STUDY OF DIFFERENT TYPES OF ABRASIVE MEDIA USED IN ABRASIVE FLOW MACHINING

A THESIS SUBMITTED IN FULFILMENT OF
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BY

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled "**Study of different types of abrasive media used in Abrasive Flow machining**" in partial fulfillment of the requirements for the award of **Master of Technology** in **Production Engineering** at **Delhi Technological University**, **Delhi** is an authentic work carried out by me under the supervision of **Dr. R.S.Walia** and **Dr. Qasim Murtaza**. The matter embodied in this report has not been submitted to any other university/institute for award of any degree.

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This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ABSTRACT

For products having internal inaccessible cavities or recesses, general finishing processes like lapping, honing etc. are used but they suffer from disadvantage of low quality of surface finish and that too with high equipment cost. Therefore need arises for an alternate process which has the capability of nano level finishing. Abrasive Flow machining (AFM) is such kind of fine finishing technique for these kind of products. This method has a unique property of simultaneous improvement in material removal and surface finish. It employs an abrasives laden semi-solid media, which acts as a self-deforming cutting tool and can finish the complex cavities under a hydraulic pressure. The work piece hardness, no of cycle, volume of media, Extrusion pressure and properties of carrier media are the important process parameters that affect the performance of AFM. Abrasive flow Machining has a limitation of low material removal. So to reduce this limitation, a number of varieties of media have been used by many researchers and scholars of this field. So main aim in this report work is to study the different types of media used in this AFM process and to choose a polymer based media to cause more material removal and better surface smoothness. The five media used in this research work is Polyborosiloxane, Silicone Rubber, SBR Rubber, Nitrile Rubber and Natural Rubber, Out of which Silicone Rubber is best media.

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CHAPTER 1

INTRODUCTION

It has been proved already that quality of surface finish can dramatically improve product performance and lifetime. It means that a product having good quality of surface finish will have greater functional performance as well as longer lifetime as compared to same product with poor quality of surface finish. The quality of the surface finishes along with dimensional and alignment accuracy are taken care of by finishing processes such as grinding, lapping, honing etc. These processes are known as traditional methods of finishing. But these traditional finishing processes are only applicable or limited to the production of workpiece of basic forms such as flat, cylindrical, etc. These finishing processes are being pushed to their limit in components of hard materials and complicated shapes. Hence, need arises to develop a finishing process with wider application area as well as better quality of the surface finish accompanied with higher productivity.

1.1 Nonconventional Manufacturing Processes

An unconventional machining process is a special kind of machining process in which there is no contact directly between the tool and the workpiece which is used for manufacturing. In unconventional machining, various form of energy is used to remove unwanted material from a workpiece. In many of the industries, hard and brittle materials like tungsten carbide, high speed steels, ceramics etc., find a variety of applications. For example, tungsten carbide is used as a cutting tool while high speed steel is used manufacturing of gear cutters, drills, milling cutters etc. If these materials are machined with the help of traditional machining processes, either the tool undergoes extreme wear or the workpiece material is damaged. This is so because, in conventional machining, always there is a direct contact between the tool and the work material. Large cutting force is required and material is removed in the form of chips so huge amounts of heat are produced in the workpiece and this induces residual stresses, which degrades the life and quality of the work material. Hence, conventional machining produces poor quality product with poor surface finish.

To overcome all these drawbacks, we use unconventional machining processes to machine hard and brittle materials. We also use unconventional machining processes to machine soft materials, in order to get better dimensional accuracy.

1.2 Abrasive Flow Machining Process

Abrasive flow machine was first introduced by U.S.A. based extrudes hone corporation in 1960. AFM is mainly used for complex internal inaccessible cavity and shapes. Abrasive flow machining (AFM) is a unique non-traditional machining process developed as a method of fine finishing, polishing by flowing an abrasive laden media. It is also use for the finishing of difficult to machine areas and surfaces. In AFM, a semi-solid media consisting of a polymer-based carrier and abrasives in required proportions is extruded to and fro from the surface to be machined. The mechanism of visco-elastic medium is similar to a deformable grinding tool whenever and wherever it is subjected to restriction to flow. The medium is so flexible enough to mould itself to any complex shape or contour, and it is able to finish hard and tough materials.

1.3 Basic principle of AFM

Commonly used AFM is Two-way AFM in which two vertically opposed cylinders extrude medium back and forth through passages formed by the workpiece and tooling as shown in figure. AFM is used to deburr, radius and finish difficult to reach surfaces by extruding an abrasive laden polymer medium with very special rheological properties. It is widely used finishing process to finish complicated shapes and profiles. The polymer abrasive medium which is used in this process, possesses easy flowability, better self-deformability and fine abrading capability.

Layer thickness of the material removed is of the order of about 1 to 10 μm. Best surface finish that has been achieved is 50 nm and tolerances are +/ - 0.5 μm. In this process tooling plays very important role in finishing of material, however hardly any literature is available on this aspect of the process. In AFM deburring, radiusing and polishing are performed simultaneously in a single operation in various areas including normally inaccessible areas. It can produce true round radii even on complex edges. AFM reduces surface roughness by 75 to 90 percent on cast and machined surfaces. It can process dozens of holes or multiple passage parts simultaneously with uniform results. Also air cooling holes on a turbine disk and hundreds of holes in a combustion liner can be deburred and radiused in a single operation. AFM maintains flexibility and jobs which require hours of highly skilled hand polishing can be processed in a few minutes; AFM produces uniform, repeatable and predictable results on an impressive range of finishing operations. 10 Important features which differentiates AFM from other finishing processes is that it is possible to control and select the intensity and location of abrasion through fixture design, medium selection and process parameters. It has applications in many areas such as aerospace, dies and moulds, and automotive industries.

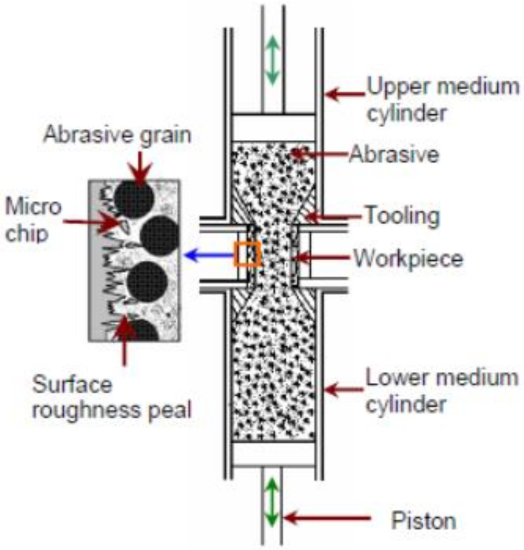

Figure 1: Principle of Material Removal Mechanism [7]

1.4 AFM TECHNOLOGY

The abrasive media is extruded back and forth through the passages formed by the work-piece and tooling with the help of hydraulic pressure system employing two opposed cylinders. Abrasion occurs wherever the medium enters and passes through the most restrictive passages. The media act as a self-modulation abrasive medium with good fluidity and viscosity so the cutting tools are flexible. Figure 1 schematically depicts the experimental apparatus for an AFM process. The equipment includes (a) a hydraulic pressure system, (b) a work-piece holding fixture, (c) a pair of medium containers, and (d) a controller. The piston pressurizes the medium in the cylinder in a forward direction and extrudes it through the work-piece into the other cylinder. Consequently, the medium abrade the work-piece in the work holder and fixture. The procedure is reversed and combination of these forward and backward strokes constitutes a process cycle.

1.4.1 One way AFM process: One way AFM Process is provided with a hydraulically activated reciprocating piston and an extrusion media chamber which is used to receive and extrude media uni-directionally across the internal surfaces of workpiece having internal cavity . In this fixture directs the flow of the media from the extrusion media chamber into the internal passages of the workpiece. In one way AFM process there is a media collector collects the media as it extrudes out from the internal passages.

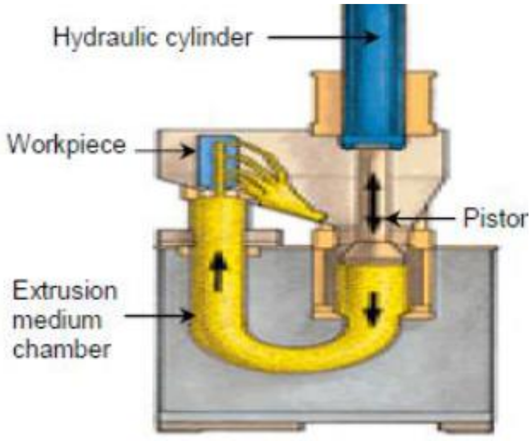

Figure 2: One way AFM machine operation [10]

The hydraulically actuated piston intermittently withdraws from its extruding position to open the extrusion medium chamber access port to collect the medium in the extrusion medium chamber. When the extrusion medium chamber is charged with the working medium, the operation is resumed.

1.4.2 Two-way AFM process: Two way AFM machine has two hydraulic cylinders and two medium cylinders. The medium is extruded, hydraulically or mechanically, from the filled chamber to the empty chamber via the restricted passageway through or past the workpiece surface to be abraded, as illustrated in Figure Typically, the medium is extruded back and forth between the chambers for the desired fixed number of cycles.

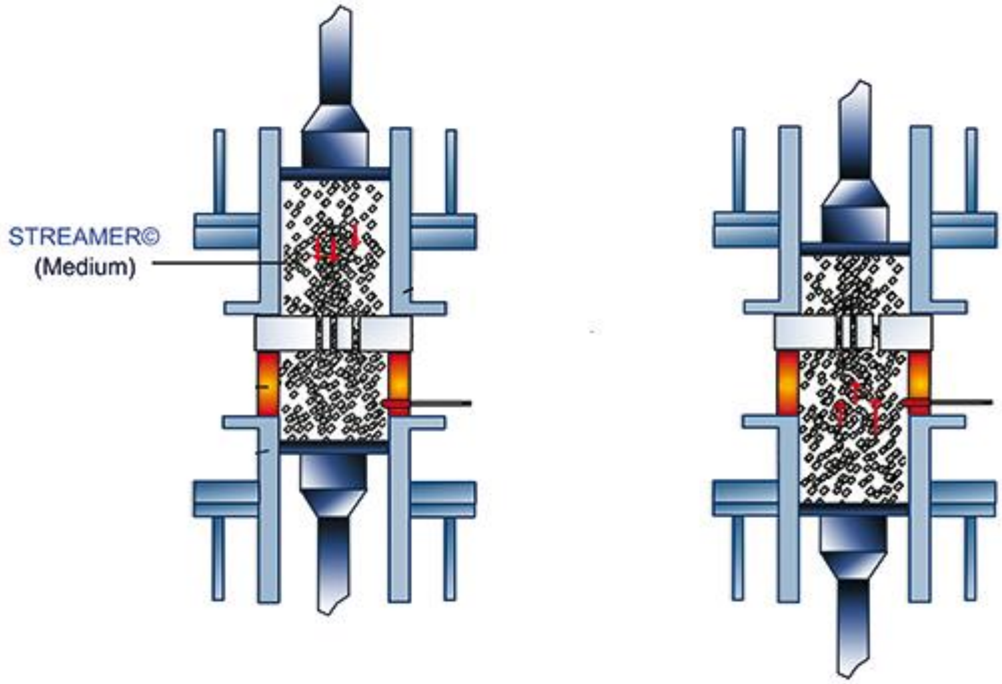

Figure 3: Two way AFM machine operation [12]

Counter bores, recessed areas and even blind cavities can be finished by using restrictors or mandrels to direct the medium flow along the surfaces to be finished.

1.4.3 Orbital AFM process: In orbital AFM, the workpiece is precisely oscillated in two or three dimensions within a slow flowing ‘pad’ of compliant elastic/plastic AFM medium, as shown in Figure. In Orbital AFM, surface and edge finishing are achieved by rapid, low-amplitude, oscillations of the workpiece relative to a self-forming elastic plastic abrasive polishing tool. The tool is a pad or layer of abrasive-laden elastic plastic medium (similar to that used in two way abrasive flow finishing), but typically higher in viscosity and more in elastic. Orbital AFM concept is to provide translational motion to the workpiece. When workpiece with complex geometry translates, it compressively displaces and tangentially slides across the compressed elastic plastic self-formed pad (layer of visco elastic abrasive medium) which is positioned on the surface of a displacer which is roughly a mirror image of the workpiece, plus or minus a gap accommodating the layer of medium and a clearance. A small orbital oscillation (0.5 to 5 mm) circular eccentric planar oscillation is applied to the workpiece.

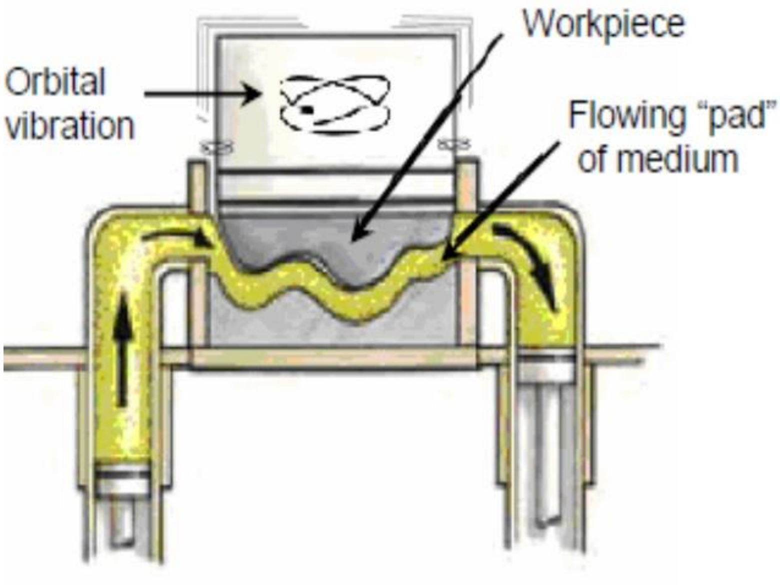

Figure 4: Orbital AFM machine operation [13]

1.5 AFM TOOLING

Fixture is made of steel, urethane, aluminum, nylon, Teflon, or a combination there of. And any number of parallel restrictions can be processed simultaneously with suitable tooling.

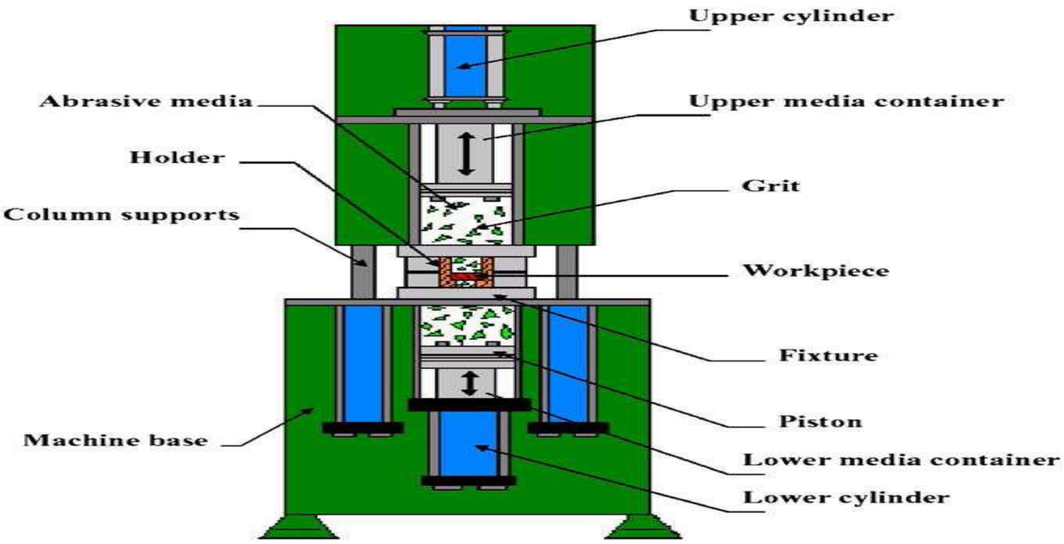

Figure 5: Schematic of Abrasive Flow Machining (Principle and Basic Operation) [10]

1.6 APPLICATIONS

A higher order of surface finish and close tolerance can be produced on a wide range of components by AFM. Major applications of the process are the finishing of aircraft hydraulic and fuel system components and critical parts, such as fuel spray nozzles, fuel control parts and bearing components which are tedious to machine. The process has ability of achieving high production rates by using the various hybrids of AFM in the processing of fuel injection systems, steering and braking systems, splines and gear, pump, valves and fittings etc.

AFM is suitable for work-pieces with complicated intersections (complex inlet manifolds and ports are polished with AFM leads to smoothness and thus more precise fuel and air distribution, resulting into more horse power and fuel efficiency of the automobile) refer figure 3, extrusion dies (for Aluminium and Plastic profiles), space and aeronautics Industry (AFM is used to remove very thin layers of coatings from the turbine blades for re-coating.), medical technology((such as machining implantable devices, pharmaceutical machines, or a slot on a staple slide for surgical instruments used to close incisions.

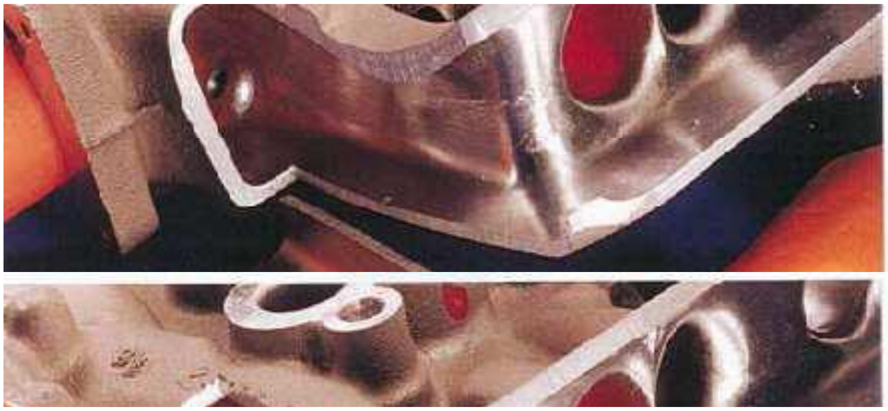

Figure 6: Intake manifold after manual AFM processing [9]

1.7 MAJOR AREAS OF RESEARCH IN AFM

EXPERIMENTAL RESEARCH

Abrasive flow machining is complex because of the little understood behavior of the non-Newtonian medium and the complicated and random nature of the mechanical action of material removal. There are numerous process parameters affecting the AFM performance and effectiveness (i.e. Material Removal Rate, Surface Finish, Abrasives Wear Rate etc.). Some of the experiments which have been conducted are effects of abrasive flow machining on various machined surfaces , Monitoring of Abrasive Flow Machining Process Using Acoustic Emission , improved fixtures, Temperature Dependence and Effect on Surface Roughness, Mechanism of Material Removal, rheological properties and the finishing behavior of abrasive gels, Forces prediction during material deformation, viscosity of media, cutting forces and active grain density ,and other parameters like number of cycles, extrusion pressure, media temperature, time, media velocity etc. Huge research is going on is going on in the field that how to increase the metal removal rate of the process. Number of researcher has given their views in the field of hybrids of abrasive flow machining, like the use of magnetic force, centrifugal force etc. these are known as hybrid AFM processes.

1.8 ABRASIVES LADEN MEDIA

This technique uses a non-Newtonian liquid polymer containing abrasive particles of aluminum oxide, silicon carbide, boron carbide or diamond as the grinding medium and additives. The additives are used to modify the base polymer to get the desired flowability and rheological characteristic of the media. The viscosity and the concentration of the abrasives can be varied .A number of researcher have concentrated on the field of media because it work as a carrier and abrasive which is grinding medium.

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CHAPTER 2

LITERATURE REVIEW AND PROBLEM IDENTIFICATION

Abrasive flow machining is a purely mechanical process. A chemically inactive and noncorrosive media, similar to soft clay is used to improve surface finish and edge condition be used the abrasive particle in the media grind away rather than shear of the material. The same type of media can be used on different used. In some cases batch of media can be used of different metals without transferring removed material between workpieces. AFM is used for surface or edge condition of internal or external or otherwise inaccessible holes, slots and edges. It is highly efficient and accurate. And can be used in one way or two way applications. The most abrasive action during AFM if a hole changes size or direction in any industry the final finishing of complex and precision component is the most time consuming and labor intensive part. This considers about 15 % expenditure on the overall manufacturing process. The complex finishing process requires manual handling which is very slow and detrimental to the health of workers. AFM process replace a lot of manual work leading to more standardization of manufactured parts, hence their interchangeability, mass production and reduced costs.

2.1 EFFECT OF AFM PROCESS PARAMETERS

The material removed from the surface and surface quality depends on the following.

1. No of Cycle
2. Extrusion pressure
3. Temperature
4. Viscosity
5. Abrasive particle size
6. Abrasive concentration

7. Particle density
8. Media flow rate
9. Particle hardness

A lot of work has been done to study the effects of important AFM process parameters. Some of the work have been reported. There are several research has been carried in the field of increasing the material removal rate and percentage improvement in surface roughness.

In modern era, the main thrust is to develop high performance products at competitive cost. This has been achieved through many ways like developing of new materials, which has high strength to weight ratio, high corrosion and erosion properties, non-chemical affinity etc. Many new processes are being developed for making the product to near net-shape. However, in order to have good performance, these materials are to be machined. Apart from the surface finish there is a drive to measure the surface integrity of the machined surface which has a direct impact on the manufacturing cost (Rhodes, 1991). Thus, there is a great demand for the manufacturing industries in developing new processes or hybrid processes towards better surface integrity. One such process is abrasive flow machining (AFM) developed by Rhodes (1991). This process was initially developed for deburring purpose but latter on extended its applications to radiusing, removing of recast layer and finishing of various materials. Apart from the above-mentioned advantages the other beauty of AFM process is that it can be used for machining of multiple workpieces simultaneously or multiple holes/cavity simultaneously of single work piece irrespective of complexity of surface. The AFM process consists of mainly three elements; machine, fixture/s and media/medium. The material is removed by random cutting edges with indefinite orientation and geometry of abrasives through restricting the flow of media by passage (Jain, 2002). Jain and Adsul (2000) have also carried out experiments to study the effect of process parameters (e.g. abrasive concentration, abrasive mesh size, numbers of cycles and flow rate of media) on material removal and surface roughness of aluminum and brass workpieces. They have concluded that the concentration of abrasives in media followed by mesh size, numbers of cycles and flow rate of media are the influencing parameters. The rheology of the MV (medium viscosity) grade polyborosiloxane has been investigated by Flether and Fioravanti (1996). They have also studied thermal conductivity, heat transfer coefficient at interface and found that the abrasives concentration has more impact as compared to the mesh size and polymer media. Davies and Fletcher (1995) have used Polyborosiloxane with abrasives as a media and inferred that the temperature is an important variable in AFM process. Jain et al. (2001) have used a mixture of commercial grade putty (a sealant material) with abrasives and varnish oil (additive) in the media and found that the media viscosity decreases with increasing shear rate, wall shear stress, medium temperature and mesh size. They have also observed that the material removal rate and surface finish increase with increasing viscosity of media. Agrawal et al. (2005) have predicted the viscosity of Polyborosiloxane based media by determining the creep compliance and bulk modulus based on the principle of viscoelasticity. Their experiment shows that viscosity of media increases with abrasive percentage and decreases with temperature. Gorana et al. (2004) have used mixture of silly putty, silicon carbides and varnish oil as a media and found that extrusion pressure, abrasive concentration and grain size affect the axial cutting forces, radial cutting forces, force ratio (ratio of radial force to axial force), active grain density and finally their influence on reduction of the surface roughness. Raju et al. (2005) have used a silicon polymer as a media and finished internal primitives of SG cast iron (600 grade). They have studied the surface finish properties of SG cast iron and concluded in terms of improvement of surface finish, bearing area fraction, out of roundness, induced residual stress and macrography. V.K.Jain et. al (2005) found the effects of different process parameters, such as number of cycles, concentration of abrasive, abrasive mesh size and media flow speed on material removal and surface finish. The dominant process parameter found is concentration of abrasive, followed by abrasive mesh size, number of cycles, and media flow speed. Experiments are performed with brass and aluminum as work materials. Experimental and theoretical results are compared. The following conclusions have been derived by them.

1. Material removal (MR) is governed by initial surface finish and workpiece hardness. Softer material has higher material removal and more improvement in surface finish as compared to harder material.

2. As the percentage concentration of abrasive in the medium increases, material removal increases while the surface roughness value decreases. However, its effect is visible only up to a certain percentage of abrasive concentration, beyond which it becomes insignificant.

3. With higher abrasive mesh size, both material removal and improvement in the Ra value decrease.

4. It is found in general that the dominant process parameter is the percentage concentration of abrasive in the medium, followed by abrasive mesh size, number of cycles and media flow speed. In the case of aluminum, in general, the value of an exponent of Eq. (1) is higher than that of the corresponding exponent for brass.

5. When a workpiece is subjected to abrasive flow machining, tool marks become visible while burrs and loose material get removed. With an increase in the number of cycles, tool marks become lighter and abrasive marks become visible only under high magnification.

S. Rajesha et. al (2004) carried out investigation and Performance evaluation of the carrier was s carried out by considering extrusion pressure, abrasive concentration, viscosity of media, and media flow rate as a process parameters and surface finish improvement and material removal as process responses. The ester based newly developed media is capable of withstanding a temperature to work up to 71°C without changing its characteristics. It is found that the developed carrier is flexible enough to be used in AFM process and performance study reveals that the new polymer based medium yields a good improvement in surface finish as well as material removal. Material removal does not get influenced significantly by the varying media flow rate, but surface finish increases with media flow rate above 796 Pa-s. An operational pressure of 20bar and abrasive concentration of 50:50 (abrasives: carrier) is observed to be better parameter levels for the conditions attempted in the present study. A. C. Wang et. al (1999) found that non-Newtonian flow can be used to simulate the motion of the abrasive media in AFM. The flow model of abrasive media can be set up by the power law, if the rheological properties of the media are found. The experiments show that the polished effect is not obvious when the abrasive media with low viscosity is used to finish the complex hole. Surface roughness is quickly reduced to a low level when Silicone is taken as the abrasive media. But the roughness is not uniform in the whole surface because the width of the cross section is not the same. These effects are very consistent with the simulated results in this study. Jain Raj.K. et.al (2002) has described the concepts of a stochastic methodology, which generates and statistically evaluates the interaction between spherical abrasive grains and work piece surface. The simulation enables prediction of the active grain density at any concentration and mesh size. A microscopic technique has also been developed to determine abrasive grain density. Grain density increases with increase in abrasive mesh size and percentage concentration of abrasives. The proposed stochastic simulation can be easily extended for simulation of surface generation in abrasive flow machining. Kara Kama K. et. al (2000) developed alternate media for AFM process from different viscoelastic carriers (natural rubber and butyl rubber), SiC abrasive and naphthenic oil. The performance of media was evaluated by an AFM setup. The characterization study through viscosity and creep compliance was also conducted to understand the behavior and performance of media. The butyl rubber, silicon carbide and naphthenic oil mixed Media showed good performance compared to natural rubber based media. As the abrasive loading increases, the improvement in surface roughness increases. But at the high percentage (above 78%) of abrasive loading, the flow becomes difficult as well as carrier acts as inefficient binder for abrasives. The experiment inferred that the 50% loading of abrasive contributed up to 43% improvement. Appropriate abrasive mesh size alone with respect to the surface conditions only revealed higher improvement and mesh size of 220 was good compared to the 800 and 1200. The investigation showed that the higher oil loading reduces the surface improvement. Saad Saeed Siddiqui et.al (2005) found that Vent considerations for media outflow in work-piece surface significantly affects performance measures, material removal (MR) and surface roughness (Ra value) in abrasive flow machining. Micro machining work-piece surfaces having single vent/passage for media outflow by abrasive flow machining produced better results in comparison with work-piece surfaces having multiple vents. Work-piece surfaces having single vent/passage for media outflow have higher material removal and more improvement in surface roughness and the performance measures decrease with increase in the number of vents for media outflow. The change in surface roughness, ΔRa increases with the increase in length of the work-piece and decreases with the increase in cross section of the work-piece. As the length of the work-piece increases, material removal increases while the surface roughness value decreases. Gorana V.K. et.al(1997) measured axial and radial forces by using a dynamometer. It was concluded that extrusion pressure, abrasive concentration and grain size affect the cutting forces, active grain density and finally reduction in surface roughness. The reduction in surface roughness (Ra value) is approximately linearly proportional to force ratio. Scanning electron microscopy shows that rubbing and ploughing are the possible mechanisms of material deformation. Jain Rajendra K. et.al (2002) demonstrated the effectiveness of using back-propagation neural networks for process modeling and optimization of AFM process. Simulation results showed a good agreement with experimental results for a wide range of machining conditions. The optimization results of the neural network coincide well with the results obtained by GA and hence validate the neural network approach. The possibility of using this neural network model for machined surface quality and MRR prediction for AFM process had been confirmed. Appropriately trained network successfully synthesized optimal input conditions for AFM process. The optimal input conditions maximized the MRR, subject to appropriate process constraints. An important consideration was that process optimization could be performed in the absence of process models and purely by observations of experimental information. The discussed neural network system was fairly general and could be extended to other abrasive processes to improve machining efficiency. Jose Cherian et.al (2004) the work piece hardness, abrasive size, abrasive hardness, Extrusion pressure and properties of carrier are the important process parameters that affects the performance of AFM. The objective of the present paper is to study the effects of process variables on surface finish and material removal. The average percent reduction in surface roughness can be increased by keeping the extrusion pressure, grain mesh number and Abrasive concentration at high levels, while the average force ratio can be increased by increasing extrusion pressure. Apart from conventional AFM processes, Hybridization of Abrasive flow machining has also been developed. In the development of Hybrid Abrasive Flow Machining Processes the aim is to improve the performance by clubbing the advantages of different machining processes and to avoid or to reduce the limitations or adverse effects of the constituent processes (Walia, 2006). Towards the development of Hybrid AFM processes, researchers have successfully integrated AFM with a number of non-conventional machining processes or clubbed additional energy sources with it to achieve the higher material removal and to produce better polished surfaces in a faster way (using less number of fast extrusion cycles).The concept of Hybrid machining processes (HMPs) is in vogue in the latest manufacturing practices in order to meet the challenges of high surface quality and tolerance requirements, often coupled with high production rates of parts having complex.

An example of HMP is **Ultrasonic Flow Polishing (UFP)** and was developed by (Jones & Hull, 1995), (Jones & Hull, 1998), (Extrude Hone, 1994) which is the combination of AFM and USM. AFM is an excellent finishing and polishing process but has disadvantage that is can be utilized with open dies whilst the USM is a highly accurate material removal method which can operate in closed dies. (Fletcher & Fioravanti, 1994) developed a model to determine the heat generation and temperature distribution for a mixture of polyborosiloxane and silicon carbide abrasive, which has been agitated using an ultrasonic system. (Fletcher & Fioravanti, 1996) determined the various thermal properties like thermal conductivity, specific heat capacity and heat transfer coefficient for this media. (Singh, et al., 2002) found that with the application of magnetic field results in increase in material removal rate, hence less number of cycles are required to achieve higher material removal. They concluded that the effect of magnetic field is observed only on non-ferromagnetic work materials. The investigations showed that under the effect of magnetic field, brass work-piece experiences more abrasion as compared to aluminium work-piece. (Singh, et al., 2002) reported that if the work piece was processed in magnetic field assisted AFM, extrusion pressure affects both material removal and surface roughness.

Magnetorheological abrasive flow finishing (MRAFF) is a process whose fluid flow properties can be controlled by altering the magnetic field for the hard or soft materials as per the requirement process provides better control over rheological properties of abrasive laden magnetorheological finishing medium. Magnetorheological (MR) polishing fluid comprises of carbonyl iron powder and silicon carbide abrasives dispersed in the visco plastic base of grease and mineral oil. It exhibits change in rheological behavior in presence of external magnetic field. This smart behaviour of MR-polishing fluid is utilized to precisely control the finishing forces, hence final surface finish. The actual finishing action is possible only after removal of initial loosely held material remaining after grinding. Authors also developed models for the formation of CIP chain structures around Sic abrasive for this process; Surface finish of 0.4 micron R_a has been achieved.

Rotational Abrasive Flow Finishing (R-AFF) is the process where better surface finish was observed due to the shearing of more number of peaks during the extrusion and also due to additional shearing forces (Sankar, et al., 2009). Preliminary experimental study reported R-AFF can produce 44% better ΔR_a and 81.8% more MR compared to AFF process. This was due to the fact that in the R-AFF process, the abrasives are cutting the material along a helical path so the abrasives-work-piece contact length increases, leading to more machining. Moreover, the rotation of work-piece imparts additional component of tangential force along with the radial and axial forces which are acting on the active abrasive grains, this enhances micro-chipping of work-piece material with lower chance of rolling of abrasive grains.

Rotational- Magnetorheological Abrasive Flow Finishing (R-MRAFF) was developed as a new polishing method by rotating a magnetic field applied to the Magnetorheological polishing

(MRP) medium in addition to the reciprocating motion provided by the hydraulic unit to finish internal surface of cylindrical stainless steel (non-magnetic) work-piece. The two motions of rotation of magnetic field and reciprocation of abrasives laden magnetorheological media were controlled to get smooth mirror like finished surface

Helical AFM (HLX-AFM) Process employed a stationary-coaxially fixed helical twist drill bit for the finishing of internal cylindrical surface and observed that material removal increased by a factor of 2.66 over the basic AFM process, along with a maximum percentage improvement in surface roughness of 74.69% (form 2 µm to 0.5 µm). The increase in efficiency is due to increase in active grain density due to a combination of flows as well as due to increased cutting forces on the active abrasive grains. (Kumar & Walia, 2012)employed HLX-AFM process for the processing of different work-piece materials namely mild steel, brass and aluminium.(Wang, et al., 2012) developed a mechanism with a four helices passageway to perform multiple flowing paths of abrasive media, whose flowing behaviour enhanced polishing effectiveness and uniformity of the surface finish by increasing the abrasive surface area and radial shear forces.

Dabrowski et al. successfully experimented on the integration of Electro-chemical Machining (ECM) with the AFM and developed **Electrochemical Aided AFM (ECAFM)** by employing polymeric electrolytes for the finishing of flat work-pieces only. Dabrowski et al. used a number of electrolytic pastes for these experiments for the finishing of steel and observed more material removal with KSCN salt based electrolytic pastes than with NaI salt based pastes. Material Removal increased with the electrochemical aid (Dabrowski, et al., 2006), (Dabrowski, et al., 2006)experimented with the electrochemically assisted abrasive flow machining (ECAFM) using polypropylene glycol PPG with NaI salt share and the ethylene glycol PEG with KSCN salt share. The abrasive properties of the electrolytes have been enhanced by adding the Al_2O_3 and SiC grains. Electrochemically assisted abrasive flow machining (ECAFM) is possible using polymeric electrolytes.

2.2 MOTIVATION

After the literature reviews there are various points come out of the box which gives the interest motivation towards this project due to following reason-

- Because of industrial revolution manual work has been replaced by machines in many industrial process but there are still many complex task and have higher demand in-
    - Surface finishing
    - Economic viability
- Because of clumsiness of our mechanical systems.
- While working manually there are also some health and safety issues.

Abrasive flow machining is complex because of the little-understood behavior of the non-Newtonian medium and the complicated and random nature of the mechanical action of material removal.

2.3 OBJECTIVE OF THE THESIS

As discussed earlier, Abrasive Flow Machining has a limitation of less material removal. Many researchers used different media to reduce this limitation. Also in AFM the media is the key elements that dominate the finishing behavior. However commercially available abrasive media are very expensive and its affordability is an issue especially for price sensitive industries. Lower-cost alternative AFM media are developed which consists of base polymers, additives and liquid plasticizer by uniformly mixing them to become the flexible mass. The media developed by optimum process variables mainly governs the performance of AFM. In the present experimental endeavor, an attempt is made in the direction of developing new media based on viscoelastic carrier.

Any media used in Abrasive Flow Machining Process must satisfy the following properties.

1. It should not get stick to surface of workpiece. If it happens, a layer of media will get stick to workpiece material and hence movement of media even at high and high velocity will not cause any metal removal and change in surface roughness values. Thus, newly developed media is of no use. Hence it becomes obsolete.
2. It should withstand the operating condition temperature of machine. Generally the maximum possible temperature recorded in AFM set up is 71^0 C. Hence it should not decompose into some other undesirable constituents.

3. Base material of media (e.g. Polymer in this thesis work) should be bouncy in nature. It means if a small quantity of base material is taken and it is made in the shape of spherical ball, it should bounce once allowed to strike on a solid surface.

These media are prepared by special procedures. For making a media, first polymer is brought to a semi solid form or paste form. This semi solid form or paste of polymer is made from solid raw polymer commercially available in market. This solid raw polymer is processed in "Two-Roll Mill" Machine. In "Two-Roll Mill" Machine, polymer is processed by adding compatible Plasticizer in appropriate quantity.

In this thesis work, five media have been developed. The gel which is used to mix with polymer is same in all the five media but the base material polymer are different in each media. So five polymers have been used in this research work. They are Silicon Rubber, Styrene- Butadiene Rubber (SBR), Natural Rubber, Nitrile Rubber and Polyborosiloxane. By using the combination of the gel with silicon carbide as a abrasive, this media is pressurized to flow through a Brass workpiece having internal diameter of 8 mm and length 16mm.

CHAPTER 3

RESPONSE SURFACE METHODOLOGY (RSM)

3.1 Introduction of RSM

RSM is nothing but an amalgamation of the statistical methods available and their usage in the mathematical manner so that they could be utilized to find out the desired values which are to be controlled. It is a method which uses apt number of experiments to find out the solutions to the multi variable problems which depend upon the factors.

Graphical depictions of these obtained problems are coined as the response surfaces, which are used to designate the individual and combined effect of the input variables on the output and to find out the relationship these variables share among themselves or between the output also known as response.

3.2 Uses of RSM

1. To find out the factor level and this will be able to satisfy the desired dimensions.
2. To find the relationship of responses on individual input parameter.
3. To obtain a quantitative knowledge of the system performance in the area
4. To forecast the properties of the product and to find out the responses it would give when the obtained settings are given.
5. To find out the all the necessary situations for the stability of the process.

3.3 METHODOLOGY OF RSM

Whole process of rsm can be divided into different parts and those parts are the sequences in which the process has to be done. In design optimization using RSM, the first task is to determine the optimization model, such as the identification of the interested system measures and the selection of the factors that influence the system measures significantly.

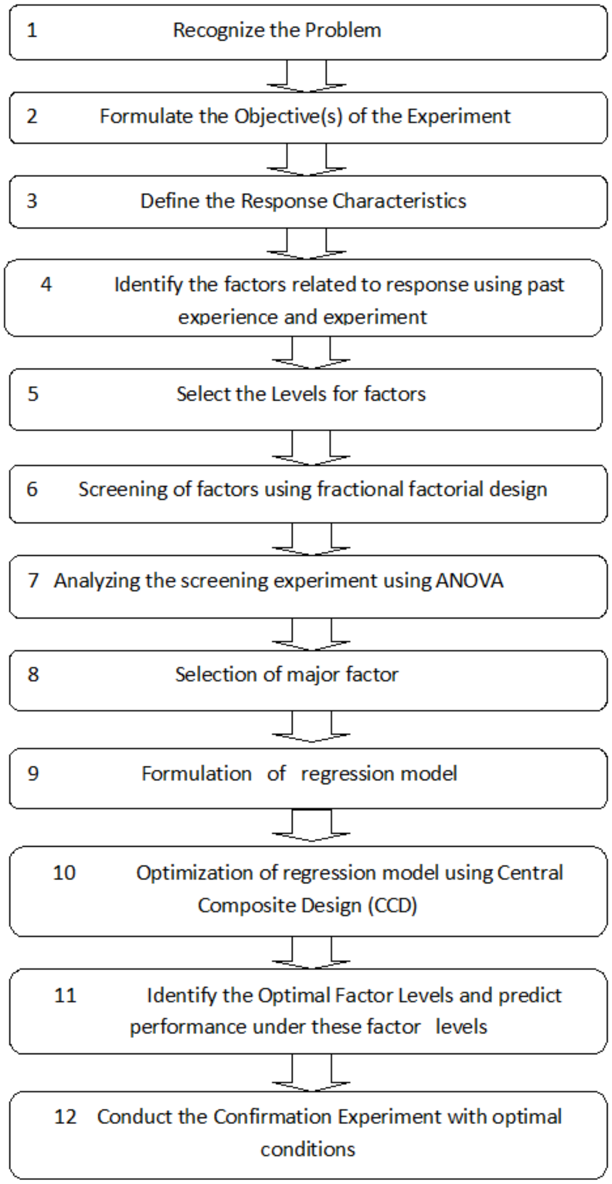

Figure7: Flow diagram of RSM methodology

To do this, an understanding of the physical meaning of the problem and some experience are both useful. After this, the important issues are the design of experiments and how to improve the fitting accuracy of the response surface models. DOE techniques are employed before, during, and after the regression analysis to evaluate the accuracy of the model. RSM also quantifies relationships among one or more measured responses and the vital input factors.

RSM, or RSM, is a collection of mathematical and statistical techniques in which a response of interest is influenced by several variables and the objective is to optimize this response. For example, suppose that a chemical engineer wishes to find the levels of temperature (x1) and pressure (x2) that maximize the yield (y) of a process. The process yield is a function of the levels of temperature and pressure, y = f (x1, x2) +e

Where e represents the noise or error observed in the response y. Then the surface depicted by h= f (x1, x2), which is called a Response surface. We usually represent the response surface graphically, where h is plotted versus the levels of x1 and x2. To help visualize the shape of a response surface, we often plot the contours of the response surface as well. In the contour plot, lines of constant response are drawn in the x1, x2 planes. Each contour corresponds to a particular height of the response surface. Objective is to optimize the response. In RSM, polynomial equations, which explain the relations between input variables and response variables, are constructed from experiments or simulations and the equations are used to find optimal conditions of input variables in order to improve response variables. For the design of RSM, many researchers have used central composite design (CCD) for their experiments. CCD is widely used for fitting a second-order response surface. CCD consists of cube point runs, plus center point runs, and plus axial point runs.

The three factors speed, feed rate, depth of cut, selected in the screening experiment, will be used in CCD. The process can be studied with a standard RSM design called a Central composite design (CCD). The factorial portion is a full factorial design with all factors at three levels, the star points are at the face of the cube portion on the design which

Correspond to value of -1. This is commonly referred to as a face centered CCD. The center points, as implied by the name, are points with all levels set to coded level 0, the midpoint of each factor range, and this is repeated six times. Twenty experiments to be performed. For each experimental trial, a new cutting edge to be used. The latest version of the Minitab or Design Expert may be used to develop the experimental plan for RSM. The same software can also be used to analyze the data collected.

3.3.1 Objective of RSM

Our goal is to start from using our best prior or current base and find for the optimum spot where the response is either maximized or minimized.

Here are the models that we will use.

Screening Response Model :

$yy=\alpha\alpha+\beta\beta xx^{1}+\gamma\gamma xx^{2}+\delta\delta xx^{1}xx^{2}+\varepsilon\varepsilon$

The screening model that we used for the first order situation involves linear effects and a single cross product factor, which represents the linear x linear interaction component.

Steepest Ascent Model

If we ignore cross products which gives an indication of the curvature of the response surface that we are fitting and just look at the first order model this is called the steepest ascent model: $y = \beta x1 + \gamma x2 + \varepsilon$

3.3.2 Optimization Model

After this, it is known that we are somewhere near the maximized or optimized value so, a second order model. This includes in addition the two second-order quadratic terms.

If the plot is in more than 2 dimensions, the method is not best suited as per the obtained plot. The method of steepest ascent tells where to take new measurements, and the response at those points can be recorded. it might move a few steps and it may be seen that the response persistently strived to move up or perhaps not - then you might do another first order experiment and reorganize the efforts. The point is, when the experiments are done for the second order model, it is hoped that the optimum will be in the range of the experiment - if it is not, then, it is extrapolation to find the optimum. In this case, the safest thing to do is to do another experiment around this estimated optimum. Since the experiment for the second order model requires more runs than experiments for the first order model, it is required to move into the right region before starting fitting second order models.

Steepest Ascent - The Second Order Model

This second order model includes linear terms, cross product terms and a second order term for each of the x's. If in generalized way, various values have k first order terms, k second order terms and all possible pair wise first-order interactions. The linear terms just have one subscript. The quadratic terms have two subscripts. There are k*(k-1)/2 interaction terms. To fit this model, it is needed to have a response surface design that has more runs than the first order designs used to move close to the optimum.

This second order model is the basis for response surface designs under the approximation that optimized value is not a perfect quadratic polynomial in k dimensions, but it provides a good approximation to the surface near the maximum or a minimum.

CHAPTER 4

DEVELOPMENT OF POLYMER BASED ABRASIVE FLOW MACHINING

4.1 AFM SET UP

Figure 8: Shows an AFM set up

The 2 way AFM pressurize the abrasive media to flow through the internal cylindrical surface of the hollow workpiece. The abrasive laden media interacts with the surface and causes material removal from it. In the two way AFM the motion from top to bottom and from bottom to top constitutes a single cycle. Figure no.8 shows the AFM setup which is available in Precision Engineering lab of DTU. The main components in the AFM Machine are as follows-

4.1.1 Hydraulic Power Pack

It is the main driving component of the workpiece. It has major function teo supply the oil from the reservoir to the respective hydraulic cylinder which causes the back and forth movement of piston in the hydraulic cylinder. It consists of motor, reservoir, filter and hydraulic pump along with accompanying hydraulic circuit.

4.1.2 Hydraulic Cylinders

In the AFM set up there are two vertical cylinders which are in the opposite of each other. These hydraulic cylinders are connected through hydraulic power pack through the pipe line. Here the diameter of pipe line is an important parameter because it develops the pressure. In this the piston moves from top to bottom and from bottom to top due to pressure difference in the cylinder barrel. The barrel is closed on one side by cylinder bottom and other end by cylinder head called as gland. The cylinder acts as a mechanical actuator by driving the piston through the action of a pressurized hydraulic fluid to generate a unidirectional force.

4.1.3 Media Cylinders

In the 2 way AFM two media cylinders are used which are vertical and opposite to each other. The media cylinder consists the mixture of the gel and the abrasive particles which is forced to flow through the hollow workpiece. The inner surface of the media cylinder should be smooth so that loss should be minimize because of the friction between the wall and media surface

4.1.4 Fixture

The fixture is made of Nylon. It holds the workpiece in a slot provided in this and causes the media to flow through the workpiece. The fixture is made of Nylon because it has good wear properties.

4.1.5 Machine Frame

It provides the support and the holding strength.

4.1.6 Power Supply

There are two type of power supply is needed for the machining, one is for the electric motor of the loading unit and loading cylinder. This power supply is of 220 volt, single phase. Electric motor of loading unit is of 0.5 HP.

4.2 NATURAL RUBBER

Natural rubber also called as India rubber consists of polymers of the organic compound isoprene with minor impurities of other organic compounds plus water. Natural rubber is a high molecular weight polymeric substance with viscoelastic properties. Structurally it is cis 1,4-polyisoprene. Isoprene is a diene and 1, 4 addition leaves a double bond in each of the isoprene unit in the polymer. Because of this, natural rubber shows all the reactions of an unsaturated polymer. It gives addition compounds with halogens, ozone, hydrogen chloride and several other reactants that react with olefins. An interesting reaction of natural rubber is its combination with sulphur. This is known as Vulcanization. This reaction converts the plastic and viscous nature of raw rubber into elastic. Vulcanized rubber will have very high tensile strength and comparatively low elongation. Its hardness and abrasion resistance also will be high when compared to raw rubber. Because of the unique combination of these properties, natural rubber finds application in the manufacture of a variety of products. The main use of natural rubber is in automobiles. In developed countries nearly sixty per cent of all rubber consumed is for automobile tyres and tubes. In heavy duty tyres, the major portion of the rubber used is NR. In addition to tyres a modern automobile has more than 300 components made out of rubber. Many of these are processed from NR. Uses of NR in hoses, footwear, battery boxes, foam mattresses, balloons, toys etc., are well known.

Natural Rubber, NR was obtained from Rubber Research Institute of India, Kottayam.

4.3 STYRENE BUTADIENE RUBBER

SBR stands for Styrene – Butadiene Rubber. It is a random copolymer from the aforesaid monomers. There are two major types of SBR- Emulsion SBR (E-SBR) and Solution SBR (S-

SBR) based on the different manufacturing process. It is used for tire production because of following properties:

- Good Processability
- Good Green strength and tack strength
- Low hysteresis
- Good Skid resistance, abrasion resistance, rolling efficiency
- Good Thermo-oxidative stability
- Low cut growth rate
- Low cost

In recent years because of the interest in fuel savings, technological efforts developed SBR to make tires. At present, there is a most important trend going on in the study and development of SBR rubbers for tire applications.

SBR was obtained from Triveni Chemicals, New Delhi.

4.4 SILICON RUBBER

Silicone rubbers are often one or two part polymers and may contain fillers to improve properties or reduce cost. Silicone rubber is generally non-reactive, stable and resistant to extreme environments and temperatures from -55 °C to +300 °C while still maintaining its useful properties**.** Due to these properties and its ease of manufacturing and shaping, silicone rubber can be found in a wide variety of products including automotive applications, cooking, baking, and food storage products, apparel such as undergarments, sportswear and footwear; electronics; medical devices and implants and in home repair and hardware with products such as silicone sealants. In its uncured state, silicone rubber is a highly-adhesive gel or liquid. In order to convert to a solid, it must be cured, vulcanized or catalyzed. This is normally carried out in a two-stage process at the point of manufacture into the desired shape, and then in a prolonged post-cure process. It can also be injection molded. Silicone rubber may be cured by a platinum catalyzed cure system a condensation cure system, a peroxide cure system or an oxide cure system. For platinum catalyzed cure system, the curing process can be accelerated by adding heat or pressure.

SBR was obtained from Standard Chemicals, New Delhi.

4.5 PLASTICIZERS

Plasticizer is used to bring the solid polymer into semi solid mass by adding a fixed amount of it. Plasticizer molecules penetrate into the polymer matrix and establish polar attractive forces between them and the chain segments. These attractive forces reduce the cohesive forces between the polymer chains and increase the segmental mobility. Mixing of plasticizer in polymer was done on a laboratory size two-roll mixing mill with friction ratio of 11.:25. A nip gap of 2 mm was set and the temperature maintained at 60^0C. The Plasticizer used are Paraffin Oil, Dio-Iso-Octyl-Pthatalate (DOP) and Dio-Iso-Octyl-Adiabate (DOA).

4.6. Workpiece Preparation

Brass workpiece have been used in this research work for determination of Material Removal and Percentage improvement in surface Roughness. The workpiece taken is of outside diameter of 10 mm and length of 16 mm. Workpiece is prepared by first of all drilling of 7 mm drill bit and after that 1mm diameter is removed by the boring operation so that there will be clear boring tool mark, which is our aim to remove by finishing operation. The workpiece has internal diameter of 8 mm. 30 samples of workpiece were taken and experiment was done on it.

Figure 9: Brass workpiece used in the experiment

4.6 ABRASIVE

The Silicone Carbide of 220 mesh size have been used in the present experimental work. These were received from M/S Central Scientific Instrument Corporation, India.

4.7 PREPARATION OF POLYMERS

All Preparation of polymers was done at “Two roll mill machine” facility in Shriram institute of industrial research, New Delhi. For preparing the flexible polymers mass, a fixed quantity of polymer is taken first and an appropriate quantity of plasticizer is added into it. This plasticizer is not added just all in once, rather it is added slowly and it is only added during the crushing and rolling of solid polymer in two roll mill machines. In order to prepare natural rubber polymer, 100 gm natural rubber is weighted. This natural rubber is available in the form of sheet. This sheet is easily available commercially. Now 40 gm paraffin oil is also weighted separately. Now, the sheet of natural is allowed to pass through the preset 2 mm gap of two roll mill machine. When this natural rubber sheet passes through this very narrow passage, it is deformed severely and this process keep on going when it becomes little soft. Now Plasticizer in the form of small batch is allowed to mix into Natural Rubber sheet during each passing of sheet in the roll. Ultimately, when all plasticizer get consumed, we get a non-sticky semi solid mass, which is ready to get mixed with gel. In the similar way, Silicon Rubber by adding DOP, SBR Rubber & Nitrile Rubber by adding DOA is obtained.

For preparation of Polyborosiloxane polymer take a vessel. Then take 1 liter of silicon oil and mix it with 60 gram boric acid. It will become of green color after stirring. Then mix 10 gram Lewis acid in it. It will become of yellow color. Stirring is done till all the particles are properly mixed. After that it was heated in a vessel and stirring is done continuously. When the mixtures starts boiling and it becomes viscous rubber type then mix 10 gram NH4CO3 in it and stirring is done continuously till it becomes very viscous which is non sticky type. Then allow it to cool. The Polyborosiloxane polymer is prepared.

Figure10 : Finally Prepared Gel

4.8 PREPARATION OF GEL

For making gel a vessel is taken and then take half kg of hydrocarbon oil and it is mixed with 30 gram aluminium stearate. It will become of white color. Proper stirring is done till the particles are properly dissolved. Then heat it for 20 to 25 minute and stirring is done continuously till it becomes a thick gel type .After that it is allowed to cool. Then the gel is prepared.

4.9 PREPARATION OF MEDIAS

Take 300 gram of polymer and 80 gram of gel and then it is mixed by hand properly. Then add 400 gram of Silicon Carbide and it is properly mixed with it. Thus the media is prepared.Other media i,e Natural Rubber, SBR Rubber, Nitrile Rubber and Natural Rubber is prepared in similar manner.

Figure10 : Finally Prepared Media

CHAPTER 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

To draw valid and objective conclusions from an experimental investigation requires conducting experimentation in accordance with proper planning and design of experiments. In performing a designed experiment, the input variables are varied and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Factors may be either qualitative (such as type of material, colour of sample etc.) or quantitative in nature. Each factor can take several values during the experiment wherein each such value of a factor is referred to as a level. A trial or run is a certain combination of input factor levels whose effect on the output is of interest. It is essential to incorporate statistical data analysis methods in the experimental design in order to draw sound and reliable conclusions from the experiment. Firm conclusions cannot be drawn from an experimental study unless proper planning, careful study and due diligence is observed in the selection of input variable factors, their chosen levels and proper recording of all the possible output responses. The selection of input variable parameters and their levels is thus a pre-requisite to a successful experimental study besides of course following the protocol in the conduct of The literature review suggested the possible process parameters that may be influencing the capability and efficiency of the process and the subsequent quality of components finished by AFM. The parameters can be classified on the basis of three major elements of the process as mentioned below.

1. **Machine Parameters:** Extrusion pressure, media flow rate, media flow volume, number of cycles.
2. **Medium Parameters:** Abrasive Size, Abrasive Type, Abrasive Concentration, Additives/Oil Concentration, Temperature and Viscosity of the medium.
3. **Work-piece Parameters:** Work-piece Material, Passage Geometry, Reduction ratio, Initial surface roughness.

Brass have been used as workpiece in this experimental work .The workpiece taken is of outside diameter of 10 mm, and length of 16 mm. Workpiece is prepared by first of all drilling of 7 mm drill bit and after that 1mm diameter is removed by the boring operation so that there will be clear boring tool mark, which is our aim to remove by finishing operation. The workpiece has internal diameter of 8 mm.

5.1 MACHINE PROCESS PARAMETER AND THEIR RANGES

Type of Press- 2 Pillar type fabricated Design
Capacity- 25 + 25 Ton
Stroke length -96 mm
Hydraulic cylinder Bore dia – 2 No.130mm
Hydraulic cylinder Stroke- 90 mm
Working Pressure-210 kg/Cm^2
Maximum Pressure in the Cylinder – 35 MPa
Stroke Length of Piston - 300mm

5.2 RESPONSE CHARACTERISTICS

The effect of these process parameters were studied on the following response characteristics of AFM process-

1. Percentage improvement in surface finishing **(** ΔR_a)
2. Material Removal (MR)

5.2.1 PERCENTAGE IMPROVEMENT IN SURFACE FINISHING

The surface roughness was measured at several random locations on the internal cylindrical surface of the brass workpiece. The mean value was taken of the random values of roughness. Then the percentage improvement in surface finishing was calculated from the formula

$$\Delta Ra = (\text{Initial Roughness} - \text{Roughness after Machining}) / (\text{Initial Roughness}) \times 100$$

SURFACE ROUGHNESS INSTRUMENT: Surface roughness is an important parameter required for the measurement of the quality of the product. Surface measurement is nothing but the comparison of the previously fixed value with the new value obtained.

The talysurf instrument used in this experiment is a Taylor Hobson unit with surtonic3+ as its product name. Surtronic 3+ is nothing but an amalgamation of technology so as to achieve high meticulousness and exactitude to have an accurate measurement of surface finish in the process no matter where the work is done, laboratory or the inspection room. With Surtronic 3+, a beginner with no skills can achieve wide range of skills that can be understood within minutes. In this device the cycles in the function are minimum during the process of measurement and the variations are minute and the response can be obtained on the screen available. The process of measurement is easy and the whole machine can be operated or navigated through a wide variety of navigations and selection.

Figure 11: A taylsurf instrument by taylor hobson surtonic 3+ at metrology lab, DTU

Table1: Specification of Taylsurf instrument for measurement of surface roughness

Gauge Range	±150µm (0.006in)
Pick up type	Variable reluctance
Traverse length (Max)	25.4mm (1.0in)
Stylus	112/1502: Diamond tip radius 5µm (200µin) 112/1503: Diamond tip radius 10µm (400µin)
Cut Off Values	0.25, 0.8, 2.5, 8mm (0.01, 0.03, 0.1, 0.3in) (8mm Cut off only available when using Talyprofile or Macro-Maker Software)
Parameters	R_a, R_q, R_z (DIN), R_y, S_m, R_t
Traverse length (Min)	0.25mm (0.01in)
Optional additional parameters	Pc (in place of Sm), tp% (in place of Rq) - with optional EPROM available on request
Overall Dimensions	130 x 80 x 65mm (5.1 x 3.3 x 2.5in)
Data Processing Module	185 x 140 x 50mm (7.5 x 5.5 x 2in)
Resolution	0.01µm (0.4µin)
Traverse Speed	1mm/sec (0.04in/sec)
Accuracy of Parameters	2% of reading + LSD µm
Power	Battery or Mains (optional)

5.2.2 Material Removal (MR)

Material removal signifies the amount of material removed from the specimen in a specified number of process cycle. Material removal was calculated from the formula given below

MR= (weight of the workpiece before machining – weight of workpiece after machining)

5.3 Scheme of experiments

The experiments were designed to study the effect of some of the AFM parameters on response characteristics of AFM process. Here Response Surface Methodology is adopted to design the experiments. The selected number of process parameters and their levels are given in the table:

Table 2: Process parameter and their value at different level

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
A	Types Of Media	Number	1	2	3	4	5
B	Pressure	N/m^2	10	15	20	25	30
C	Number of cycle	Number	4	6	8	10	12
D	Volume Of Media	mm^3	175	200	225	250	275

Workpiece Material- Brass

Temperature- 32±2’C

Initial Roughness - 1.10 to2.96 micron

CHAPTER 6

RESULT AND DISCUSSION

6.1 Analysis of DATA

The design table to be used was made by deciding the values of the parameters to be set in the experiment namely (1) Type of media (2) Pressure (3) the number of cycle (4) Volume of Media. These were set accordingly. The values were defined on basis of the values available in the machine so as to perform the experiment.

Table 3: Input parameter of variable

Types Of Media	Pressure (N/m^2)	Number of cycle	Volume of media (mm^3)
1	10	4	175
2	15	6	200
3	20	8	225
4	25	10	250
5	30	12	275

The values or the factors were thus defined and with help of Design Expert, the RSM value table was then generated which would set the values or the order of the readings in the experiment.

CCD:-

No's of Factor:	4
Replicas:	1
Total runs:	30
Number of Base blocks:	1
Total number of blocks:	1
2-level factorial:	Full factorial
Number of Cube points:	8
Center points taken in the cube:	6

Number of Axial points taken: 6

Center points taken in axial: 0

Alpha: 1

6.2 Design Table

Table 4: Design table in terms of actual factors

Run	Types Of Media	Pressure (N/m^2)	No. of cycle	Volume of media (mm^3)
1	4	25	6	200
2	3	20	8	225
3	4	15	10	200
4	2	25	10	200
5	1	20	8	225
6	4	15	6	200
7	3	10	8	225
8	3	30	8	225
9	4	25	10	200
10	2	25	6	250
11	2	25	6	200
12	3	20	4	225
13	4	25	6	250
14	4	15	10	250
15	2	15	6	200
16	3	20	12	225
17	2	15	10	250
18	3	20	8	225
19	4	25	10	250
20	3	20	8	225
21	3	20	8	225
22	3	20	8	275
23	2	15	6	250

24	2	25	10	250
25	5	20	8	225
26	3	20	8	175
27	2	15	10	200
28	3	20	8	225
29	3	20	8	225
30	4	15	6	250

The parameters thus after being defined were made constant for the process and the optimization was thus taken forward. The design was then set and the graphs were obtained between different values depending upon the required values and considerations.

Table5: Table shows value of response as well as variable parameter

Run	Types Of Media	Pressure (N/m^2)	No. of cycle	Volume of media(mm^3)	% Improvement in surface Roughness	Material Removal
1	4	25	6	200	27.5	1.9543
2	3	20	8	225	23.5	2.6532
3	4	15	10	200	22.5	1.5329
4	2	25	10	200	21.5	1.3932
5	1	20	8	225	16.5	0.8032
6	4	15	6	200	27	1.8578
7	3	10	8	225	20.5	0.7593
8	3	30	8	225	19.5	0.8029
9	4	25	10	200	25	2.2076
10	2	25	6	250	20.5	1.1029
11	2	25	6	200	21.7	1.4191
12	3	20	4	225	18.5	1.1529
13	4	25	6	250	17.5	0.9043

14	4	15	10	250	21	1.2866
15	2	15	6	200	28	2.0546
16	3	20	12	225	25	1.2874
17	2	15	10	250	21.5	0.8031
18	3	20	8	225	27	2.0021
19	4	25	10	250	17.5	0.9041
20	3	20	8	225	23	2.5234
21	3	20	8	225	24	2.2872
22	3	20	8	275	23.5	2.3987
23	2	15	6	250	20	0.8155
24	2	25	10	250	20.5	1.1027
25	5	20	8	225	21	1.2874
26	3	20	8	175	28.5	2.0832
27	2	15	10	200	20	1.0571
28	3	20	8	225	25.5	2.7352
29	3	20	8	225	23	2.5229
30	4	15	6	250	21	1.2876

6.3 Discussion on Percentage improvement in material removal

ANOVA table for Material Removal is given below, which clearly show that Model is Significant and “ Lack of fit ” is not significant.

Table 6: ANOVA table for Material Removal

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	

Model	10.09	14	0.72	5.68	0.0009	**Significant**
A-Type of Media	*0.41*	*1*	*0.41*	*3.27*	*0.0906*	
B-Extrusion Pressure	*6.023E-003*	*1*	*6.023E-003*	*0.047*	*0.8304*	
C-No of Cycles	*0.029*	*1*	*0.029*	*0.23*	*0.6372*	
D- Vol of media	*0.90*	*1*	*0.90*	*7.07*	*0.0179*	
AB	*4.977E-003*	*1*	*4.977E-003*	*0.039*	*0.8456*	
AC	*0.058*	*1*	*0.058*	*0.46*	*0.5092*	
AD	*0.072*	*1*	*0.072*	*0.56*	*0.4641*	
BC	*0.15*	*1*	*0.15*	*1.20*	*0.2899*	
BD	*0.026*	*1*	*0.026*	*0.21*	*0.6544*	
CD	*0.073*	*1*	*0.073*	*0.58*	*0.4596*	
A^2	*3.30*	*1*	*3.30*	*25.98*	*0.0001*	
B^2	*4.67*	*1*	*4.67*	*36.83*	*< 0.0001*	
C^2	*2.52*	*1*	*2.52*	*19.84*	*0.0005*	
D^2	*0.062*	*1*	*0.062*	*0.49*	*0.4937*	
Residual	1.90	15	0.13			
Lack of Fit	*1.54*	*10*	*0.15*	2.14	*0.2075*	**Not Significant**
Pure Error	*0.36*	*5*	*0.072*			
Cor Total	12.00	29				

The Model F-value of 5.68 implies the model is significant. There is only a 0.09 % chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case D, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.14 implies the Lack of Fit is not significant relative to the pure error. There is a 20.75% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good and we want the model to fit.

Table 7: Table shows the statics control terminology

Std. Dev.	0.36	R-Squared	0.8414
Mean	1.57	Adj R-Squared	0.6934
C.V. %	22.74	Pred R-Squared	0.2163
PRESS	9.40	Adeq Precision	7.458

The "Pred R-Squared" of 0.2163 is in reasonable agreement with the "Adj R-Squared" of 0.6934; i.e. the difference is more than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 7.458 indicates an adequate signal. This model can be used to navigate the design space.

6.3.1 Final Equation in Terms of Coded Factors:

Material Removal =
+1.29

+0.13 * A

+0.016 * B

-0.12 * C

-0.31 * D

-0.018 * AB

+0.060 * AC

-0.067 * AD

+0.098 * BC

-0.041 * BD

+0.068 * CD

-0.047 * A^2

-0.11 * B^2

+0.12 * C^2

+0.077 * D^2

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

6.3.2 Final Equation in Terms of Actual Factors:

Material Removal =

+11.32085

+0.84292

+0.18907 * Type of Media

-1.13728 * Extrusion Pressure

-0.064329 * No of Cycles

-3.52750E-003 * Vol of media

+0.030100 * Type of Media * Extrusion Pressure

-2.67550E-003 * Type of Media * No of Cycles

+9.76750E-003 * Type of Media * Vol of media

-3.25300E-004 * Extrusion Pressure * No of Cycles

+1.35150E-003 * Extrusion Pressure * Vol of media

-0.046619 * No of Cycles * Vol of media

-4.50675E-003 * Type of Media ^{2}

+0.030523 * Extrusion Pressure ^{2}

+1.23670E-004 * No of Cycles ^{2}

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

6.3.3 Diagnosis of static properties of the model

Check point for the Diagnosis

1) Normal probability plot of the studentized residuals to check for normality of residuals.

2) Studentized residuals versus predicted values to check for constant error.

3) Externally Studentized Residuals to look for outliers, i.e., influential values.

4) Box-Cox plot for power transformations.

If all the model statistics and diagnostic plots are OK, finish up with the Model Graphs icon.

6.3.4 Variation in 3D Surface

As this graph clearly says that the value of Material Removal is increasing with the media number. Thus it can be concluded that Media no. 1 is less efficient and media no. 5 is highly efficient. Thus Polyborosiloxane is less efficient and silicon rubber is very good media for abrasive flow machining. Material Removal capacity of Natural Rubber, SBR Rubber and Nitrile Rubber lies in between them.

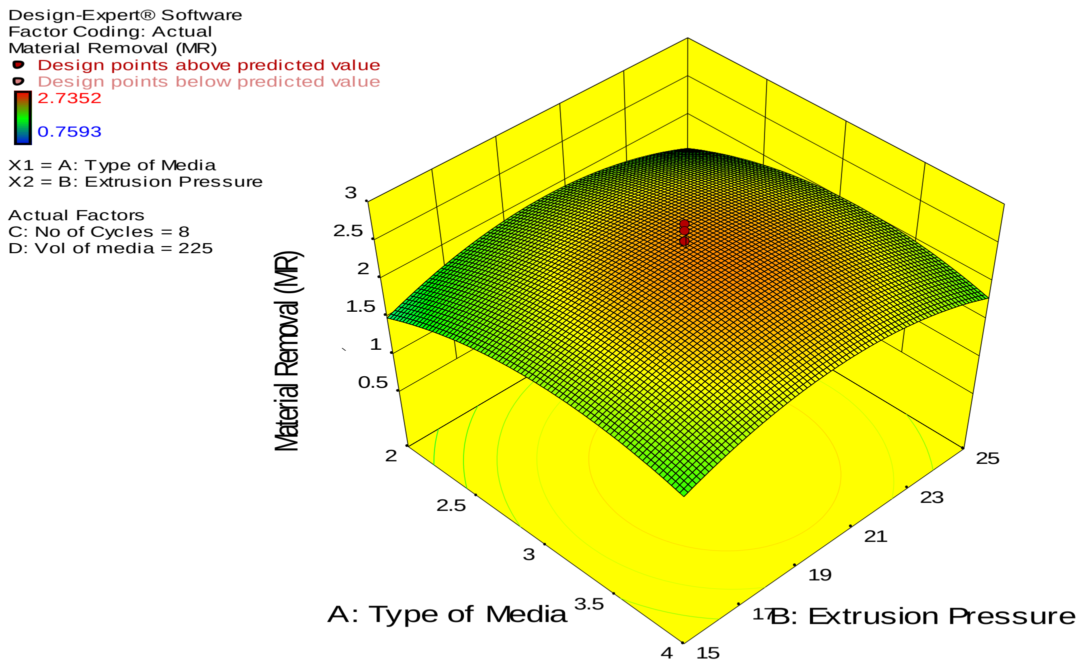

Figure 12: 3D surface Model for Type of media (surface view from top)

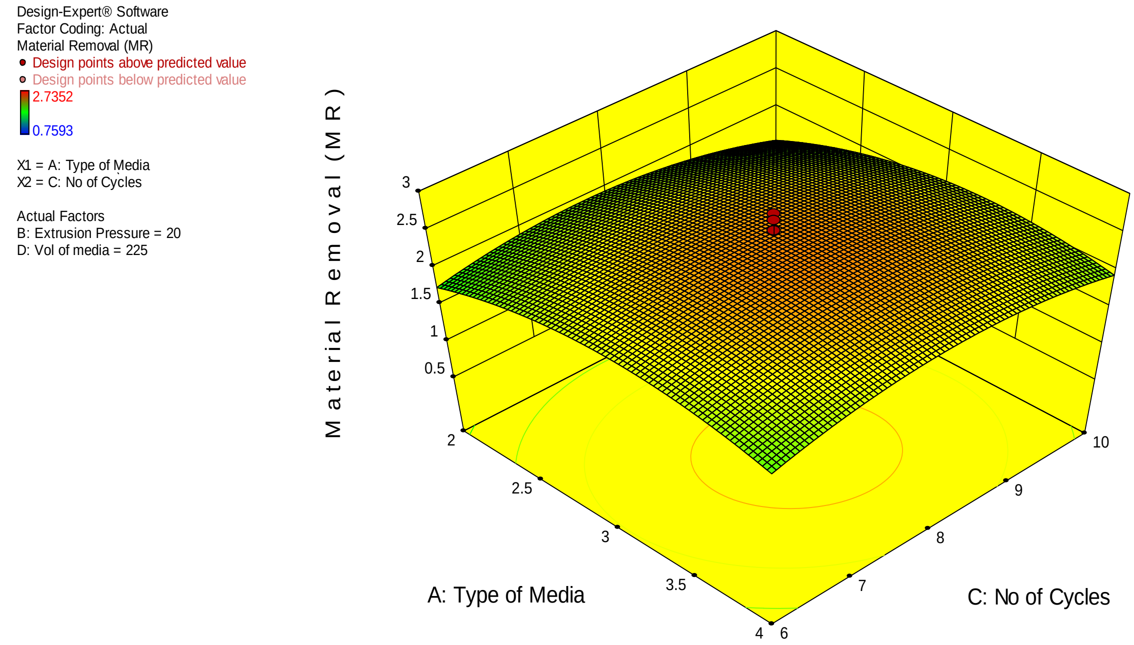

Figure 13: 3D surface Model for Type of media (surface view from front)

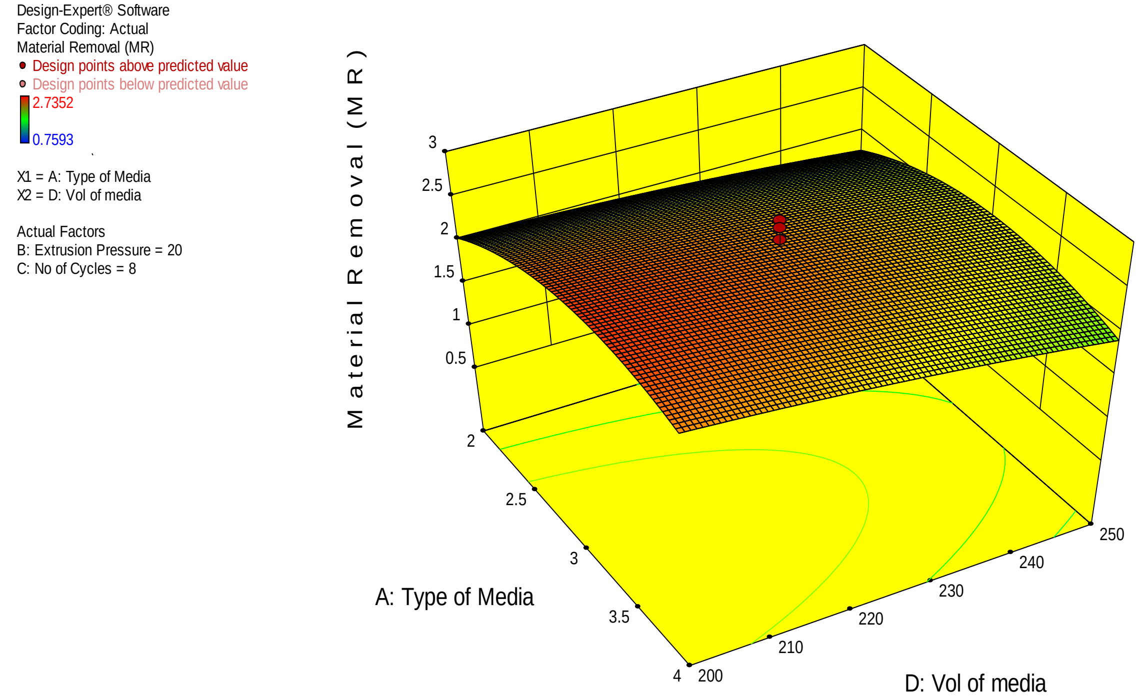

Figure 14: 3D surface model for Extrusion Pressure (surface view from top)

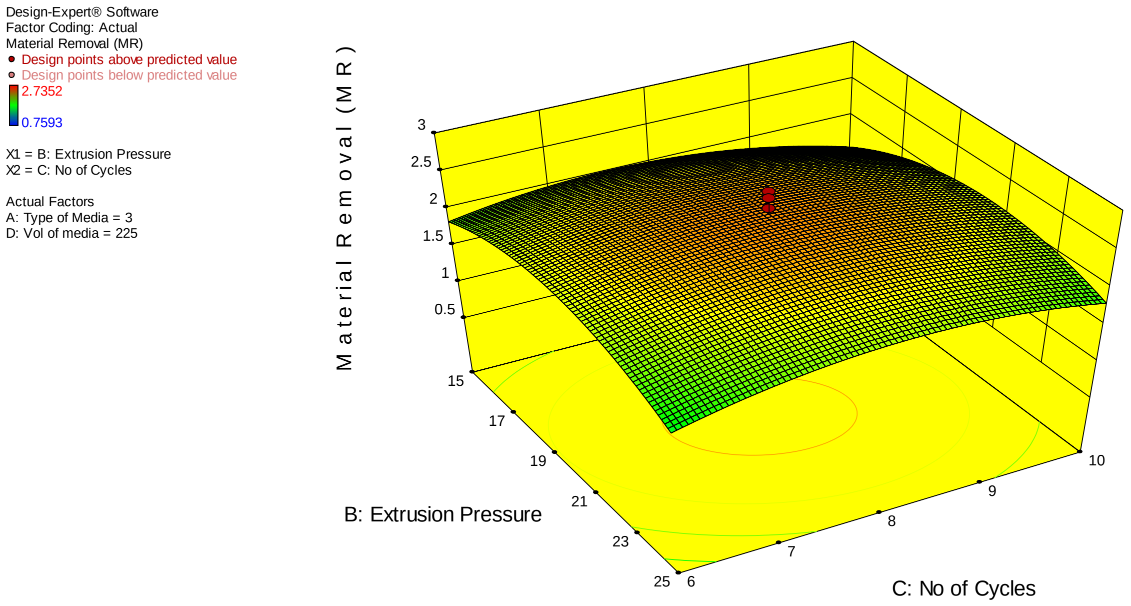

Figure 15: 3D surface model for Extrusion Pressure (surface view from front)

6.4 Discussion on Percentage improvement in Surface Roughness

ANOVA table for Percentage improvement in Surface Roughness is given below, which clearly show that Model is Significant and “Lack of fit” is not significant.

Table 8: ANOVA Table for Percentage improvement in Surface Roughness

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	390.63	14	27.90	3.30	0.0141	**Significant**
A-Type of Media	*31.05*	*1*	*31.05*	*3.68*	*0.0744*	
B-Extrusion	*0.92*	*1*	*0.92*	*0.11*	*0.7458*	

Pressure						
C- No of Cycles	*31.97*	*1*	*31.97*	*3.79*	*0.0706*	
D- Vol of media	*185.37*	*1*	*185.37*	*21.96*	*0.0003*	
AB	*0.18*	*1*	*0.18*	*0.021*	*0.8857*	
AC	*2.81*	*1*	*2.81*	*0.33*	*0.5729*	
AD	*11.06*	*1*	*11.06*	*1.31*	*0.2704*	
BC	*14.63*	*1*	*14.63*	*1.73*	*0.2078*	
BD	*0.46*	*1*	*0.46*	*0.054*	*0.8194*	
CD	*5.88*	*1*	*5.88*	*0.70*	*0.4171*	
A^2	*3.71*	*1*	*3.71*	*0.44*	*0.5175*	
B^2	*27.03*	*1*	*27.03*	*3.20*	*0.0938*	
C^2	*43.36*	*1*	*43.36*	*5.14*	*0.0387*	
D^2	*18.43*	*1*	*18.43*	*2.18*	*0.1602*	
Residual	126.65	15	8.44			
Lack of Fit	*78.31*	*10*	*7.83*	*0.81*	*0.6379*	**not significant**
Pure Error	*48.33*	*5*	*9.67*			
Cor Total	517.28	29				

The Model F-value of 3.30 implies the model is significant. There is only a 1.41% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case D, A^2 , B^2 is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 0.81 implies the Lack of Fit is not significant relative to the pure error. There is a 63.79% chance that a "Lack of Fit F-value". This large could occur due to noise. Non-significant lack of fit is good and we want the model to fit.

Table 9: Variation in statics terminology for material removal

Std. Dev.	2.31	R-Squared	0.7350
Mean	22.39	Adj R-Squared	0.4877
C.V. %	10.32	Pred R-Squared	-0.3430
PRESS	406.30	Adeq Precision	7.660

The "Pred R-Squared" of 0.0066 is not as close to the "Adj R-Squared" of 0.5267 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. “Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Ratio of 6.455indicates an adequate signal. This model can be used to navigate the design space.

6.4.1 Final Equation in Terms of Coded Factors:

Surface Roughness =

$$\begin{array}{ll}
+20.83 & \\
+1.14 & * A \\
+0.20 & * B \\
-1.15 & * C \\
-2.78 & * D \\
-0.11 & * AB \\
+0.42 & * AC \\
-0.83 & * AD \\
+0.96 & * BC \\
-0.17 & * BD \\
+0.61 & * CD \\
-0.37 & * A^2 \\
-0.99 & * B^2 \\
+1.26 & * C^2 \\
+0.82 & * D^2
\end{array}$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

6.4.2 Final Equation in Terms of Actual Factors:

Surface Roughhness =

+125.95000
+9.57500 * Type of Media
+1.23000 * Extrusion Pressure
-10.87500 * No of Cycles
-0.67167 * Vol of media
-0.021250 * Type of Media * Extrusion Pressure
+0.20938 * Type of Media * No of Cycles
-0.033250 * Type of Media * Vol of media
+0.095625 * Extrusion Pressure * No of Cycles
-1.35000E-003 * Extrusion Pressure * Vol of media
+0.012125 * No of Cycles * Vol of media
-0.36771 * Type of Media^2
-0.039708 * Extrusion Pressure^2
+0.31432 * No of Cycles^2
+1.31167E-003 * Vol of media^2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

6.4.3 Diagnosis of static properties of the model

Check point for the Diagnosis

1) Normal probability plot of the studentized residuals to check for normality of residuals.

2) Studentized residuals versus predicted values to check for constant error.

3) Externally Studentized Residuals to look for outliers, i.e., influential values.

4) Box-Cox plot for power transformations.

If all the model statistics and diagnostic plots are OK, finish up with the Model Graphs icon.

6.3.4 Variation in 3D Surface

As this graph clearly says that the percentage improvement in surface roughness is increasing with the media number. Thus it can be concluded that Media no. 1 is less efficient and media no. 5 is highly efficient. Thus Polyborosiloxane is less efficient and silicon rubber is very good media for abrasive flow machining. Ra value caused due to Natural Rubber, SBR Rubber and Nitrile Rubber lies in between them.

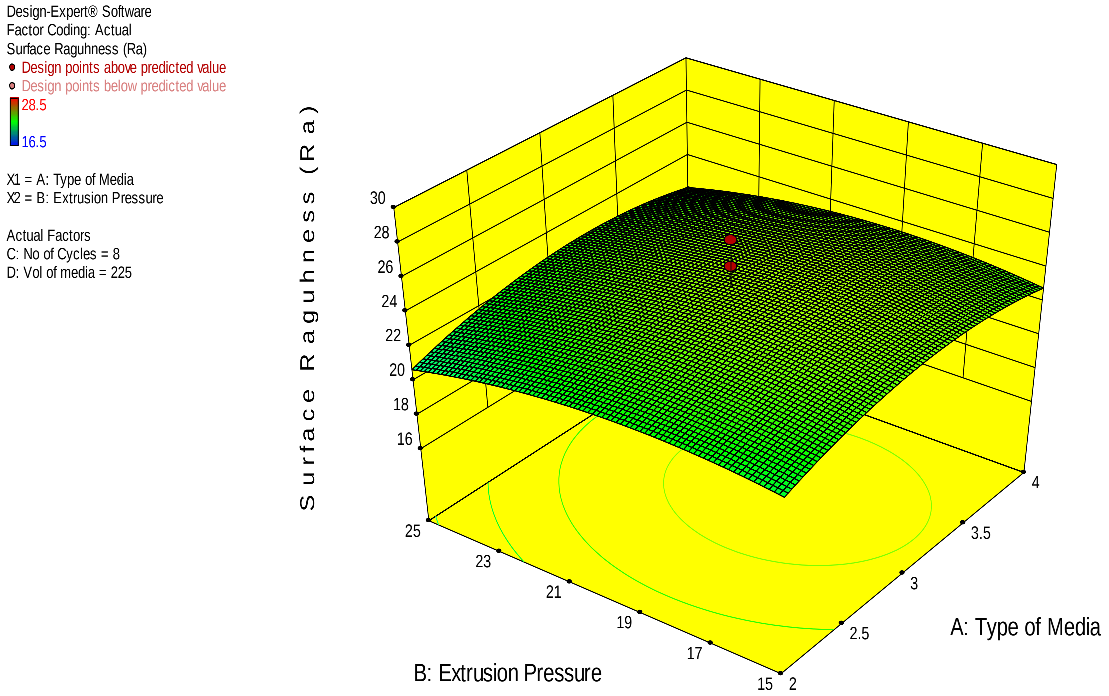

Figure 16: 3D surface model for Type of Media (surface view from top)

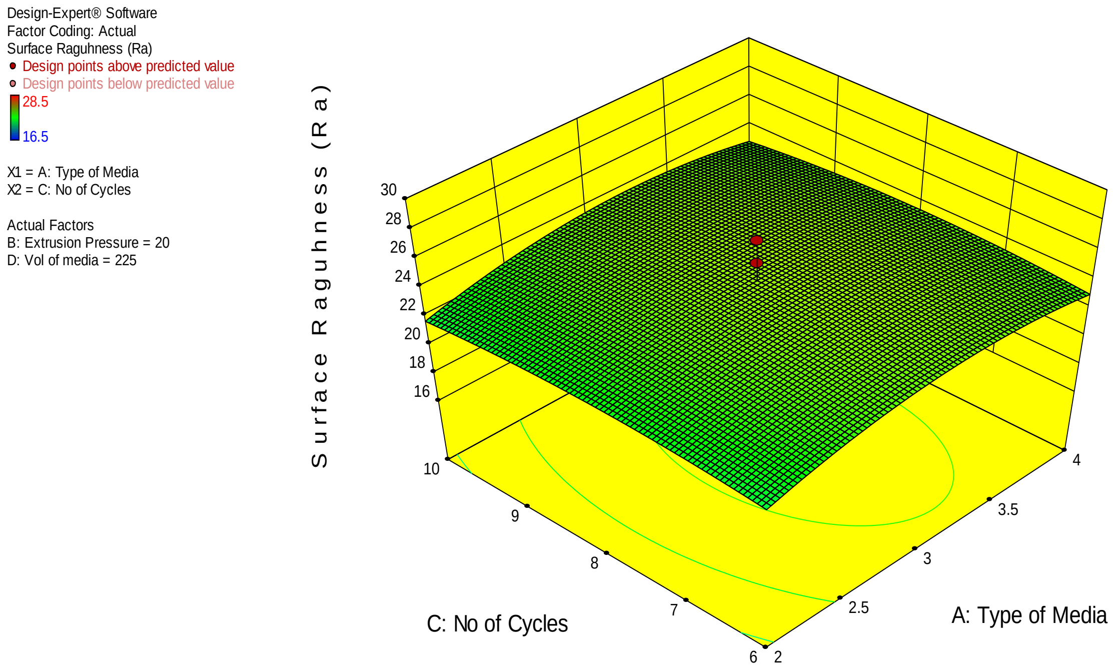

Figure 17: 3D surface model for Type of Media (surface view from front)

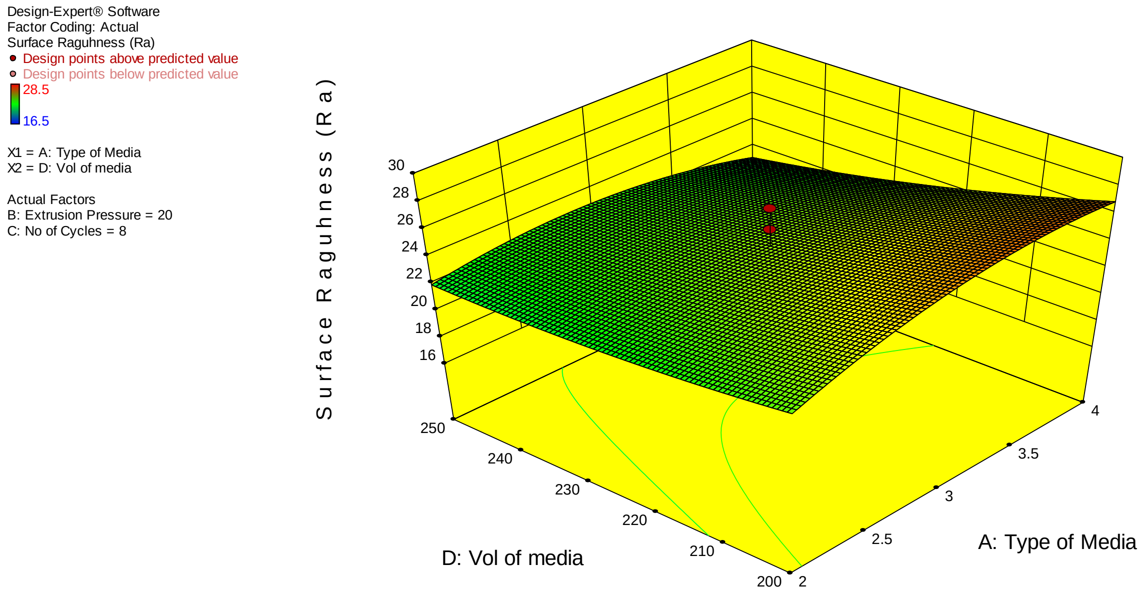

Figure 18: 3D surface model for Extrusion Pressure (surface view from top)

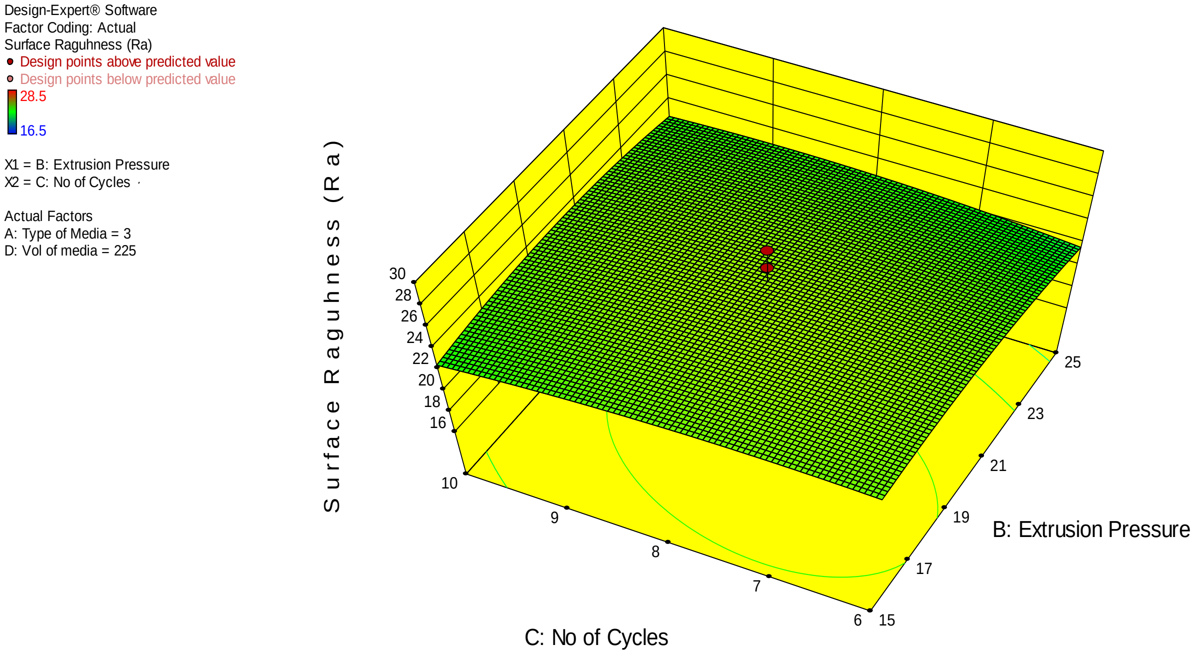

Figure 19: 3D surface model for Extrusion Pressure (surface view from front)

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

There is a tremendous possibility of improvement in the process of Abrasive Flow Machining by using the other type of media. This improvement can be brought by using hybrid AFM Processes also; it provides extra energy to the abrasive particle which increases the momentum to the abrasive particle so that it increases the material removal rate. Various points discussed below can be drawn as conclusion.

CONCLUSION

1. The study of different types of abrasive media used in AFM on brass was done successfully.
2. The effects of using variable " type of media" were properly analyzed.
3. It was seen that as the Extrusion Pressure increases initially the surface finish improves but later its slope decrease.
4. As the No. of Cycles increases the surface finish increases.
5. It was obtained from the experiment that as pressure increases, material removal increases up to certain level after that it decreases.
6. Graph of % improvement in Ra follow the quadratic curve.
7. Graph of Material Removal follow the quadratic curve.

SCOPE FOR FUTURE WORK

1. This process can be improved or automated by using servo control hydraulic units.
2. The set up can be optimized for many other process parameters like different shapes of work materials, different abrasives, flow rate of media etc.

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