Experimental Study of Process Parameters and Optimization of MRAF Process

G.Nallaiya[1], K.S.Sekar[2]

[1]*Lecturer, Department of Tool and Die Making Engineering, Murugappa Polytechnic College, Chennai*

[2]*Lecturer senior Grade, Department of Mechanical Engineering, Murugappa Polytechnic College, Chennai*

Abstract**- One of the newly developed methods for obtaining super finished surfaces for steel specimen is Magneto rheological abrasive finishing fluid (MRAFF). MRAFF is an advanced finishing process in which the grinding force is controlled by magnetic field. The material removal in MRAFF is governed by the magneto rheological abrasive fluid which mainly consists of carbonyl iron (CI), abrasives particles, carrier fluids and additives. MRAFF process is capable of giving nanometer-scale surface finish. The process makes use of a magneto rheological abrasive fluid as a tool that acts as a flexible magnetic abrasive brush (FMAB) that provides finishing action. The relative motion between the finishing medium and the work piece can be obtained either by rotating the work piece, rotating the finishing medium, or both. In the present work, experiments were conducted to finish free form jobs of steel material using the developed setup. The effects of various process parameters viz. composition of the MRA fluid, number of cycles and vessel containing MRA fluid, mesh size of abrasives on surface finish were explored.**

Index Terms**- MRA fluid, Magneto rheological finishing (MRF), Steel Specimen, Surface finish.**

1. INTRODUCTION

1.1 INTRODUCTION TO MRAFF

Precision finishing of internal surfaces and complex geometries is always of concern being labor intensive and difficult to control. Small multiple cutting edges of abrasives are generally used to obtain desired geometrical accuracy and surface characteristics by removal of unwanted superfluous material from the workpiece surface. All traditional finishing processes (grinding, lapping, honing, etc.) work on this mechanism of finishing. Due to the development of new difficulties to machine materials (carbide, composite materials etc.) and complex geometrical shapes of engineering components, the available traditional finishing processes alone are incapable of producing required surface finish and other characteristics. Even if these processes can be used, they require expensive equipment's and large labor, hence making them economically incompetent.

These are incapable of finishing internal intricate shapes and passages. AFM process has the capability of finishing any geometry by allowing abrasive laden polymeric medium to flow over it. In AFM, the medium acts as compliant part and overcomes shape limitation inherent in almost all traditional finishing processes. As abrading forces in AFM process mainly depend on rheological behaviour of polymeric medium, which is least controllable by external means, hence lacks determinism. In 1988, scientists at Belarus explored the new possibilities of using slurry comprised of aqueous MRfluid and cerium oxide abrasives to polish glass up to nanometer level. The process named as MRF (Figure 1.1) uses magnetically stiffened ribbon to deterministically finish optical flats, spheres and aspheres(sunil jha et al 2004)..

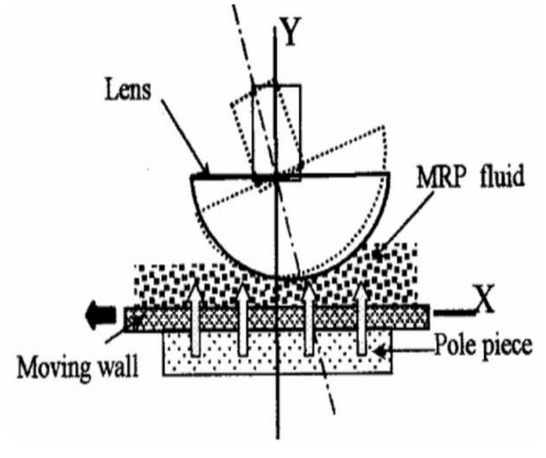

Figure 1: Magneto Rheological finishing Process

1.2 MRAFF PROCESS

In order to maintain the versatility of AFM process and at the same time introducing determinism and controllability of rheological properties of abrasive laden medium, a new hybrid process termed as ‘‘Magneto rheological abrasive flow finishing (MRAFF)’’ is developed. This process relies on smart magneto rheological fluids whose rheological behavior is controllable by means of external magnetic field. The use of magneto rheological polishing fluid with cerium oxide abrasives for finishing optical lenses up to the level of 0.8 nm root mean square (RMS) value has already been demonstrated by MRF process. Figure 1.2 illustrates the development of magneto rheological abrasive flow finishing process from two different processes namely MRF and AFM.

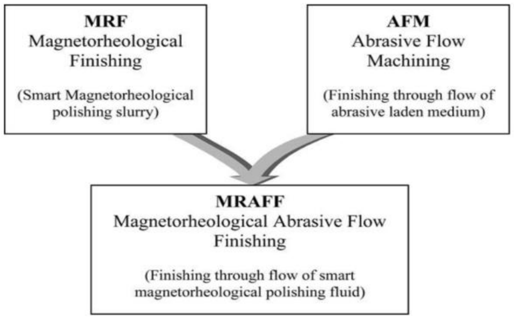

Figure 2: MRAFF Process

MRAFF process has the capability of finishing complex internal geometries up to nanometer level. It imparts better control of the process behavior as compared to AFM process due to better control over abrading medium’s rheological behavior.

2. PREPARATION OF MAGNETORHEOLOGICAL ABRASIVE FLUID

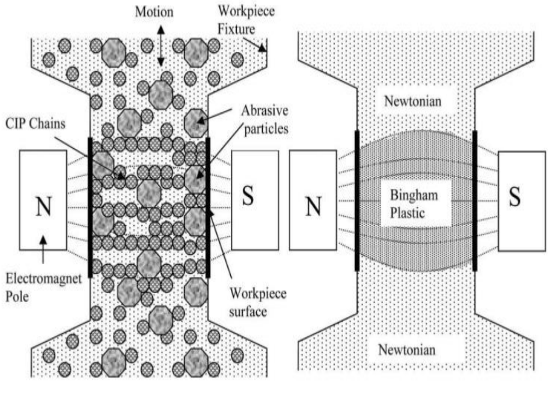

Figure 3: Preparation of MRFF Fluid

2.1 INGREDIENTS OF MR FLUID

- Volume of silicone oil base fluid is 60%.
- Volume of Cerium oxide is 20 %.
- Volume of ferrous particle is 20 %

2.2 PREPARATION OF FERROUS NANO PARTICLES

All samples must also be of an appropriate size to fit in the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub. Several models of SEM can examine any part of a 6-inch (15 cm) semiconductor wafer, and some can tilt an object of that size to 45°.

For conventional imaging in the SEM, specimens must be electrically conductive, at least at the surface, and electrically grounded to prevent the accumulation of electrostatic charge at the surface. Metal objects require little special preparation for SEM except for cleaning and mounting on a specimen stub. Nonconductive specimens tend to charge when scanned by the electron beam, and especially in secondary electron imaging mode, this causes scanning faults and other image artifacts. They are therefore usually coated with an ultrathin coating of electrically-conducting material, commonly gold, deposited on the sample either by low vacuum sputter coating or by high vacuum evaporation. Coating prevents the accumulation of static electric charge on the specimen during electron irradiation.

2.3 SEM ANALYSIS OF FERROUS PARTICLES

The nano particles which were prepared by the high energy ball mill in dry process was taken as sample. The sample was measured by the scanning electron microscope. The sample was focused at different location and viewed at different magnification.

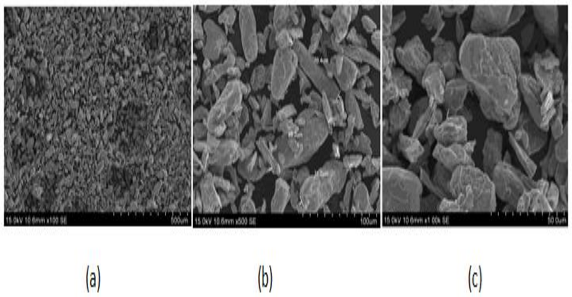

Figure 4: SEM Image of the micron size ferrous powders at 100X, 500X and 1000X Magnification

2.4 SEM ANALYSIS OF ABRASIVE PARTICLES

Cerium oxide is the abrasive constituent of MRA fluid and its nano particles were prepared by ball milling using titanium balls. SEM analysis was carried out both before and after the ball milling.

Figure 4 shows the SEM Image of the Micron size Abrasive Powders at 3000X Magnification, 5000X Magnification and 15000X Magnification.

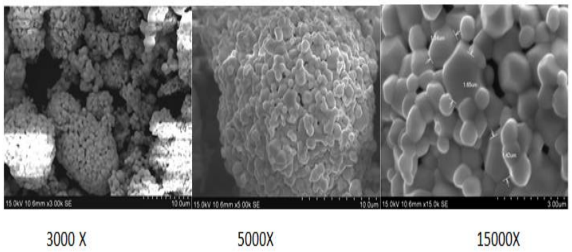

Figure 5: SEM Analysis of Abrasive Particles

2.5 ABRASIVE PARTICLE – CERIUM OXIDE

Cerium oxide is used as the abrasive constituent of Magneto rheological abrasive fluid. It is generally to use to prepare the glass polishing powders.

Appearance : yellowish powder
Formula : CeO_2
Uses : It is mainly used as the glass decolorizing agent and the glass polishing powder.
Grade : oxide powder

2.5.1 Standard Mesh Size

16, 24, 36, 46, 60, 80, 100, 120, 150, 180, 220, 240, 280, 320, 400

2.5.2 Key Properties

Atomic No : 58
Brinell hardness No : 412MN/m²
Young’s Modulus : 34 GPa
Melting Point : 1068 K
Thermal Conductivity : 11 W/m/k
Density of Solid : 6689 Kg/m³.
Electrical Resistivity : 75 Ω.
Co.eff. Of linear expansion : 6.3X 1O^-6K^{1}

2.6 PREPARATION OF MRA FLUID

- Cerium oxide and ferrous particle are added with the oleic acid which is a surfactant which is used to keep the particles in Brownian motion.
- The mixture is stirred with the magnetic stirrer or the mechanical stirrer.
- The stirring action takes place for 30 minutes.
- Then this liquid is mixed with the silicone oil with the help of mechanical stirrer

2.7 Experimental Setup

There are various parts in MRAFF setup that are shown in Figure 5,

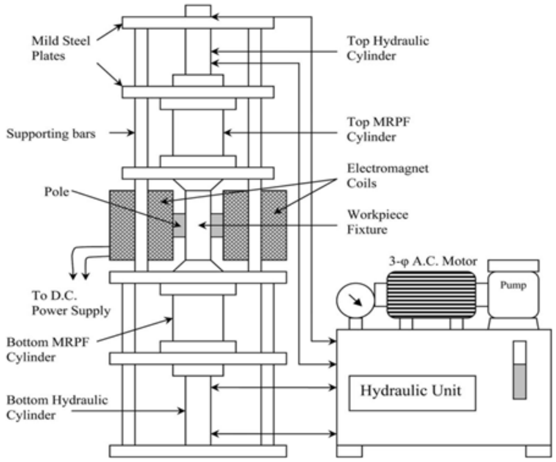

Figure 6: MRAFF Setup

The various parts of the machine are
1) Hydraulic cylinders
2) Magneto rheological polishing fluid (MRPF) containers
3) Work piece fixture
4) Supporting system
5) Electromagnet

3. DESIGN OF EXPERIMENTS & SURFACE ANALYSIS

3.1 Material Selection

Stainless steel-316L works pieces of size 35x10x3 mm with a roughness value of 0.82µm were fixed on the work piece fixture. The composition of stainless steel- 316L is given in table.4.1. Magneto rheological abrasive (MRA) fluid was prepared with the 20% of carbonized iron particles and 20% of cerium oxide particles and 60 % of silicone oil as a

3.2. Design of Experiments - Taguchi Technique

The effects of Extrusion Pressure, current and number of cycles of the MRAFF on the surface roughness of the stainless-steel316L work piece and in order to optimize these process parameters by Taguchi technique, L27 series was preferred. Base fluid and it is filled in MRAF container. The stainless steel-316L work pieces machined by MRAFF process were analyzed by Talysurf Coherence Correlation Interferometer (CCI). In order to optimize the process parameters of Magneto Rheological Abrasive Flow finishing process by Taguchi technique, L-27 series of experiments were conducted and optimization was carried out by Minitab 16.0, optimization software.

3.3 Surface Analysis

After conducting the Magneto rheological abrasive flow finishing process on the stainless steel work pieces, their final surface finish was analysed by Talysurf interferometer.

3.4 CCI Images

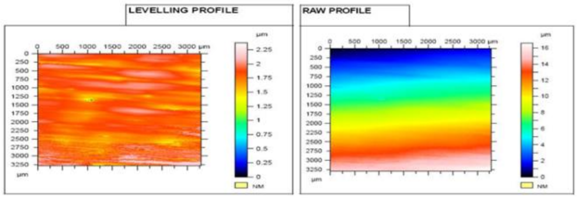

Figure 7: CCI Raw and Leveling Profile

EX.No	Pressure (Bar)	Current A	No.of Cycles	Ra (nm)
1	20	2	100	38.21
2	20	2	200	37.22
3	20	2	300	36.74
4	20	4	100	34.66
5	20	4	200	34.03
6	20	4	300	33.57
7	20	6	100	31.41
8	20	6	200	30.82
9	20	6	300	30.39
10	30	2	100	37.28
11	30	2	200	36.78
12	30	2	300	36.42
13	30	4	100	34.05
14	30	4	200	33.59
15	30	4	300	33.25
16	30	6	100	30.8
17	30	6	200	30.38
18	30	6	300	30.07
19	40	2	100	36.63
20	40	2	200	36.3
21	40	2	300	36.05
22	40	4	100	33.4
23	40	4	200	33.11
24	40	4	300	32.88

Table 1.Surface roughness obtained in L-27 series of experiments

3.5 Surface Roughness by ANN and Regression Analysis

ANN

Neural networks, as used in artificial intelligence which are simplified models of neural processing in the human brain. The evolution of neural networks are based on efforts to model information processing done in biological systems, which depend largely on parallel processing as well as implicit instructions based on recognition of patterns of "sensory" input from external sources . Human body consists of trillions of cells. A portion of them is the nerve cells called "neurons". These neurons have different shapes and sizes [23]. A neuron collects signals from others through fine structures called dendrites. The neuron sends out spikes of electrical activity through a long, thin stand known as axon, which splits into thousands of branches. At the end of each branch, a structure called a synapse converts the activity from the axon into electrical effects that inhibit or excite activity in the connected neurons. When a neuron receives excitatory input that is sufficiently large compared with its inhibitory input, it sends a spike of electrical activity down its axon. Learning occurs by changing the effectiveness of the synapses so that the influence of one neuron on another changes.

Trial	Pressure (Bar)	Current (A)	No.of Cycles	Surface Roughness, nm		
				Exp	Regression	ANN
4	20	4	100	34.66	34.56	34.82
8	20	6	200	30.82	30.94	30.74
12	30	2	300	36.42	36.94	37.44
16	30	6	100	30.8	30.85	31.8
20	40	2	200	36.3	36.39	36.35
24	40	4	300	32.88	32.77	31.4

Table 2: Surface Roughness Comparison Table

The comparison of the surface roughness values obtained using ANN and regression analysis with the experimental values used for network training. It is observed that a perfect prediction is obtained for surface roughness with the trained neural network model and regression analysis.

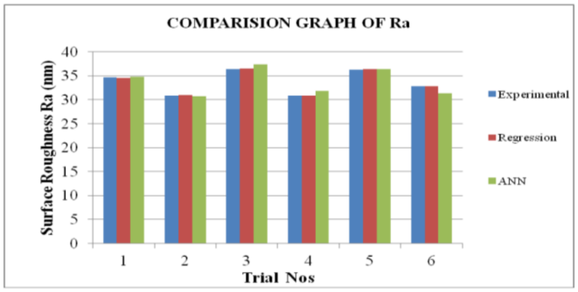

Figure 8: Comparison of surface roughness by experiment, ANN and Regression

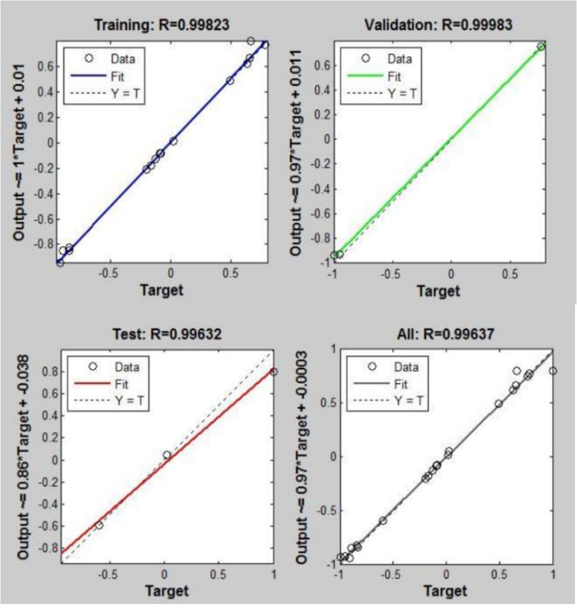

Figure 9: Regression Plots

Fig.9.shows the regression plots of combination of training, validation and test run of the ANN network. The regression value obtained during training the given input data's to the output data's is 0.99823, whereas for validation the regression value obtained is 0.99983 and the regression value during testing the data's during training itself is 0.99623. The overall regression value obtained for the training, validation and testing and is 0.99637, which is very much satisfactory. Hence with continuous training almost an accurate value of regression can be obtained with the ANN. From the regression graphs obtained during training, it is seen that the obtained ANN model predict the surface roughness almost similar to the actual values.

4. RESULTS & DISCUSSION

The effect of the input parameters of the MRAFF process on the surface finish of the 316L stainless steel work pieces are discussed as follows.

4.1 Effect of Extrusion Pressure on Surface Roughness

It was observed that there was no much noticeable effect of extrusion pressure on the final surface roughness under the experimental condition.

Sunil jha et al (2007) observed that major part of the MR polishing fluid during the experimentation is in a sheared state and the role of unsheared cores participating in material removal is almost negligible, while rubbing and abrasion due to abrasive particle rolling in sheared fluid is more of three body natures. In this mode the abrasive not only slide but also roll the scratches due to sliding of abrasives can lead to cutting wear and craters caused by rolling can lead to plastic deformation. Beyond certain optimum pressure the three body abrasive mode of wear also vanishes owing to a decrease in the plug flow radius and an increase in the shear flow region. Hence no further significant improvement in the surface finish was observed after optimum pressure.

4.2 Effect of Current on Surface Roughness

It was observed that when the current increases from 2 to 6 A there was good improvement in the surface finish as well as reduction in surface reduction Ra. Manas das et al (2008) observed that with the increase in current in the electromagnet, magnetic field also increases forming strong chains of CIPs. Due to the increased bonding strength of the abrasive particles by the surrounding CIP chains, there is a lesser chance of rotation of the abrasive particles which are taking part in material removal getting higher reduction in surface roughness value of the work piece.

4.3 Effect of Number of Cycles on Surface Roughness

It was observed that when the number of cycles increases from 100 to 300, there was significant on the surface finish of the work piece and reduction in roughness value (Δ) is increased with the increase in number of cycles. Sunil jha et al (2007) was observed that the measured value of the surface roughness decreases for the first 200 cycles and then increases further to reach a maximum after 300 cycles with the continuous improvement of texture. The decrease in the Ra value for the first 200 cycles is mainly due to the removal of loosely held material left after ploughing during surface grinding. After complete removal of this ploughed material the actual deeper grinding marks are exposed and results in gradual increase reduction in Ra value.

5. CONCLUSION

Experiments were conducted to study the effect of current, number of cycles, extrusion pressure, on the surface finish towards the optimization of MRAFF process to obtain a nano level surface finish on stain less steel work pieces.

Based on the experimental analysis following conclusions have been derived. Optimization of process parameters was carried out by Minitab 6.0, an optimization tool.

- It was observed that there is no much noticeable effect of extrusion pressure on the final surface roughness under the experimental condition. Beyond certain optimum pressure the three body abrasive mode of wear also vanishes owing to a decrease in the plug flow radius and an increase in the shear flow region. Hence no further significant improvement in the surface finish was observed after optimum pressure.
- Reduction in surface roughness value was observed to be increasing with an increase in current (A). Due to the increased bonding strength of the abrasive particles by the surrounding CIP chains, there is a lesser chance of rotation of the abrasive particles which are taking part in material removal getting higher reduction in surface roughness value of the work piece.
- Reduction in surface roughness value was observed to be increasing with an increase in number of finishing cycles. The decrease in the Ra value for the first 200 cycles is mainly due to the removal of loosely held material left after ploughing during surface grinding. After complete removal of this ploughed material the actual deeper grinding marks are exposed and results in gradual increase reduction in Ra value. Regression equation of optimization is given by:Surface finish = 43.7056 + 0.198333 pressure - 2.2 current - 0.0308333 No of cycles.The results reported indicate that ultrafine surface finish of stainless steel 316L achieved in the MRAFF process is also reflected in its characteristic, rich surface architecture at nano-scale.

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