International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Special Issue - AMET-2018

Investigating the Behavior of Parameters using Magnetorheological Abrasive Flow Finishing Process

Vilas S. Kanthale†, D.W. Pande‡

†Assistant Professor, Department of Mechanical Engineering, MAEER's MITCOE, Pune 411038, Maharashtra, India

‡Professor, Department of Mechanical Engineering, Government College of Engineering, Pune 411005, Maharashtra, India

Abstract

The main aim of this study was to experimentally investigate and analyze the behavior of various process parameters like the ratio of concentration of CIPs and Al_2O_3 abrasives, the current supplied to the electromagnet, rotating speed of tool, feed rate of the workpiece, the working gap between rotating tool and the workpiece surface, and workpiece hardnesses of AISI D3 steel material on the response of surface roughness, Ra and difference between initial surface roughness and final surface roughness obtained using magnetorheological fluid based finishing process. Also possible reasons for trends have been proposed through extensive trials and examination. These initial values form the basis of selection of ranges for each parameter for the further process characterization and optimization for improving the finishing performance of the MR fluid assisted process. The experimentation was carried out on the vertical machining center (VMC) machine with customized setup.

Keywords: *Magnetorheological fluid finishing (MRF), abrasion, surface roughness, die steel.*

1. Introduction

Nano finished surfaces find wide application in the various industries, especially in automobile and die making industry. The ultra precision is the prime requirement in manufacturing industries. It is well known that the fatigue life of any component mainly depends upon its surface finish (Bayoumi, 1995). Now, the ultra finished surfaces can be obtained using controllable smart fluid that is magnetorheological (MR) fluid (Jacob, 1995). The MR fluid plays a significant role for polishing the hard material components because its rheological properties can be altered during finishing process under the effect of magnetic field (Kormann, 1996 & Laun, 2000).

The main constituents of MR fluid based finishing processes are magnetized particles, non magnetized abrasive particles and the base fluid. In earlier days, MR fluid was used for vibration isolators and shock absorbers without adding the abrasive particles. Meanwhile, some researchers (Tani, 1984, Kurobe 1984, Suzuki, 1989 and Kordonski, 1996) have used magnetorheological fluid for polishing the glass and other hard materials. Nowadays, MR fluid becomes an important part of ultra precision polishing process. Magnetorheological finishing process (Arrasmith, 1999) was mainly used to polish the external surfaces of glass material and unable to finish the internal surfaces thereby new hybrid process developed such as magnetorheological abrasive flow finishing process and rotational magnetorheological abrasive flow finishing process for finishing the small internal and cylindrical surfaces of hard materials (Jha, 2004 & Das, 2009)

MRAFF process is in its early stage of development. Hence, Sustainable research is required to make the process standardize so that it is possible to polish the surfaces of any shape and sizes with different kind of materials. Also, there is no much more information available in the literature regarding the behavior of input process parameters for polishing the hard materials such as die steel. However, the existing set up of the MR fluid based process is very complicated for polishing the large components with hard materials especially for die and punch components. Thus, it is essential to characterize the process by knowing the behavior of process parameters.

The main objective of this paper is to experimentally investigate the feasibility and reliability of the developed magnetorheological abrasive flow finishing process setup incorporated with VMC machine also, studying the behavior of independent input parameters like the ratio of concentration of CIPs and the abrasives particles (Al_2O_3), current, working gap, feed rate, rotational speed of the tool and workpiece hardness during the process on the response of surface roughness, (R_a) and the difference between the initial surface roughness(R_{ai}) and final surface roughness (R_{af}).

2. EXPERIMENTAL DETAILS

2.1 Experimental material

For the research work, AISI D3 was chosen as the work material. As the appearance and fatigue life of the finished components, mainly depends upon the quality of finishes of the die and punch surface, polishing of die is one of great importance and challenging due to its hardness property owing to this D3 material is selected.

The dimensions of the workpieces were selected 70 mm X 25 mm X 5 mm as per the size of the flask in which specimen was to be fixed for polishing. In order to study the characterization and performance of the MR fluid based process, the experiments were performed with three different hardness of die steel material such as 30HRc, 45HRc and 65HRc.

2.2 Design of experimental setup

The schematic drawing of MR fluid based finishing setup is shown in figure 1, and the details of the design of each part are given as below.

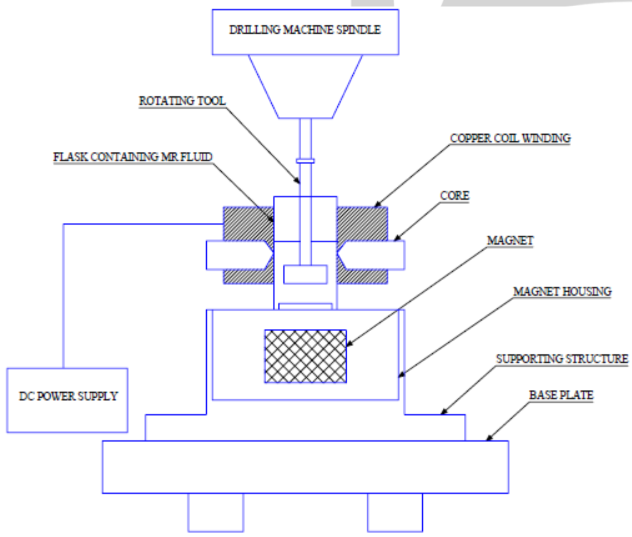

Fig. 1 A schematic view of MR fluid finishing setup

2.2.1 Base plate

Base plate was designed for providing the support to all the parts of the finishing setup such as the brackets (for holding the electromagnet core) and the magnet housing with mounting plate are bolted to the base plate, thus carrying all the load of the equipment. For this aluminum sheet of 3mm was used as the material for making of the lightweight base plate.

2.2.2 Design of electromagnet

In order to get a stable and strong magnetic field with a uniform chain of the carbonyl iron particles, it was necessary to use the shape of electromagnet appropriately. For this reason various shapes of electromagnet were designed and analyzed its results. It was found that the C-shaped core exhibits better results than other shaped shoe because no losses of magnetic flux due to continuous shape of the electromagnet shoe, whereas in other type of electromagnet shoe its other end remains free due to which the chances of losses of magnetic flux incurred during finishing operation. Initially, the distance between S and N poles was kept 100 mm. It was found that the strength of the magnetic field at the center of the gap (where the specimen was supposed to be placed) observed very low. Later, the gap was reduced to 32 mm (to fit a 30mm width flask), also the winding of the coil was increased to get required strength. A taper was also provided at the end of the pole so that the field could be concentrated in a small area and a large magnetic field could be obtained in the working zone of specimen.

Winding is made around the core arm for generating the high magnetic field. A DC supply is provided as the source current to the coil. A lightweight, portable AC to DC converter was specially designed and fabricated which provides varying voltage from 0V to 230V.

2.2.3 Permanent magnet for holding specimen

In order to restrict the movement of the specimen during the surface finishing operation a permanent magnet was used. This housing with magnet was kept below the MR fluid container. This permanent magnet in the housing are supposed to provide required attractive force on the bottom side of specimen to keep it steady because after applying the magnetic field through the electromagnet, specimen uplifted due to the magnetic force produced by an electromagnet thereby its alignment changed as a result poor surface roughness observed. Hence, it is essential to hold the specimen at the bottom surface of flask firmly during the finishing operation. For this reason, two permanent magnets (Sintered Nd-Fe-B, N48 Grade), of dimension 50mmx50mmx20mm were used as the holding mechanism for the specimen. It was held inside an acrylic box. A holder is also provided at the side of the box for the easy of handling. The magnet has the field strength of 3000 Gauss. The field strength of this magnet may also help in strengthening the stiffness of the MR fluid.

2.2.4 MR fluid contained flask

The flask used to hold the specimen with MR fluid is made of acrylic material because its permeability is very high. The design of the flask is done according to the gap available between the two poles. Enough height is provided to the flask so that there is no scope for the spilling of the MR fluid during the operation. Thus, the rectangular shape of flask dimensions was decided as 100 mmx30 mmx70 mm. Additional projections are also provided inside the flask for restricting the rotation of the workpiece.

2.2.5 MR fluid rotating tool

A tool was designed and developed for rotating the MR fluid over the surface of workpiece in order to get the finishing operation. The tool consists of stainless steel material with a shank diameter firmly clamped in the tool holder of the machine. At the end of the tool, the larger diameter was kept for getting the maximum polished surface area. This tool was designed in such a way that it does operations smoothly without wobbling during the operation. In order to prevent the tool from getting magnetic due to strong magnetic fields that's why the tool was made of stainless steel material.

2.2.6 MR fluid preparation

MR fluid was prepared mainly from three constituents, namely, magnetized carbonyl iron particles (CIPs), non magnetized aluminum oxide (Al_2O_3) particles and heavy paraffin liquid as a base of the fluid for polishing the surfaces of work material. These three constituents measured with the help of electronic balancing machine in terms of percentage by weight. The concentration of the MR fluid prepared as per the plan of experiments. In this work, the quantity of the paraffin oil kept as a constant parameter throughout the experiments and only varied the proportion of carbonyl iron particles and abrasive particles the reason behind that to understand the behavior of surface roughness against the proportion of CIP and abrasive particles.

3 MR Fluid Assisted Finishing Process

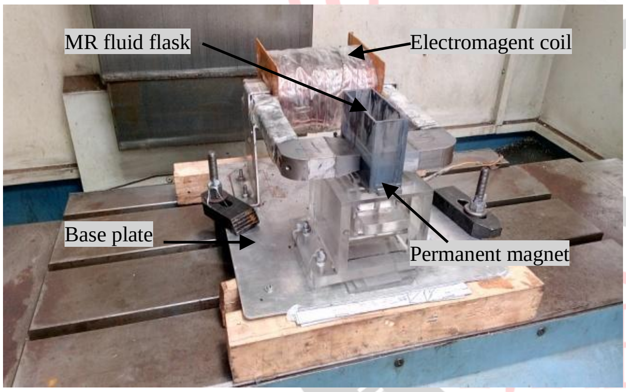

Fig. 2 Photograph of actual MR fluid finishing setup

The finishing process was performed on a vertical machining center (VMC) of Premier Machine Tools Ltd. The stability of the machine is 0.005 mm and the accuracy is ±0. 003 mm. An experimental setup was designed and fabricated as shown in figure 2. The entire setup is mounted on the horizontal bed of machine and firmly clamped with the help of bolting. During clamping the setup on the machine, the utmost care has been taken of leveling the surface of setup so that workpiece surface and tool surface remain parallel to each other during operation and get a uniform finishing over the surface of workpiece. The rotating tool was clamped in the tool arm of VMC machine for rotating the MR fluid over the polishing surface of specimen. The specimen was firmly clamped inside the flask of MR fluid and then dry run was taken for deciding the working gap between workpiece and bottom surface of rotating tool. The concentration of MR fluid is prepared as per the design of experiments. This prepared MR fluid is poured into the flask in which already specimen fixed at the center of the flask, and then this flask was placed on the fixture provided in the setup and firmly clamped with the help of fixture supporter. The magnetic field was applied to the fluid through an electromagnet. The strength of the magnetic field is varied for experimentation with the help of variable D.C. supply. The rotating tool is rotated as per the desired speed (as per the condition of design of experiments) over the MR fluid without touching to the surface of workpiece. The linear motion is provided to the worktable on which specimen was mounted and rotating the MR fluid inside the flask through the rotating tool at its stationary position. The motion of the work table and the speed of the rotating tool were controlled through the CNC programming. Current is supplied to the electromagnet which generates the magnetic field across the MR fluid. Due to this magnetic field, the liquid form of the MR fluid gets converted into the solid form under the effect of magnetic fields. The generated magnetic field produces the magnetic force and acted upon the abrasive particles. Carbonyl iron particles aggregate in a columnar structure along the direction of applied magnetic field in which abrasive particles locked. The gripping strength of abrasive particles depends upon the strength of magnetic field supplied to the MR fluid. The chains of CIPs along with abrasive particles rotate along with rotating tool. The rotating tool acts the normal force on the abrasive particles whereas longitudinal motion to the work piece applies tangential force on the abrasive particles. Abrasive particles moved over the surface of the specimen as a result of which the embedded particles removes the peaks from the surface of the work material. The surface gets flattened after the numbers of cycles of abrasive particles rotate over the surface of workpiece. The particles of carbonyl iron and abrasives are tightly joined with each other under the application of magnetic field and rotated due to the rotation of rotating tool.

4. Results and Discussion

In this work, experimental parameters such as rotating speed of tool (RPM), the current supplied to the electromagnet (Amp), feed rate of the workpiece (mm/min), working gap (mm), concentration of MR fluid (% by weight) and hardness of material (HRC) were considered on the basis of literature review. Several variables were put under close control, including the CNC machine on which finishing operation was performed. The same CNC machine was used for all experimental work. The surface roughness data were collected randomly for different levels of parameters without executing the design of experimentation in order to estimate the effects know the behavior of all input process parameters as well as finding the stability and reliability of the CNC machine for polishing the die steel work material surfaces with the help of MR fluid. The finishing characteristics of die steel surfaces are analyzed by measuring the surface roughness of the workpieces, which was measured at three different locations before and after finishing using a surface roughness analyzer (Mitutoyo SJ-210) with a cut off length 0.8mm over three sampling lengths and then averaged to quantify the roughness obtained on finished surfaces.

4.1 Influence of concentration of MR fluid

Experiments were carried out in order to observe the behaviour of concentration of CIPs and abrasive (Al_2O_3) particles. The results of the effect of concentration of MR fluid against the response of surface roughness R_a is shown in figure 3 and 4. It is observed that the surface roughness remains constant by altering the proportion of CIPs and abrasives with paraffin oil as constant constituents. The proportion of paraffin oil decreased in the concentration then surface roughness increases because the concentration of MR fluid become very hard as a result of which scratch mark of the particles increases thereby surface roughness increase.

The normal force and tangential force increases with increasing CIPs concentration. As the concentration of CIPs increases, CIPs form stronger and thicker chains along the lines of magnetic flux which result in higher yield stress of the MR fluid. On the other hand addition of the CIP particles to the MR fluid will make the fluid more and more viscous. After certain proportion the MR Fluid will become too hard and it will lead to a reduction in the surface roughness during the operation. Similarly, if abrasive particles are in high proportion it will increase the surface roughness and also the temperature of the fluid which will change its properties.

The other important component is oil. Oil performs mainly two functions in the MR fluid viz. i) Acts as a lubricant in a fluid which helps in dissipating the heat produced between tool and the work piece. The heat produced can damage the surface, hence affecting the result. ii) It also acts as binders between CIP and abrasive particles. On the basis of the literature survey, it was concluded that paraffin, engine oil, and glycerol oils can be used as carrier fluids.

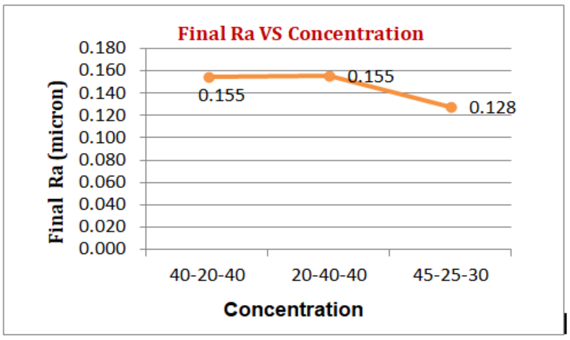

Fig.3 Influence of concentration of MR fluid on final R_a

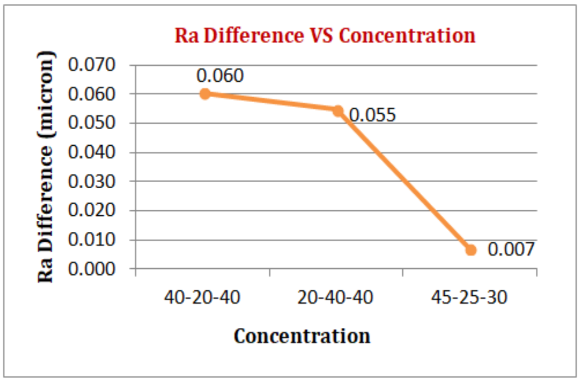

Fig.4 Influence of concentration of MR fluid on Ra difference

4.2 Influence of magnetizing current

The magneto rheological process is completely based upon the alignment of CIP particles and chain formation. The stronger the alignment more is the surface erosion that takes place, which results in a higher surface finish. The alignment of the CIP particles directly depends upon the strength of the magnetic field. Stronger the magnetic field stronger will be alignment of CIP. It is observed that the magnetic field is directly proportional to the current; hence magnetic field increases with the increase in the current resulting increase in the surface roughness and vice – versa. With the increase in too much current heat generated also increases resulting in a worse surface finish, hence to get good surface finish current should be supplied at optimum rating.

Figure 5 and 6 shows the effect of magnetized current supplied to the MR fluid. It is seen that as the current goes on increasing, the surface roughness R_a value decreases or the difference between initial and final R_a value increases. This is due to the fact that as the current increases the magnetic field strength increases, which results in strong bond formation among the carbonyl iron particles due to which the strongest chain was formed which carries abrasive particles with it efficiently.

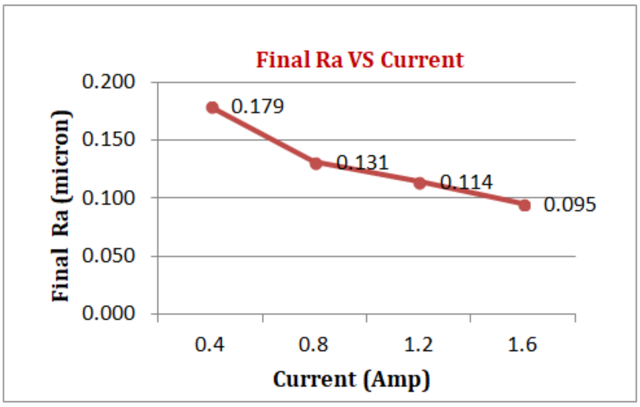

Fig. 5 Influence of current on final R_a

 DOI : 10.18231/2454-9150.2018.1427

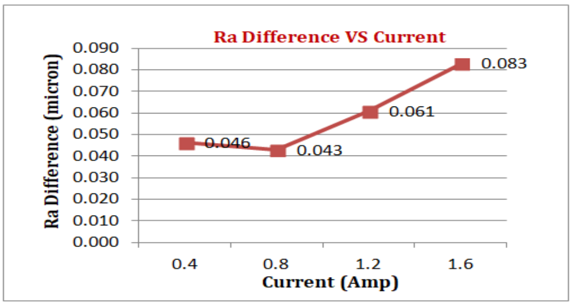

Fig. 6 Influence of current on R_a difference

4.3 Influence of rotating speed of tool

From the figure 7 and 8, it is seen that as the rotational speed is increased the surface roughness R_a value goes on decreasing, i.e. polishing goes on increasing up to a certain limit. After attaining the certain speed the centrifugal force exceeds due to which the abrasive particles are thrown away from the finished zone as a result the surface roughness increases. Also, the chain of carbonyl iron particles breaks and hence the polishing surface of the workpiece deteriorates. It means that the speed increased beyond the certain limit then the surface roughness of the workpiece goes on increasing.

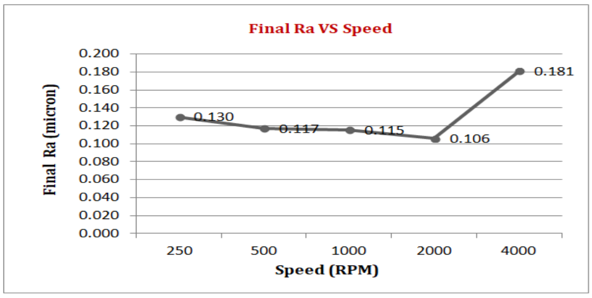

Fig.7 Influence of tool speed on final R_a

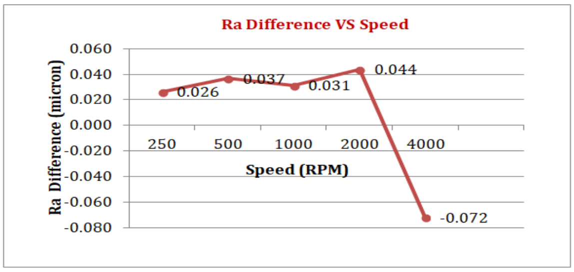

Fig. 8 Influence of tool speed on R_a difference

4.4 Influence of feed rate of the workpiece

Linear movement was provided to the work table on which the workpiece was fixed. It is observed from the figure 9 and 10 that the surface roughness decreases by increasing the feed rate to the workpiece. As the feed rate of the workpiece decreased then the number of abrasive particles comes in contact with the surface goes on increasing resulting into poor finish. It is clearly seen that the number of passes of the abrasive particles over the finishing surface need to be less for getting the good surface finish.

As the optimum surface roughness is required for fine polishing the corresponding feed rate should be kept up to certain higher side.

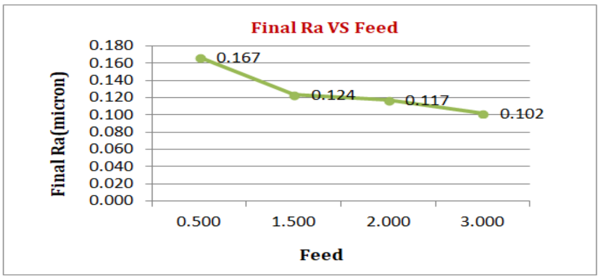

Fig. 9 Influence of feed rate of the workpiece on final R_a

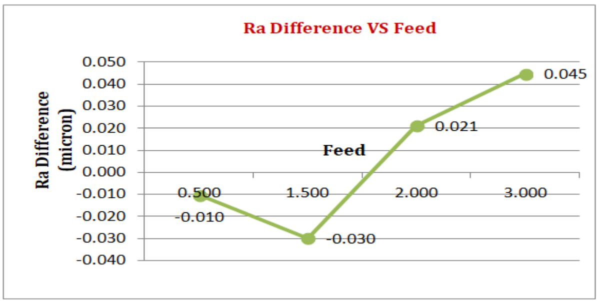

Fig. 10 Influence of feed rate of w/p on R_a difference

4.5 Influence of working gap

Figure 11 and 12 shows the influence of working gap on the response of surface roughness R_a and the difference between the initial surface roughness and final surface roughness. It is observed from the experimental work that the working gap plays significant role to get the better surface finish. The magnitude of cutting forces goes on increasing from zero working gap to a certain value. After the certain value of the gap then the contact pressure and magnitude of cutting forces goes on decreasing. As a result of which, the adequate pressure not generated consequently the penetration of abrasives in the surface of workpiece was not obtained therefore the working gap was kept on the lower side.

Figure 13 and 14 clearly indicates that the surface roughness goes on increasing by increasing the working gap between tool surface and workpiece surface. Also normal force and tangential force both decrease with an increase in working gap. To get the better surface finish then the working gap should be kept at the lower side.

 DOI : 10.18231/2454-9150.2018.1427

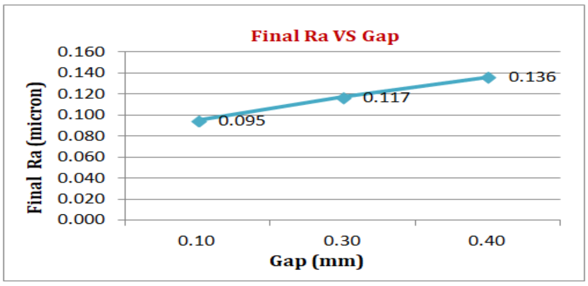

Fig. 11 Influence of working gap on final R_a

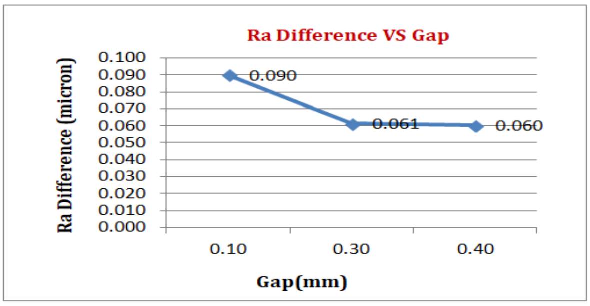

Fig.12 Influence of working gap on R_a difference

4.6 Influence of workpiece hardness

D3 material is selected for specimen because it is hardest die tool material. Also D3 material has excellent mechanical and chemical properties so if its surface finish increases, it can be used for many applications in industry. In case any other material is used, other parameter changes accordingly.

In the experimental work, we have selected three ranges of hardness of workpieces namely 25-30 HRC, 40-45 HRC and 60-65 HRC to know the behavior of hardness of surfaces over a wide range of hardness on the response of surface roughness R_a. As seen from the figure 15 and 16, as the hardness goes on increasing then the surface roughness also goes on increasing. This effect may be attributed to a penetration effect of abrasive particles in the surface of workpiece. As the hardness increases, it becomes difficult for the abrasive particles to remove the material from the workpiece consequently the surface roughness goes on increasing.

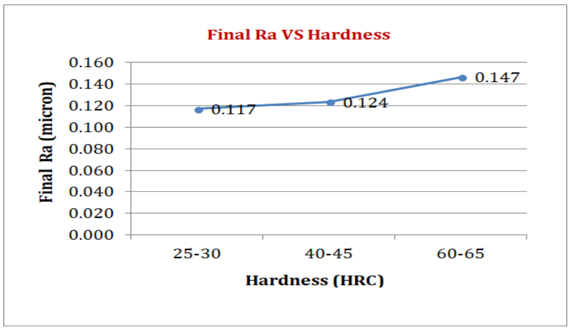

Fig.13 Influence of workpiece hardness on final R_a

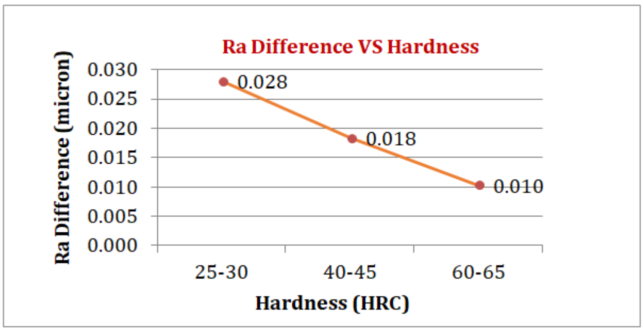

Fig. 14 Influence of w/p hardness on R_a difference

6. Conclusion

In this work, experimentation has been carried out on the material of die steel D3 to know the influence of input process parameters such as concentration of MR fluid, magnetizing current, rotating speed of tool, feed rate of the workpiece, working gap and workpiece hardness. From the experimental results it is observed that all the selected parameters plays a significant role in the finishing operation. Following conclusions are drawn from the experimental work to get the better surface finish on the die steel materials.

1) Concentration of the MR fluid is required to be kept in the proportion of carbonyl iron 20% by weight, abrasive particles (Al_2O_3) 40 % by weight and paraffin oil 40 % by weight.
2) Magnetizing current needs to be varied in the range of 0.8 Ampere to 1.6 Ampere.
3) MR fluid rotating speed of the tool should be maintained in the range of 1000 rpm to 2000 rpm.
4) Keep the feed rate to the workpiece within the limit of 1.5 mm/minute to the 3.0 mm/minute.
5) Maintain the working gap between the tool and the workpiece surface between 0.10 mm to 0.30 mm.
6) It is concluded that the better surface finish can be obtained on the hard material surfaces with the help of this new developed MR fluid assisted finishing set up.

References

Bayoumi M.R, Abdellatif A.K, (1995) Effect of Surface Finish on Fatigue Strength, Engineering Fracture Mechanics 51(5), 861-870

Jacobs S.D., Golini D., Hsu Y, Puchebner B.E, and Straffoid D, (1995) Magnetorheological Finishing: A Deterministic Process, International Conference on Optical Fabrication and Testing, 2576, pp.372-382.

Kormann C., Laun H.M, Laun H.J, (1996) MR fluids with nano magnetic particles, International Journal of Modern Physics, 10, 3167-3172.

Laun S.D., Arrasmith S.R., Kozhinova I.A., Gregg L, Romanofsky A.B, Golini D, (2000), Studies of Material Removal in MRF from Polishing Spots, Ceramica Transactions, 102, 201-212.

 DOI : 10.18231/2454-9150.2018.1427

Tani Y., Kawata K., and Nakayama K., (1984) Development of high efficient fine finishing process using magnetic fluid, CIRP Annals-Manufacturing Technology, 33(1),217-220.

Kurobe T., Imanaka O., (1984) Magnetic field assisted finshing, Precision Engineering,6(3), 119-124.

Suzuki H., Hara S., Matsunaga H., & Kurobe T., (1989) Magnetic field assisted polishing –Application to a curved surface, Precision Engineering,11(4), 197-202.

Kordonski W.I., Jacobs S.D., (1996) Magnetorheological Finishing, International Journal of Modern Physics,10, 2837-2848.

Arrasmith S.A., Jacobs S.D., Romanofsky H.J., Gregg L.L., Shorey A.B., (1999) Studies of material removal in magnetorheological finishing (MRF) from polishing spots, Symposium D: Finishing of Advanced Ceramics and Glasses, Ceramic Transactions, 102.

S. Jha, V.K. Jain, (2004) Design and development of the magnetorheological abrasive flow finishing process, International Journal of Machine Tools and Manufacure 44, 1019-1029.

Das M., Jain V.K., Ghoshdastidar P.S., (2009) Parameteric study of process parameters and characterization of surface texture using rotational magnetorheological abrasive flow finishing (R-MRAFF), International Manufacturing Science and Engineering Conference.