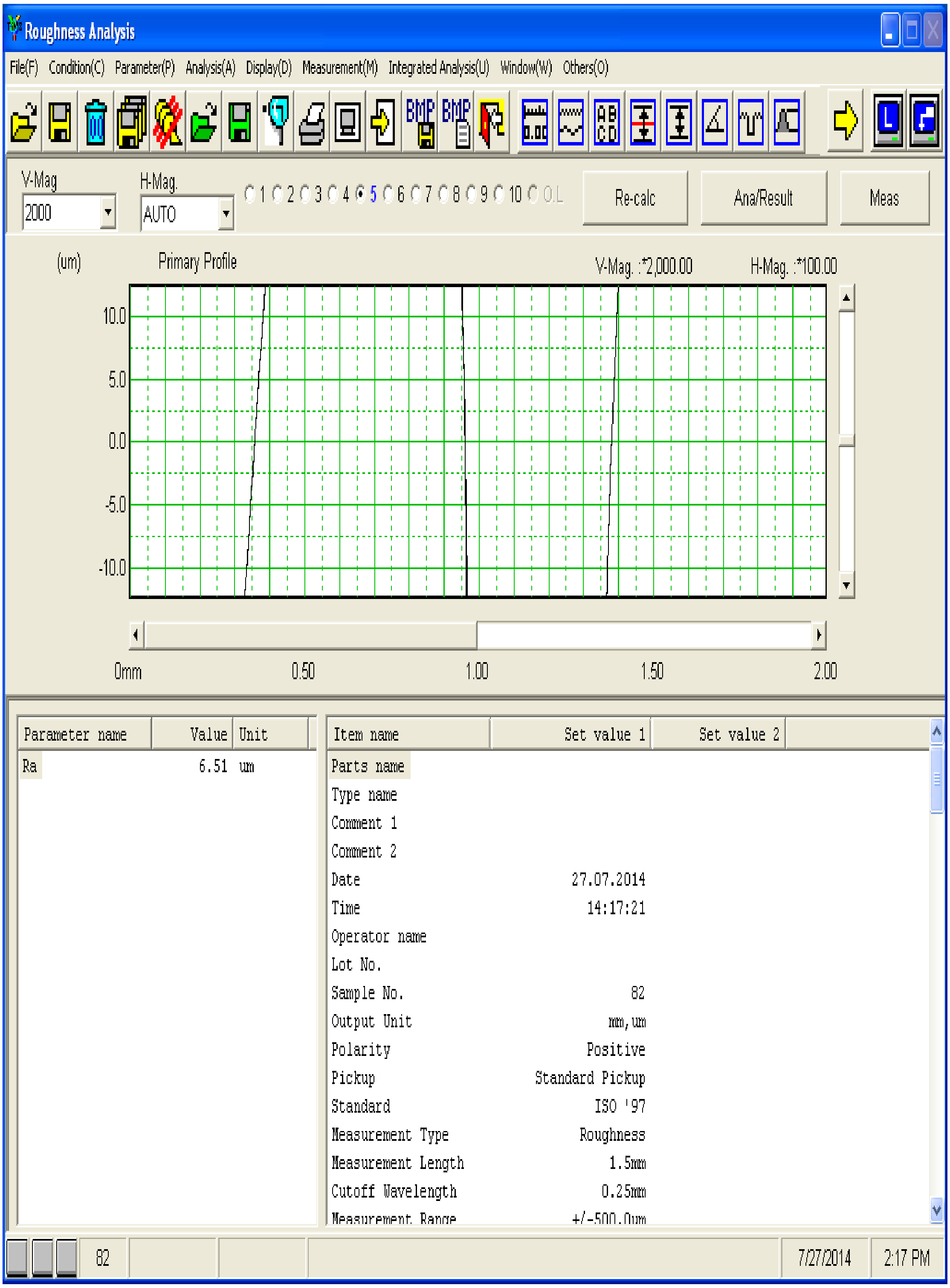


Figure 6.3 ABS 02

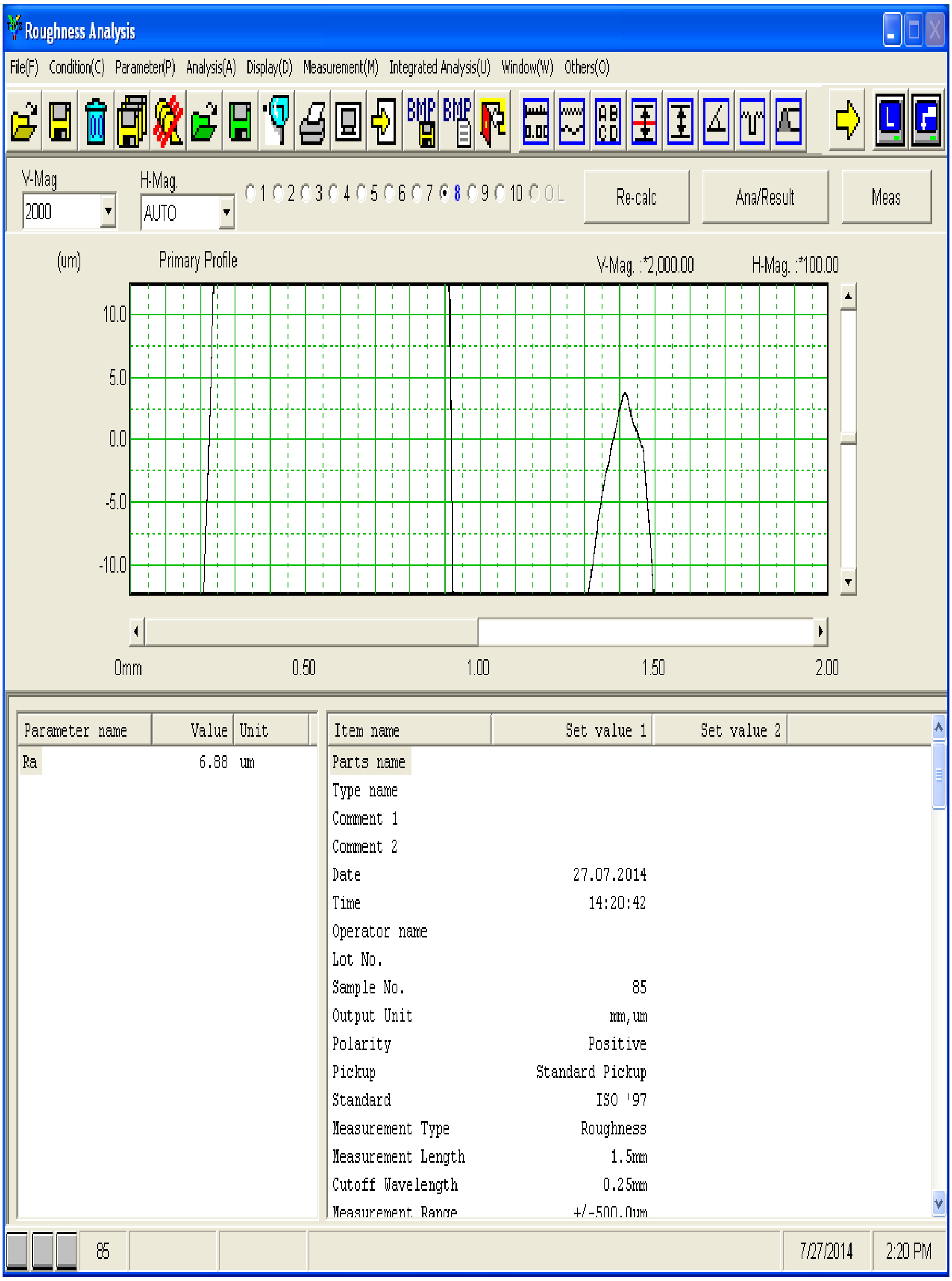


Figure 6.4 WAX 02

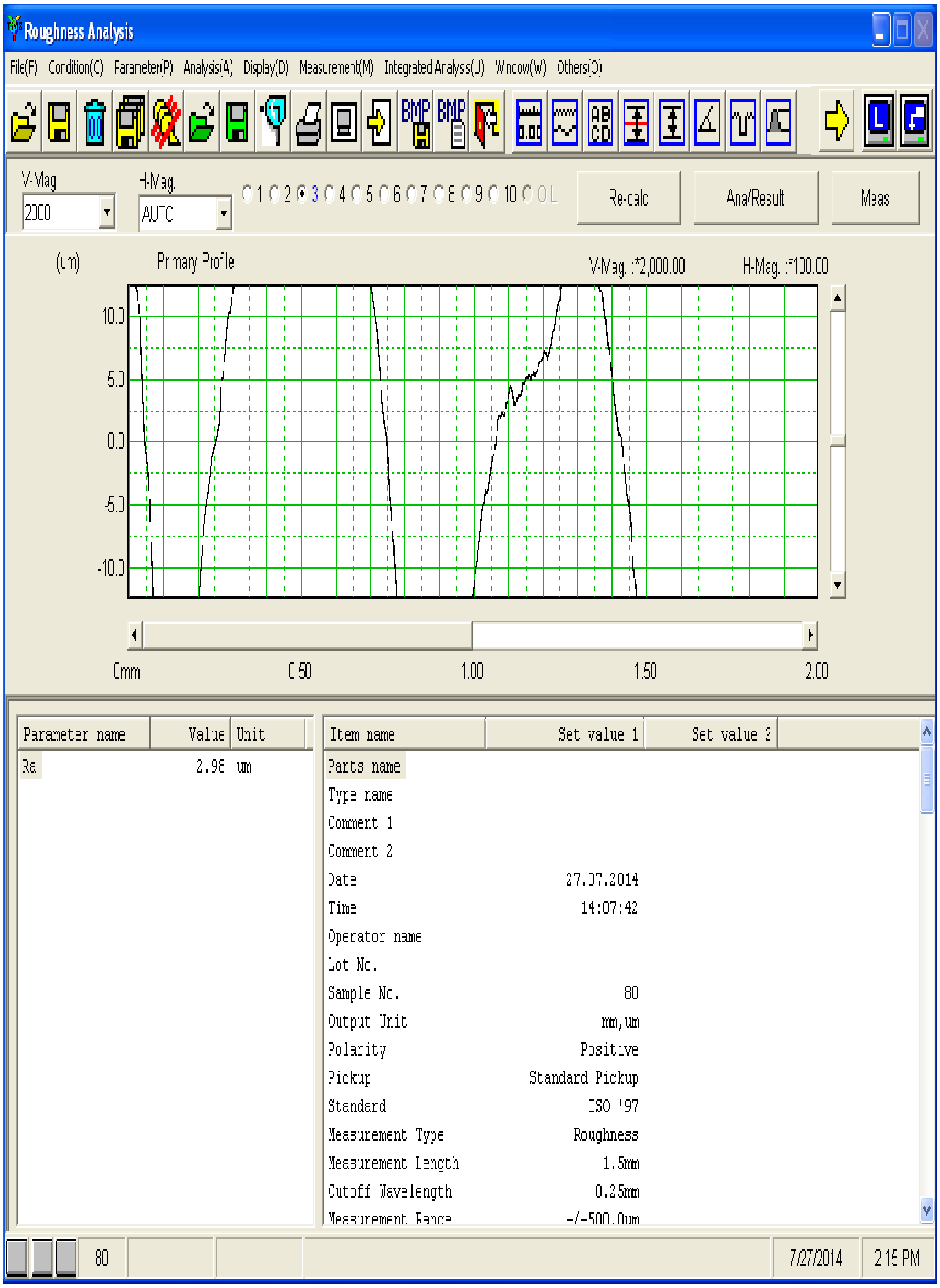


Figure 6.5 ABS 03

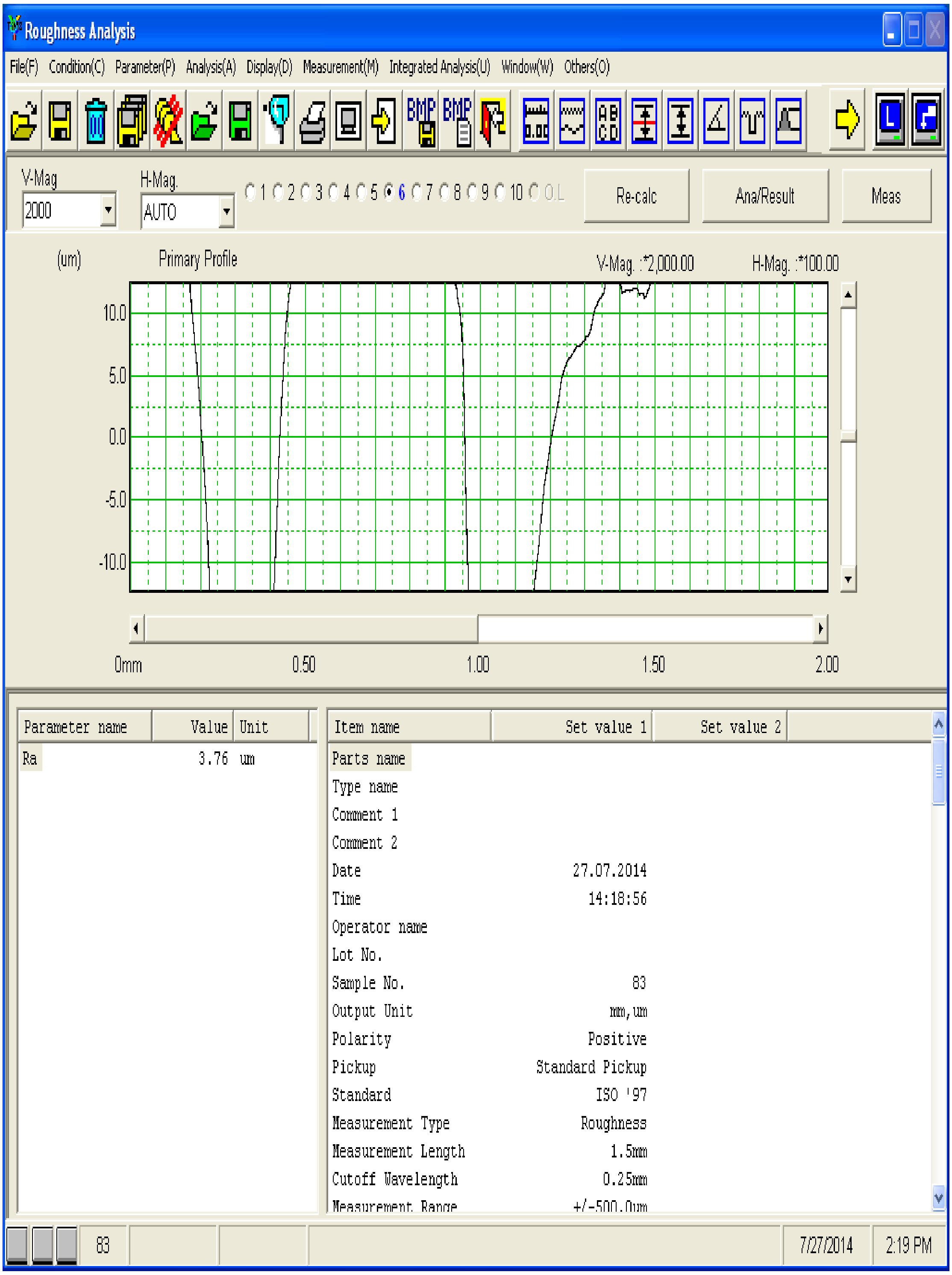
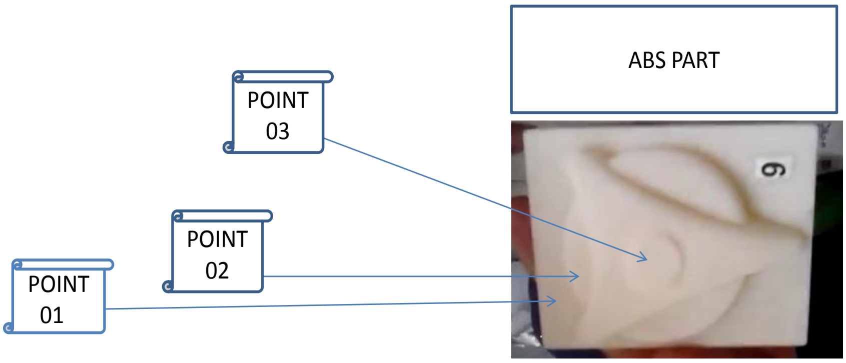
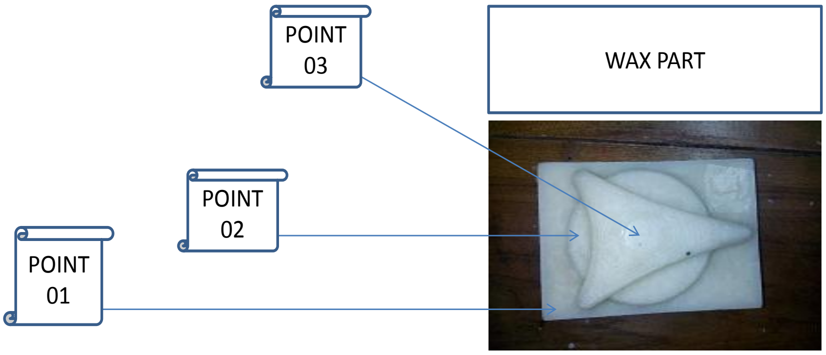


Figure 6.6 WAX 03





The above ABS vs. WAX comparison shows the following surface roughness output:

PART TYPE → / Ra VALUE (µm) ↓	ABS	WAX
POINT 01	3.07	3.64
POINT 02	6.51	6.88
POINT 03	2.98	3.76

The closeness of above values suggests that the feasibility criteria of RP-assisted silicone rubber moulding method discussed above is quite useful. The values also validates the surface roughness of three different simultaneous surfaces both at ABS & wax parts. Though the comparable set of values are quite near but discernible variation for point 03 is due to part mishandling.

6.3 CONCLUSIONS

In casting product development, design information is important in process determination, tooling design, casting system, and product assurance and control. Traditionally, this information can only be revealed via the tryout realization of design solution in workshop.

With FDM patterns, investment casting is practical for casting low volume of products. Production of investment casting patterns out of ABS materials saves time. In this modern world, demand of customers keep on changing day by day and if in case a products design need to be changed then cost of the tool making through conventional method results in very high cost. Apart from this an ABS pattern can be easily built from FDM process within no time. With this process technique companies can take advantage of on the efficiency, capability and quality of investment casting. As a conclusion, the proposed solution of platinum cured silicone rubber as moulding material in investment casting process is proved to be effective for the producing wax patterns and then following the investment casting, in very short times.

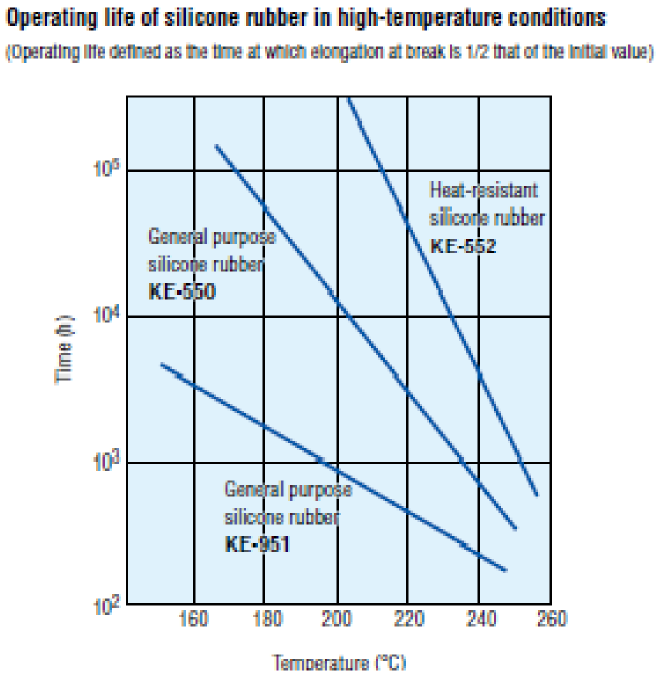
- Complex shapes can be easily manufactured by this technique.
- Various applications in medical field.
- Pattern built from ABS offer a no. of quality advantage.
- Time required for tool making is almost half of that required in conventional tool making which may prove as the best utilisation of time.

APPENDIX

APPENDIX A- SILICONE RUBBER

Manufacturer and product description

Manufacture	Description
Wacker	4511 (T21, T24 etc.)
MG chemicals	RTV 630
Shinetsu	KE1310ST
MCP	VTX950



FigureA.1 Operating life v/s temperature

Results of long-term outdoor exposure testing of various rubbers

Rubber type \ Deterioration conditions / Location	Time until surface cracks are first apparent (years)		Time of sunlight exposure until elongation is 1/2 that of the initial value (years)	
	Panama	Rock Island	Panama	Rock Island
Styrene butadiene	2 - 3.5	Over 10 years	4	10
Nitrile	0.5 - 1	—	7	10
Chloroprene	—	—	8.5	Over 10 years
Silicone (methyl vinyl)	Over 10 years	Over 10 years	Over 10 years	Over 10 years to decline to 75%
Silicone (methylphenyl)	—	—	Over 10 years	Over 10 years
Fluorosilicone	—	—	0.5	4
Ethylene propylene	—	—	10	Over 8.5 years to decline to 75%
Fluorine	10	10	Over 10 years to decline to 90%	

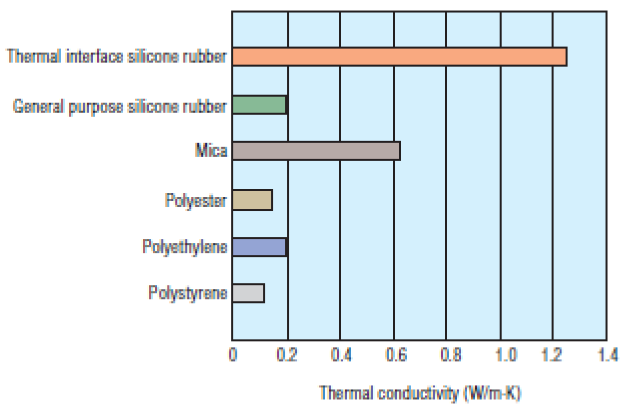
FigureA. 2 Weather ability

TableA.2 Change in volume of rubbers

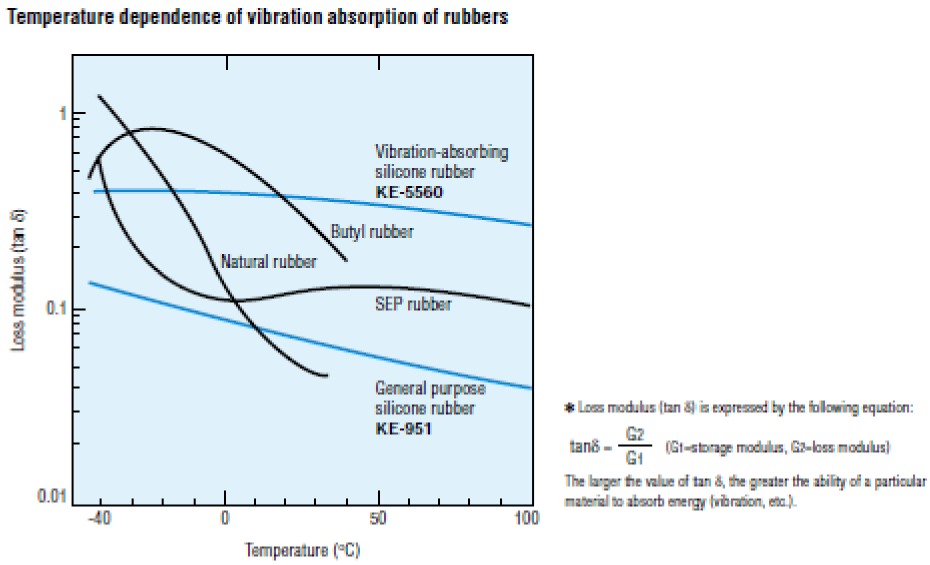
Change in volume of rubbers caused by various fluids (after 168-hour immersion)

Fluid type	Temperature °C	Nitrile			Chloroprene	Natural rubber	Styrene butadiene	Butyl	Silicone	Hypalon®
		28%	33%	38%						
Gasoline	50	15	10	6	55	250	140	240	260	85
ASTM #1 oil	50	-1	-1.5	-2	5	60	12	20	4	4
ASTM #3 oil	50	10	3	0.5	65	200	130	120	40	65
Diesel oil	50	20	12	5	70	250	150	250	150	120
Olive oil	50	-2	-2	-2	27	100	50	10	4	40
Lard	50	0.5	1	1.5	30	110	50	10	4	45
Formaldehyde	50	10	10	10	25	6	7	0.5	1	1.2
Ethanol	50	20	20	18	7	3	-5	2	15	5
Glycol	50	0.5	0.5	0.5	2	0.5	0.5	-0.2	1	0.5
Ethyl ether	50	50	30	20	95	170	135	90	270	85
Methyl ethyl ketone	50	250	250	250	150	85	80	15	150	150
Trichloroethylene	50	290	230	230	380	420	400	300	300	600
Carbon tetrachloride	50	110	75	55	330	420	400	275	300	350
Benzene	50	250	200	160	300	350	350	150	240	430
Aniline	50	360	380	420	125	15	30	10	7	70
Phenol	50	450	470	510	85	35	60	3	10	80
Cyclohexanol	50	50	40	25	40	55	35	7	25	20
Distilled water	100	10	11	12	12	10	2.5	5	2	4
Sea water	50	2	3	3	5	2	7	0.5	0.5	0.5

Thermal conductivity of thermal interface silicone rubber



FigureA. 3 Comparison of thermal conductivity



FigureA.4 Vibration absorption dependency over temperature

APPENDIX B-BIOSINT

TableA.2 Technical data sheet for zirconium sand

TECHNICAL DATA FOR ZIRCONIUM SAND	
Mixing ratio	100 g powder : 15 ml liquid
Total expansion	0.95 % - 1.65 %
Mixing time under vacuum	60 second
Processing time span	3 – 5 min
Compression strength	According to concentration of the expansion liquid between 15 and 20 MPa

The total expansion, i.e. the sum of setting expansion and thermal expansion can be changed by diluting the Biosol-E mixing liquid as shown in table 2.

TableA.3 Effect of BIOSOL-E on total expansion

EFFECT OF BIOSOL-E ON TOTAL EXPANSION				
Mixing Liquid Consisting of:		Concentration of Biosol E	Total Sum of:	
Water	Biosol E		Setting exp.	Thermal exp.
4 parts	0 parts	0 %	0.30 %	0.65 %
2 parts	2 parts	50 %	0.35 %	0.95 %
1 parts	3 parts	75 %	0.45 %	1.05 %
0 parts	4 parts	100 %	0.50 %	1.15 %

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