PERMANENT MAGNET TYPE MAGNETORHEOLOGICAL FINISHING TOOL FOR EXTERNAL CYLINDRICAL SURFACE

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ABSTRACT

Another newly magnetorheological finishing tool has been developed to finish the external surfaces of cylindrical components. The cylindrical workpiece is connected to a rotating chuck and placed in between the permanent magnets The newly developed tool has ability to finish the external surface of cylindrical components with good accuracy. The MR polishing fluid is applied on the faces of magnetic, which gets stick on them under the action of magnetic field. The MR fluid produces a semi-solid layer over the surface of workpiece and does the job of finishing. The finite element (FE) analysis of distribution of magnetic field density with the working gap has been observed on Maxwell Ansoft V13 software. In the present work, the preliminary experimentations have been performed to evaluate the finishing capability of the present developed tool. Experimentations have been performed over the cylindrical workpiece made of copper which can be used as an electron discharge machining (EDM) electrode. In the present work, the shear force exerted by the abrasives to erode the roughness peaks from the external cylindrical surface and the resisting shear force by the workpiece material have also been evaluated mathematically. The finishing capability of the developed finishing tool has also been confirmed mathematically. After the experimentations of 45 minutes over the entire cylindrical workpiece made of copper, the surface roughness parameter R_a gets reduced from 228 nm to 98 nm with negligible surface defects which confirm the finishing performance of the developed finishing tool.

Keywords: Magnetorheological finishing, roughness, peaks, external diameters, variable surface.

INTRODUCTION

Precision finishing and accuracy of various complex engineering components are one of the most important parameters in industrial era due to recent development of new engineering materials. Surface finish plays a vital role in today’s manufacturing world for improving the life of the product. Various conventional finishing processes are in use since from long time for finishing of simple shapes. The conventional finishing processes like Grinding, Lapping, and Honing have no control over the finishing forces, because large amount of heat is generated during these processes which causes several harmful defects on the surfaces topography such as thermal residual stress, micro cracks, heat affected zone (HAZ), malfunctioning, and excessive wear etc. The conventional finishing process is considered less valuable because the forces are not controllable which damage the surface topography (Shaw 1996). Due to the development of new engineering materials, the conventional finishing process are alone not capable to produce the objects which have superior precision finishing and other surface parameters. The conventional finishing process does not offer a flexible cost effective option for various complex precision devices into a desired level. Predefined relative movement of the front line as for the workpiece surface is a noteworthy constraint in completing complex geometries (Bedi and Singh, 2018).Conventional finishing does not give a standard finishing of various complex shapes in engineering applications. Improvement in cutting edge completing procedure over the most recent couple of decades have ascribed to the unwinding of constraint of hardware hardness necessity for example in EDM, ECM, USM, AJM and so on.To overcome these limitations and acquire good control over the finishing forces, various advanced finishing processes have been flourished in the last two decades. These advanced finishing processes make use of magnetic field for finishing operation. In the presence of magnetic field, abrasives perform the finishing operation in these processes. By regulating the magnitude of magnetic field in these advanced finishing processes, finishing forces acting by the abrasives over the workpiece surface can easily be controlled. Various advanced finishing processes like magnetorheological jet finishing (MRJF), magnetorheological abrasive flow finishing (MRAFF), magnetorheological abrasive honing (MRAH), ball end magnetorheological finishing (BEMRF) and magnetorheological honing (MRH) process have been developed. These advanced finishing processes make use of smart fluid i.e. magnetorheological (MR) polishing fluid for finishing the surfaces. MR fluid is composed of carbonyl iron particles (CIPs) and abrasives dispersed in base fluid. Base fluid consists of heavy paraffin oil, grease, surfactants or additives. Under the action of magnetic field, carbonyl iron particles forms the chain like structure, grip the abrasives and perform the finishing.

The finishing tool is designed in such a way that the three cylindrical permanent magnets can be adjusted to move to and fro about their respective central axis. The design of tool has been constructed in such a way that it can be used to finish the external surface of cylindrical workpieces with different outer diameter. The three cylindrical permanent magnets are positioned in such a way that all three maintain an equal working gap with external surface of cylindrical workpiece. MR polishing fluid is inserted in the working gap which gets stiff due to the magnetic field. With the rotation of cylindrical workpiece, surface roughness peaks present over the external surface of cylindrical workpiece get removed out due to relative motion with the gripped abrasives and results in surface finishing.

Magnetorheological Fluid

Magnetorheological effect is one of the direct influences on the mechanical properties. Magnetorheological fluid is a fascinating smart fluid with the ability to switch back and forth from a liquid to a near-solid with controllable yield strength under the influence of magnetic field. Magnetorheological fluid is a smart type of fluid whose rheological properties changes when applied to magnetic field or electric field. When MR fluids are subjected to a magnetic field, the fluid greatly increases its apparent viscosity to the point of becoming of viscoelastic solid. The traditional MR fluids are composed of spherical particles, micron-scale, ferromagnetic; (typically 30 to 40 volume percent) floating in a silicone, aqueous carrier fluid, or hydrocarbons (Klingenberg, 2001).The apparent shear strength and viscosity of the MR fluid can be controlled by raising the strength of an applied magnetic field.

The structure of particles in an MR fluid gradually changes when an alternating magnetic field is applied. When magnetic field is applied to the MR fluid the particles acquire a magnetic polarization and attract one another forming chain like structures that join to form columnar structures parallel to the applied field. The newly formed columns span the surface of the device parallel to the field lines resulting in a material that behaves as Bingham plastic fluid, with increased viscosity and apparent yield stress under shear (R,C Bell, D,T Zimmerman and N,M Wereley). The viscosity and yield stress of the fluid is scalable with the magnitude of the applied magnetic field until magnetic saturation of the particle is reached (Jones and Saha, 1990). The magnetic lines of forcemoves from the region of higher flux gradient to the lower flux gradient. During no magnetic field across the MR polishing fluid the magnetic and abrasive particles gets randomly dispersed. Fig.1 shows the effect of magnetic field on MR fluid.

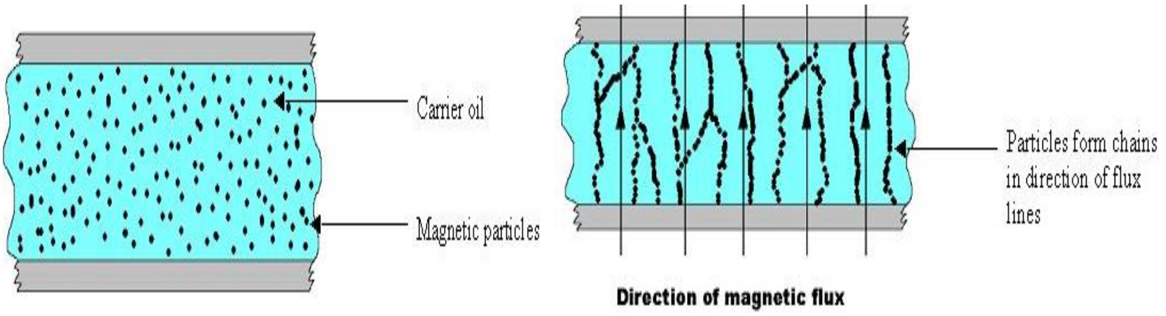


Fig.1**.** Effect of magnetorheological fluid with (a) no magnetic field (b) external applied magnetic field.

Schematic of novel tool design along with its mountings

This novel tool design has the advantage to be flexible according to the size of the cylindrical workpiece. In this design, the tool is capable to finish the workpiece having outer diameter ranging from 30 mm to 50 mm. The three permanent magnets (made of NdFe35) are placed at an angle of 90^{o}to each other as shown in Fig. 2. The three permanent magnets of diameter as 25 mm were individually mounted on the separate cylindrical bush made of brass. The cylindrical bush was further attached to shaft by means of rectangular bracket. With the help of rotating wheel, the magnets can be easily adjusted by means of metric threads. The workpiece was fixed in the rotating chuck of a lathe machine. The rectangular bracket along the assembled magnets was fixed on the tool post portion of lathe machine. The linear movement of magnets was provided through lathe machine, whereas the workpiece was rotated by the rotation of chuck of lathe machine. The MR fluid gets stick on the faces of magnets which are adjusted in such a way that MR fluid finishes the cylindrical workpiece which is located in between the magnets. The cylindrical workpiece rotates with the help of rotating chuck and the chuck is connected to a lathe machine. The MR fluid generates a fluid layer on the surface of workpiece and does the job of finishing with precise accuracy and without damaging the surface topography.

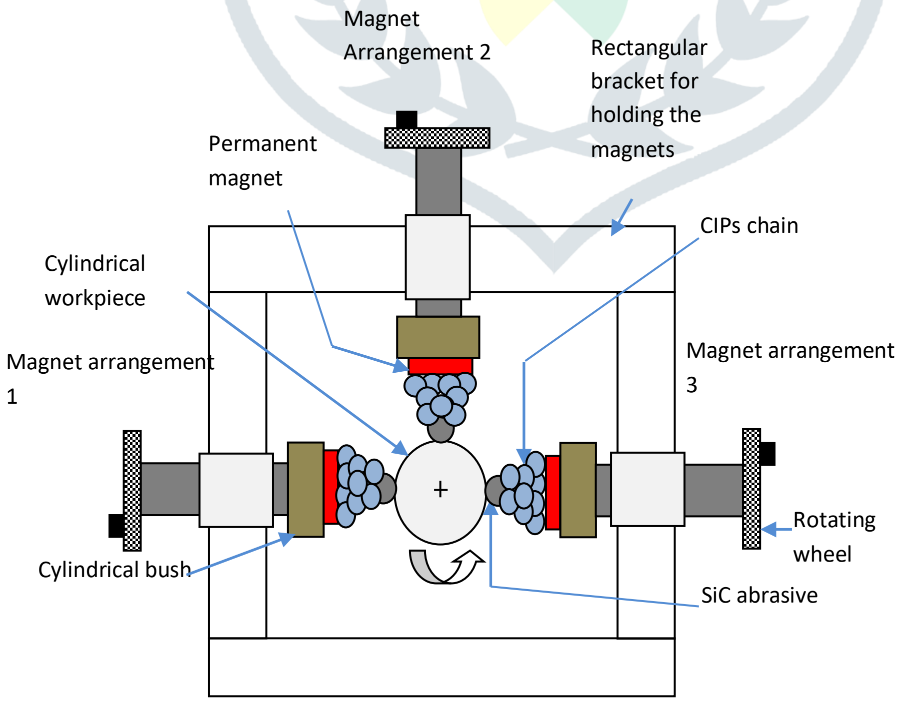


Figure 2 Schematic of novel tool design along with its mountings.

The clear visualize of magnetic field distribution along within the working gap, investigation of finite element analysis has been done by using Maxwell Ansoft V13 software. In this model, the relative permeability of permanent magnet of 1.009, copper workpiece of 0.999991 and MR polishing fluid of 5 was taken. The distribution of magnetic flux density in the present developed setup, obtained through finite element (FE) Analysis using Maxwell Ansoft V13 software as shown in Fig3(a). The simulation shows that the magnitude of magnetic flux density was obtained higher of the peramenant magnets as compared to cylindrical workpiece surface as represented through 2d magnetic surface as shown in Fig 3(b). The CIPs of MR fluid gets stick on the faces of magnet but not on the surface of the cylindrical cooper workpiece surface because of non-ferromagnetic in nature. The newly developed tool combined the effect of magnets and would be helpful for achieving a better and uniform surface quality on the workpiece surface. The magnets provide a linear magnetic flux density along the axis of cylindrical workpiece, which results in precision surface accuracy and without damaging the surface topography. The CIPs edges form a layer on the workpiece and do the job of finishing. While performing finishing with the developed finishing tool, magnetic normal force acts over the CIPs (present in the working gap) which in turn exert indentation force over the active SiC particles. This indentation force makes the SiC abrasives to indent into the peaks of surface roughness present over the external surface of cylindrical workpiece. With the linear movement of finishing tool and rotating movement of cylindrical workpiece, relative movement occurs with cutting-edged SiC particles and roughness peaks which are present over the cylindrical workpiece and results in surface finishing. Indented active abrasives exert cutting axial force (F_{AX}) over the roughness peaks which in turn removes out the material from the workpiece surface.

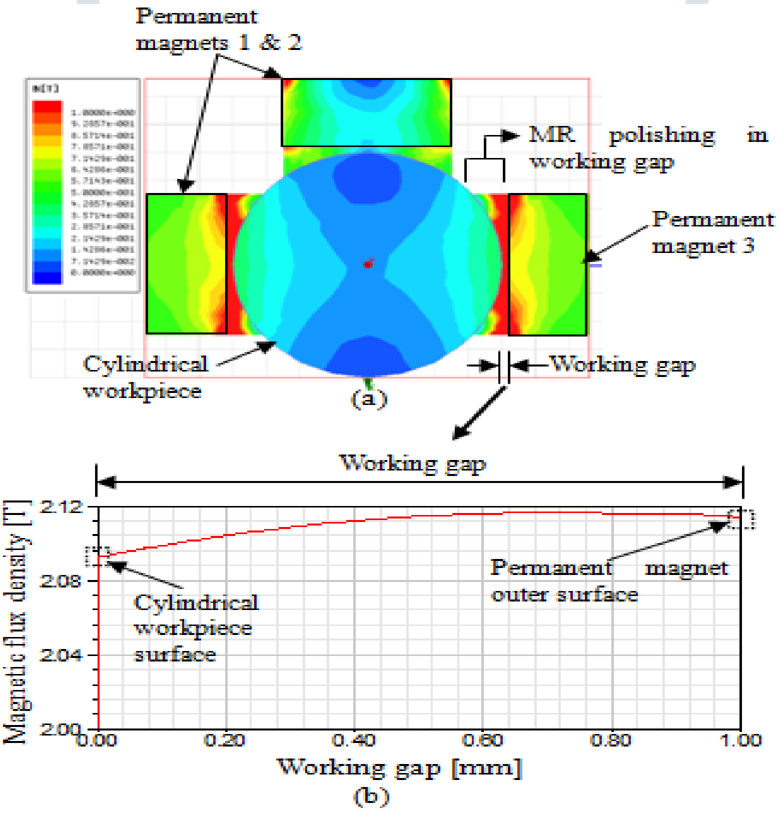


Figure3.(a) Distribution of magnetic flux density in present developed setup and (b) 2D field report of magnetic flux density in the working gap.

Mechanism of material removal from workpiece

One of most significant task is to attain precise quality of a workpiece during finishing. We need to understand the mechanism of material removal rate involved during the process. The material gets removed due to action of mechanical abrasion phenomenon. The material removal from initial surface to final finished surface during finishing by using three permanent magnets along with CIPs abrasive sticks on the faces of magnets is shown in Fig. 3. Initially, the outside round and hallow surfaces of workpiece was not found high in surface quality due to uncontrollable forces acted by the rigid abrasive stone results in non-uniform surface roughness. This non-uniformity of surfaces cause the defects in surfaces such as geometrical inaccuracy, cavities, surface pits etc.The effect of magnetic flux density under MR polishing fluid forms a semi-solid structure of the surface of workpiece. The MR polishing fluid consists of non-magnetic abrasive particles held tightly by a CIPs chains as shown in fig 3. When the semi-solid layer structure contiouniously moves over the workpiece surface, the MR fluid removes the defected surface from the workpiece and results high surface quality. The whole action of MR fluid over the workpiece is shown in different stages of Fig 4.To understand the actual finishing performance, it is important to understand the effect of finishing forces during finishing, the only workpiece was rotated but the tool was given a linear motion. The indentation force F_I was applied by the abrasive particles on the workpiece surface as shown in Fig 4 (a). When the tool was moved linearly in forward or backward direction, the axial force F_{AX} was induced (Fig. 4b). The combined effect of F_I and F_{AX} helps in removing the roughness peaks from the workpiece surface. When the tool was moved linearly in backward direction, the linear forward force F_{LB} was induced. The combined effect of F_I and F_{LB} helps in removing the roughness peaks from the workpiece.

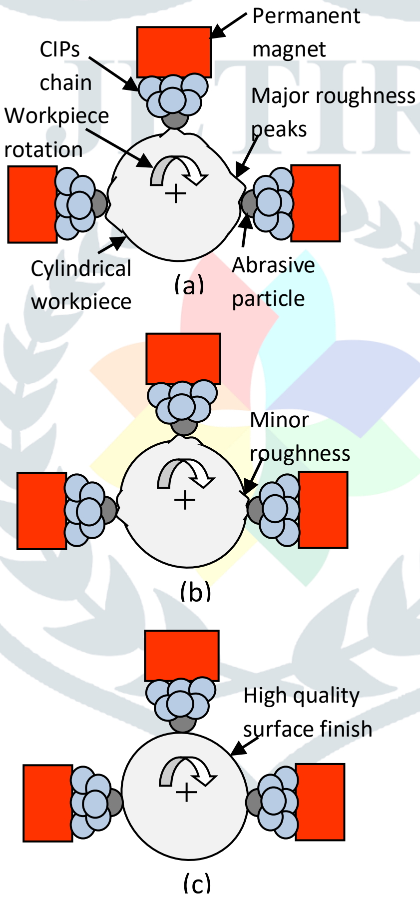


Figure 4. Different stages of material removal mechanism during finishing of cylindrical copper workpiece.

Experimentation on cylindrical surfaces

A preliminary experimentation has been performed with the novel developed tool. The developed tool was mounted on the tool post of lathe machine. The cylindrical workpiece used in this study was made of copper which can be used as an electron discharge machining (EDM) electrode for making a cylindrical cavity in the dies. A high quality surface is needed on this cylindrical workpiece for getting a defect free cavity on the die material. During experimentation, the cylindrical workpiece was fixed with the help of rotating chuck of lathe machine. The actual photograph of an experimental setup during finishing of copper cylindrical workpiece is shown in Fig. 5. The experimental conditions like tool linear speed of 30 mm/min and workpiece rotational speed of 300 rpm were used during finishing. The total length of workpiece to be finished was 20 mm. The composition of MR polishing fluid used for copper finishing was taken as by volume concentration i.e. 25% of silicon carbide (SiC) abrasives, 15% carbonyl iron particles (CIPs) and 60% base fluid (20% grease and 80% paraffin oil). This similar composition of MR polishing fluid was already taken during finishing of flat copper workpiece. The surface roughness profiles of initially ground and final finished surface were measured by using Surftest SJ-210 (Mitutoyo). During measurement, the cut off length as 0.25 mm and filter as Gaussian was taken. The actual photograph of an experimental setup during finishing of copper cylindrical workpiece is shown in Fig. 5.

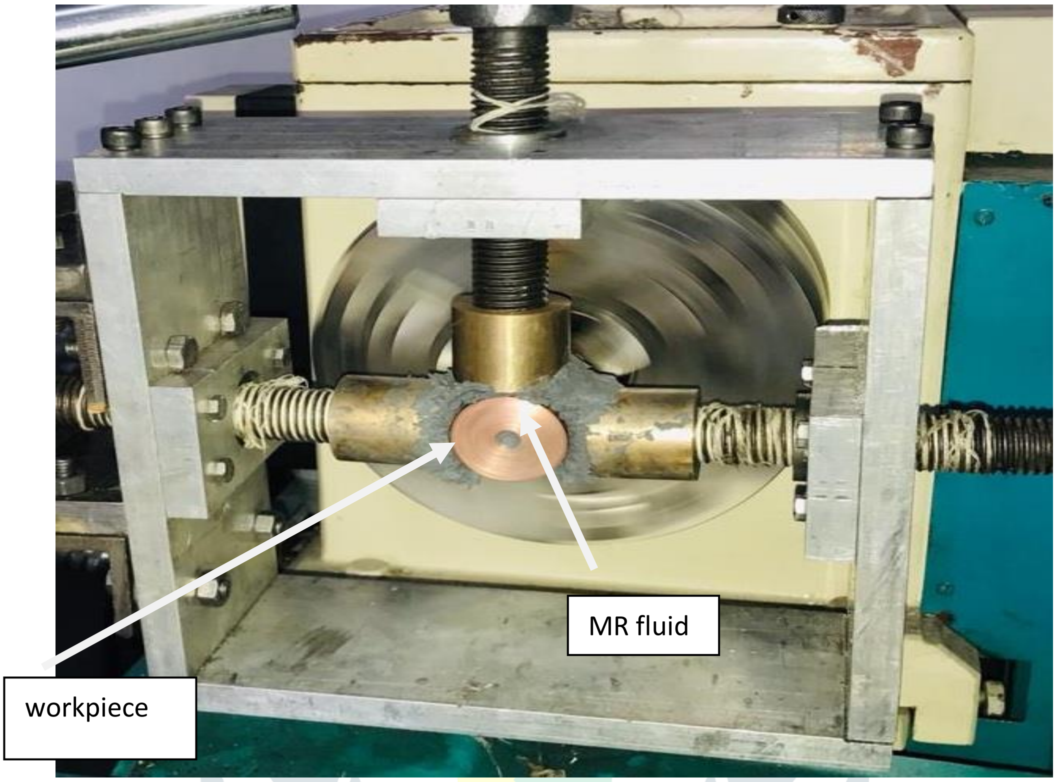


Figure4. Actual photograph of an experimental setup during finishing of copper cylindrical workpiece.

Observation and experimental findings on cylindrical workpiece

After experimentation, the surface roughness value changes from initial surface (R_a= 228 nm) to final surface (R_a= 98 nm) after 45 minutes of finishing with the present developed tool as shown in Fig. 5. Correspondingly, the surface roughness profiles of initial surface and final finished surface are shown in Fig. 6. The copper cylindrical workpiece was initially finished by the traditional finishing operation such as grinding. The initial surface roughness (R_a) value was 228 nm. It consists of a major roughness peaks on the circumference of copper cylindrical workpiece as shown in Fig. 3 (a). During 15 minutes of finishing operation takes place with the present developed MR tool, the SiC abrasives eroded the major roughness peaks and further reduced the surface roughness value i.e. R_a= 170 nm (it is represented by the first finishing stage). After finishing, the roughness peaks get reduced and converted to minor roughness peaks.

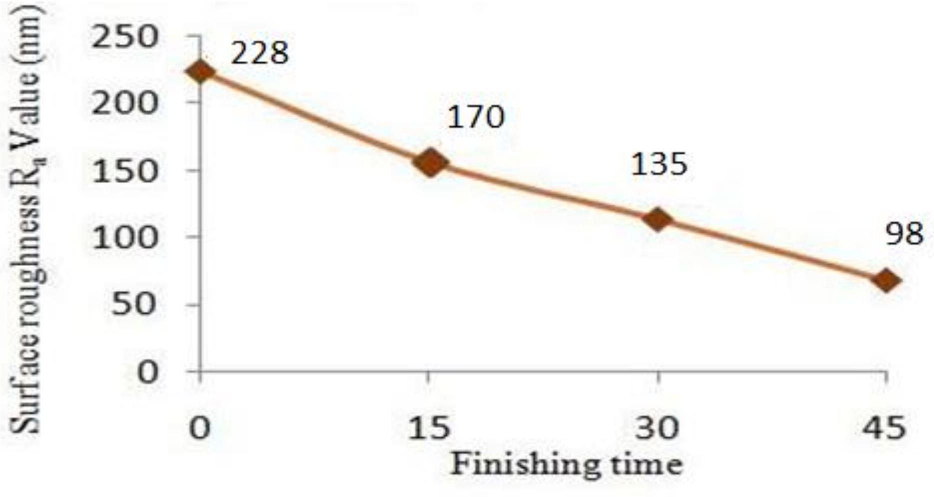
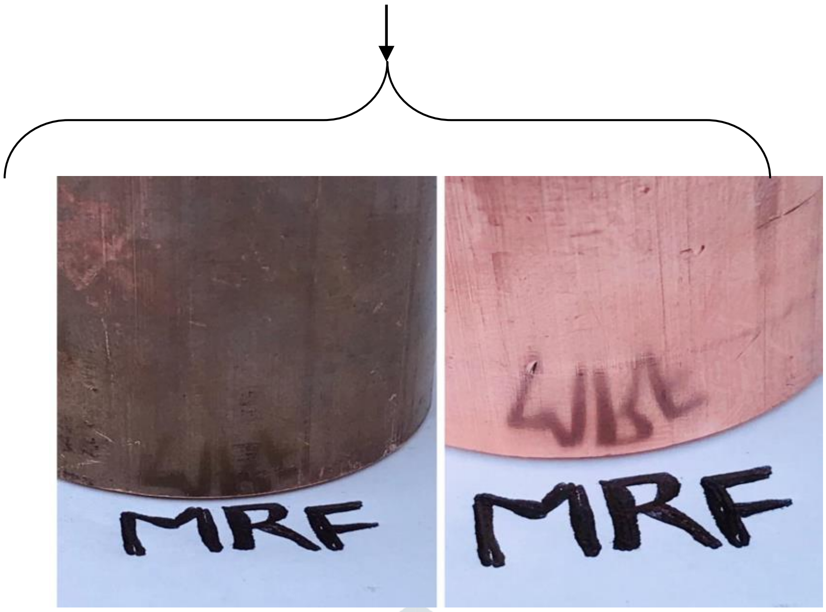


Figure 6. Change in surface roughness (R_a value) after 45 minutes of finishing.

The cutting of roughness peaks is because of the continuous movement of gripped SiC particle over the cylindrical surface of copper workpiece by mechanical abrasion phenomenon. Further the new MR polishing fluid was applied between the working gap for next 15 minutes of finishing i.e. second finishing stage. The surface roughness R_a value got reduced to 135 nm from 170 nm. The change in R_a value in second finishing stage was less because the minor roughness peaks have the lesser shearing tendency as compared to major roughness peaks. In the third finishing stage i.e. next 15 minutes of finishing, again the new MR polishing fluid was applied within the working gap. The surface roughness R_a value reduced to 135 nm from 98 nm. This results in a better surface quality as compared to the initial ground surface. After further finishing, the surface roughness remained almost same. Hence, the surface roughness finishing was shown after 45 minutes of finishing. The actual photograph of copper cylindrical workpiece before and after external surface finishing with the present developed tool is shown in Fig. 6. The high quality surface was obtained as a mirror image of an alphabet MRF was clearly visible in copper workpiece (Fig. 6 b). From the above, it is cleared that the present developed tool is regarded as better option for high quality finishing of different cylindrical diameters (ranges from 30 mm to 50 mm).



(a) (b)

Figure 6.Actual photograph of copper cylindrical workpiece (a) before finishing and (b) after finishing.

CONCLUSION

- The newly developed tool along with three permanent magnets rotating along the surface of cylindrical workpieces having outer diameter ranges from 30 mm to 50 mm have flexible and great control over the finishing forces.
- From the simulation of magnetic field density it has been observed that the MR fluid gets stick on the faces of magnets rather than the surface of workpiece, which results in high and precision surface finishing.
- It has been found mathematically, that the shear force employed by the action of abrasive over the workpiece is greater than the resisting shear force by the workpiece material which confirms the finishing capability of the developed finishing tool for copper workpiece.
- The surface roughness changes from initial R_a= 228 nm to final R_a= 98 nm after 45 minutes of experimentation as it can clearly determine by its surface roughness profiles.
- This newly developed magnetorheological finishing tool can also be useful for finishing various cylindrical surfaces made of aluminum, stainless steel etc.

REFRENCES

- Jha, S.; Jain, V.K. (2004). “Design and development of the magnetorheological abrasive flow finishing (MRAFF) process. *“International Journal of Machine Tools and Manufacture*, 44, pp. 1019–1029.
- Jha S, Jain V K (2005) “Nano finishing techniques.” *Micro manufacturing and Nano- Technology. Mahalik*, N.P. ed. Springer Verlag, New York, 171-195.
- Kordonski W I, Shorey A B, Tricard, M (2006) “Magnetorheological jet finishing technology. *“Transactions of ASME, 128*, 20-26.
- Jha S, Jain V K, Komanduri R (2007) “Effect of extrusion pressure and number of finishing cycles on surface roughness in Magnetorheological Abrasive Flow Finishing (MRAFF) process.” *International Journal of Advanced Manufacturing Technology*, *33*(7-8), 725-729.

- Cheng, H., Yeung, Y., Tong. H. (2008) Viscosity behavior of magnetic suspension in fluid-assisted finishing. Progress in natural science 18:91-96.
- Jain V K (2009) "Magnetic field assisted abrasive based micro-/nano-finishing."*Journal of Materials Processing Technology*, *209*, 6022-6038.
- Sadiq A, Shunmugan M S (2009) "Investigation into magnetorheological abrasive honing. *"International Journal of Machine Tools and Manufacture*, *49*, 554-560
- Sadiq A, Shunmugan, M S (2010) "A novel method to improve finish on non-magnetic surface in magnetorheological abrasive honing process. *"Tribology International*, *43*, 1122-1126.
- Singh A K, Jha S, Pandey P M (2011) "Design and development of nanofinishing process for 3D surfaces using ball end MR finishing tool." *International Journal of Machine Tools and Manufacture,51*, 142-151.
- Singh A k., S. Jha, and P. M pandey. (2012) Nanofinishing of a typical 3D ferromagnetic workpiece using a ball end magnetorheological finishing process. International journal of machine tools and manufacture 63:21-31.
- Singh A K, Jha S, Pandey P M (2012) "Nano finishing of a typical 3D ferromagnetic workpiece using a ball end magnetorheological finishing process." *International Journal of Machine tools and Manufacture*, *63*, 21-31.
- Singh A K , Jha S, Pandey P M (2013) "Mechanism of material removal in ball end magnetorheological finishing process." *Wear*, *302*, 1180-1191.
- Spaggiari, A (2013) "Properties and applications of Magnetorheological fluids. *FratturaedIntegrità Strutturale*, *23*, 57-61.
- Singh G, Singh A K, Garg P (2016) "Development of magnetorheological finishing process for external cylindrical surfaces." *Materials and Manufacturing Processes*, doi:10.1080/10426914.2016.1221082
- Bedi T S, Singh A K (2016) "Magnetorheological methods for nanofinishing- a review." *Particulate Science and Technology*, *34*(4), 412-422.
- Grover, V.; Singh, A.K. (2018). "Improved magnetorheological honing process for nanofinishing of variable cylindrical internal surfaces," *Materials and Manufacturing Processes*, 33 (11), pp. 1177–1187.