Proceedings of 10th International Conference on Precision, Meso, Micro and Nano Engineering (COPEN 10)
December 07 – 09, 2017, Indian Institute of Technology Madras, Chennai – 600 036 INDIA

Magnetorheological Polishing Tool for Nano-Finishing of Biomaterials

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Abstract

Conventional finishing processes find great difficulty in achieving a high quality of surface roughness (R_a), especially on complex external and internal surface features. Fine surface finishing is of critical requirement for biomaterials as it directly affects the performance and critical life. In this work, Ball end magnetorheological finishing (Ball end MRF) tool has been developed which utilizes magnetorheological polishing (MRP) fluid as the polishing medium for achieving ultra-smooth surfaces with no subsurface damage. The MRP fluid used was consists of magnetic carbonyl iron particles (CIPs) and non-magnetic abrasive particles, water or other carrier liquid, and surfactant. In Ball end MRF, stiffened MRP fluid forms a conformal polishing tool and therefore it can polish a variety of shapes, including flat, convex, and concave. The experiments have been performed to investigate the performance of developed Ball end MRF tool. The effect of various process variables on surface roughness values have been investigated. The results shows that the developed tool is capable of finishing the biomaterials at nano-metric level.

Keywords: Ball end, magnetorheological finishing, nanofinishing, biomaterials.

1. INTRODUCTION

Designer always tries to design machinery that can run faster, last longer, and operate more efficiently. Producing a precise part is always a tedious task due to its higher cost and labor intensive job. The traditional finishing processes alone sometimes are not capable of producing the required surface characteristics. The modern developments of high-speed machines have resulted in higher loading and increased speed of moving parts like bearings, seals, shafts, machine ways, and gears. These moving parts must be accurate both dimensionally and geometrically because they have to work under a tremendous amount of stress. Now a days researchers are trying to achieve nano metric level finishing using magnetorheological (MR) fluid based process. Magnetic field assisted finishing (MFAF) is a non-traditional finishing process that is capable of achieving the finishing at nano metric level. MFAF produces excellent surface finish of processes part with minimal sub-surface damage. MFAF uses MR fluid in which abrasive particles are mixed with carrier fluid. The abrasive particle acts as a polishing medium. In MFAF, MR fluid contain carbonyl iron particles (CIPs), abrasive particles, stabilizers, and carrier fluid. In general, the performance of MFAF is mainly affected by various involved parameters like the hardness of work piece materials, magnetic properties of the tool, rheological properties of MR fluid, machine intelligence, finishing forces etc. various studies have been reported on design, development, and assessment of new MFAF processes. Kumar et al. [1] developed MR fluid-based finishing tool mounted on the three-axis computerized numerical control based milling machine with a permanent magnet enclosed in a fixture at the end of the MFAF tool for finishing knee joint implant. Singh et al. [2, 3] proposed a MFAF process using an electromagnetic finishing tool to form a ball end shape of polishing fluid at tip of the rotating tool.

They named the process as Ball end Magnetorheological Finishing (Ball end MRF) and evaluated the performance of proposed process on different workpiece surfaces. Jha el at. [4] studied the effect of magnetic flux density on surface finish on magnetorheological abrasive flow finishing (MRAFF) and reported that the surface finish was better at higher level of magnetic field strength and rotational speed of magnet was predominate factor among all factor and they were able to achieve surface finish up to 16 nm on stainless steel. Korndoski et al. [5] developed a model to predict the material removal MR fluid based finishing process. They claimed that the developed model shows very close resemblance with experimental results for magnetorheological finishing (MRF) and MR jet finishing. Barman et al. [6] developed a FEM model to understand the distribution of magnetic flux density on the work piece surface and behavior of MR polishing medium during finishing. They claimed that the developed model is capable of representing the experimental results. Sidpara et al. [7] proposed two theoretical model for MR finishing process (normal and tangential forces) to get better understanding towards the material removal. They claimed that their modal shows close resemblance to experimental data. Das et al. [8-9] proposed a computational fluid dynamics (CFD) analysis of the medium flow during MRAFF process. Sidpara el at. [10] studied the rheological characterization of MR fluid using different models and they also predicted effect of volume concentration of each component in MR fluid using response surface methodology (RSM). Jung et al. [11] investigated the two method for increasing machining condition in MRF process, namely, superposition of a fast rectilinear alternating motion and use of more effective abrasive. Jain et al .[12] investigated the effect of different input parameter in abrasive flow machining and it was found that concentration of abrasive was predominate parameter followed by abrasive and mesh size.

From the literature, it has been found that MRF techniques are capable to achieve micro to nano metric level finishing. Therefore, in this work, we tried to develop a novel tool which utilizes the magnetic assistance while finishing biomaterials.

2. EXPERIMENTAL SETUP AND PROCEDURE

The experiments were performed on a flat Titanium (properties are shown in Table 1) workpiece. Titanium is chosen as a work piece material due to its large application in the medical industry. The dimension of the work piece is 150 × 50 × 20 mm. For better handling of the work piece during finishing process, the work

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ISBN: 978-93-80689-28-9

piece is mounted using cold mounting method. The experimental setup is shown in Fig. 1

(a)

(b)

Fig. 1. (a) Magnetic field assisted finishing experimental setup and, (b) Novel developed tool

Table 1 Hardness and composition of the work piece material.

Material	Properties	Composition (wt%,)
Titanium alloy Ti4Al6C	Hardness: 320 HV	Ti- 89.9 Al- 4 V- 6

3. MAGGNETORHEOLOGICAL FLUID (MR FLUID)

The MR polishing fluid was prepared by mixing carbonyl iron particle (CIP) of EN grade (8 μm) from BASF, Germany and SiC abrasive particle in the base medium (Table 2). The base medium consisted of 3 ml Hydrofluoric acid (HF), 6 ml Nitric acid (HNO3), and 100 ml Distilled water. The MR fluid was propoerly mixed with the help of a laboratory stirrer for one hour to get the required consistency. MR fluid belongs to those special kind of fluid whose rheological property can be controlled using some kind of energy. In the presence of magnetic field MR fluid exhibits magnetorheological effect but in the absence of magnetic field it exhibits newtonian behavior.In the presence of magnetic field, magnetic particle present in non-magnetic carrier fluid acquire dipole moment proportional to strength of magnetic strength (H). When the bipolar intersection between particles exceeds the internal resistive force magnetic particle form a chain structure which is responsible for large "controlled" finite yield. When applied stress exceeds their induced yield stress, their chain like structure gets deform in the direction of strain, but when the magnetic field is removed the magnetic particle return to their random position and exhibits its original newtonian behavior.

$\tau = \tau_0(H)+\eta\dot{\gamma}$ to $\tau \geq \tau_0$

$\tau = 0$ for $\tau < \tau_0$

where, τ= applied shear stress, $\dot{\gamma}$= shear rate, η= dynamic velocity, τ_0= feed induced shear strain, H= megnetic field strength.

4 MEGNETORHEOLOGICAL FINISHING

In Megnetorheological finishing, a squeeze layer of Megnetorheological fluid is extruded back and forth across the selected area.finishing occure selectiviely only where MR fluid is squeezed between tool and the work piece surface.In any finishing process, knowing the cutting forces is one of the most important aspect for achieving desired surface finish on the component after setting all required process parameter. When the tool interact with work piece surfaces many type of forces start to show their effect on the surface hence the surface finish is directly related to this forces. In MRF, the forces are broadly classified into two category (i) Normal force (f_n) (ii) Tangential force (f_t.). These forces develop due to many process parameter like constituent of MR fluid, magnetic field, rotation of carrier wheel, squeezing of MR fluid into the gap. Fig 2 shows the schematic diagram of lower half of Magnetorheological finishing process.

A cylindrical shape magnet is used for magnetization of MR fluid. A thick layer of MR fluid is formed over the tip of the tool due to magnetization of MR fluid in the presence of magnet. Fig 3 shows the magnified view of finishing zone. Fine iron particles and CIPs particle try to move toward the magnet due to its magnetic property while abrasive moves toward periphery due to its non-magnetic property. These abrasive particles interacts with workpiece surface which result in material removal at micro-nano level.

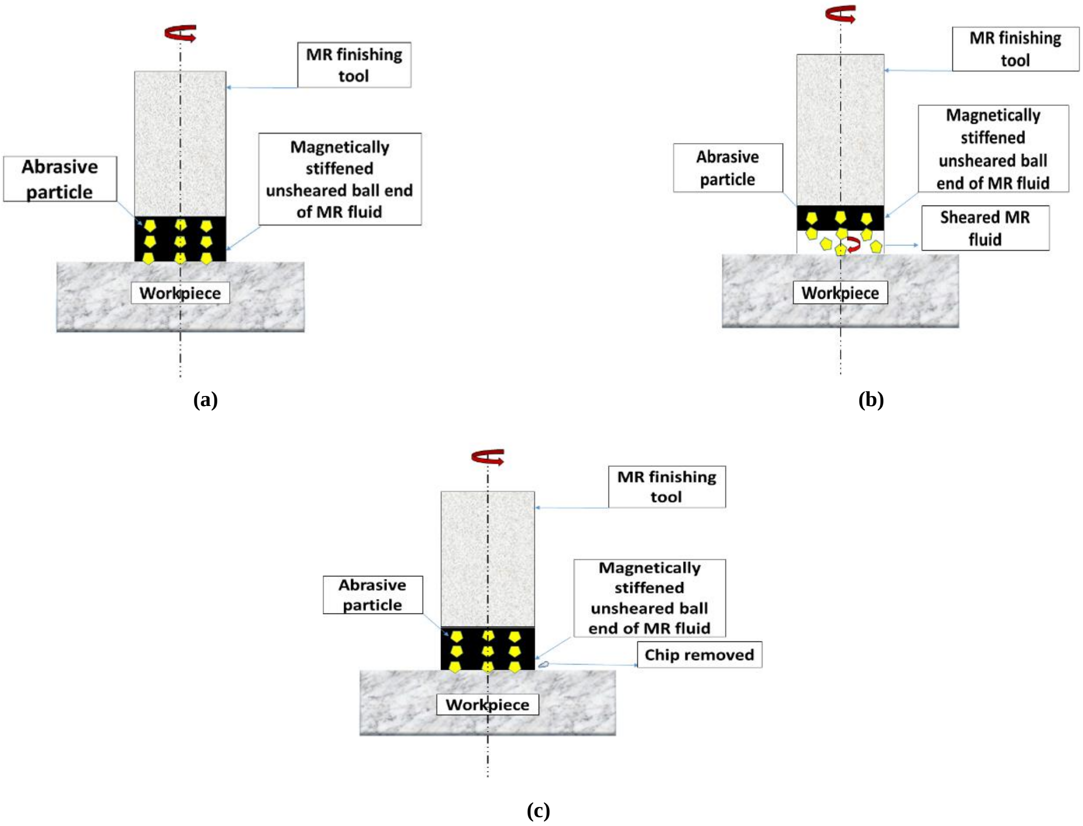

Fig 2. Finishing action in the presence of magnetic field at the tip of the MR finishing tool (a) Abrasive grains of MR fluid just approaching the roughness peak, (b) Abrasive grains slowly rolling over the roughness peak in absence of enough bonding forces and (c) abrasive grain stakes a small cut on roughness peak in the presence of enough bonding force

5 RESULTS AND DISCUSSION

This section presents the effects of input process parameters viz. gap distance, abrasive size, tool rotational speed and concentration of abrasive on R_a.

5.1 Effect Of Gap Distance On R_a

The set of experiment was carried out to determine the effects of gap distance for different machining time 10min, 15min, 25min, 25min, 30min. It was observed (see, Fig 3) that R_a increases as gap distance decreases for all time interval. This is due to the fact that magnetic flux density between tool tip and work piece surface increases as gap distance decreases. In other words, the shear stress between tool tip and surface of work piece increases and relative velocity between them also increase which lead to rapid increases R_a similar result was also observed by Jung et al. [11].

5.2 Effect of tool Rotational Speed on R_a

From the experimentation, it was observed (see, Fig 4) that R_a first increases till 1000 RPM but after start to decrease. This characteristic might be explain by centrifugal force theory. The centrifugal force acting on CIP particle at given position start to increase beyond the magnetic force attraction exerted by lower level but after 1000 RPM, R_a start to decrease. The similar effect was observed by Jung et al.[11]

5.3 Effect of Abrasive Mesh Size on R_a

The set of experiment performed to observe the effect abrasive size on R_a for different machining time10 min, 15 min, 20min, 25 min, 30 min. From, Fig 5, it is clear that R_a increases with an increase in abrasive size because small size abrasive lead to form small chip as compared to bigger size of chips formed in case of bigger size of abrasive [12].

5.4 Effect of Abrasive Concentration on R_a

Fig 6 shows the effect of abrasive concentration on process parameter (R_a) for machining time 10 min, 15 min, 20 min, 25 min, 30 min. It was seen that the R_a increases with an increase in concentration up to 20% but after that point R_a start to decrease. This is due to the fact that with an increase in concentration of abrasive particle, it leads to the increase in the abrasive particle available for cutting area. The R_a decreases up to a certain point but when this limit is reached R_a start to increase because the excess abrasive particle start to form crater on the workpiece surface which increases irregularity on the surface. This ultimately leads to the increases in the R_a

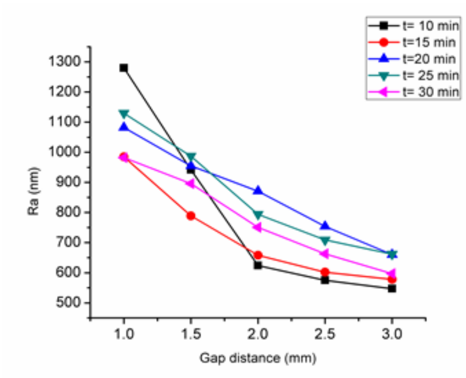

Fig 3 Effect of gap distance on R_a

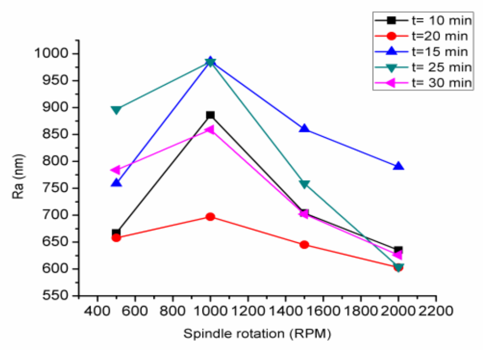

Fig 4 Effect of tool rotation speed on R_a

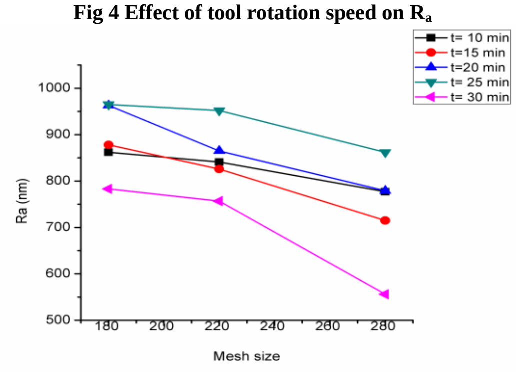

Fig 5 Effect of mesh size on R_a

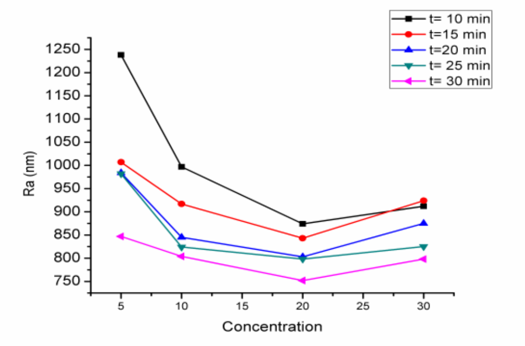

Fig 6 Effect of concentration on R_a

5. CONCLUSIONS

In this paper, a study was carried out to understand the effect of four process parameters gap distance, mesh size, tool rotational speed, and concentration of abrasive on R_a during with a novel MR fluid based tool. The finishing capability of tool in biomaterial Ti4Al6C was demonstrated. The surface finish up to the R_a value 500 nm was achieved. The tool rotational speed and gap distance were found to be predominant factors followed by mesh size, and abrasive concentration affecting the R_a.

References

[1] S. Kumar, V. K. Jain, and A. Sidpara, "Nanofinishing of freeform surfaces (knee joint implant) by rotational-magnetorheological abrasive flow finishing (R-MRAFF) process," *Precision Engineering*, vol. 42 (2015) 165-178.

[2] A. Kumar Singh, S. Jha, and P. M. Pandey, "Design and development of nanofinishing process for 3D surfaces using ball end MR finishing tool," *International Journal of Machine Tools and Manufacture*, vol. 51 (2011) 142-151.

[3] A. Kumar Singh, S. Jha, and P. M. Pandey, "Nanofinishing of a typical 3D ferromagnetic workpiece using ball end magnetorheological finishing process," *International Journal of Machine Tools and Manufacture*, vol. 63 (2012) 21-31.

[4] S. Jha and V. K. Jain, "Design and development of the magnetorheological abrasive flow finishing (MRAFF) process," *International Journal of Machine Tools and Manufacture*, vol. 44 (2004) 1019-1029.

[5] W. Kordonski and S. Gorodkin, "Material removal in magnetorheological finishing of optics," *Applied Optics*, vol. 50 (2011) 1984

[6] A. Barman and M. Das, "Simulation of Magnetic Field Assisted Finishing (MFAF) Process Utilizing Smart MR Polishing Tool," *Journal of The Institution of Engineers (India): Series C*, vol. 98 (2016) 75-82.

[7] A. Sidpara and V. K. Jain, "Theoretical analysis of forces in magnetorheological fluid based finishing process," *International Journal of Mechanical Sciences*, vol. 56, (2012) 50-59.

[8] M. Das, V. K. Jain, and P. S. Ghoshdastidar, "Analysis of magnetorheological abrasive flow finishing (MRAFF) process," *The International Journal of Advanced Manufacturing Technology*, vol. 38 (2007) 613-621.

[9] M. Das, V. K. Jain, and P. S. Ghoshdastidar, "Fluid flow analysis of magnetorheological abrasive flow finishing (MRAFF) process," *International Journal of Machine Tools and Manufacture*, vol. 48 (2008) 415-426.

[10] A. Sidpara, M. Das, and V. K. Jain, "Rheological Characterization of Magnetorheological Finishing Fluid," *Materials and Manufacturing Processes*, vol. 24 (2009) 1467-1478.

[11] B. Jung, K.-I. Jang, B.-K. Min, S. J. Lee, and J. Seok, "Magnetorheological finishing process for hard materials using sintered iron-CNT compound abrasives," *International Journal of Machine Tools and Manufacture*, vol. 49 (2009) 409-418.

[12] V. K. Jain and S. G. Adsul, "Experimental investigations into abrasive flow machining (AFM)," *International Journal of Machine Tools and Manufacture*, vol. 40 (2000) 1003-1021