Extrusion pressure-based magnetorheological finishing setup for the improved finishing of the non-ferromagnetic surfaces

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Permanent Magnet,
Fluid Delivery System.

ABSTRACT

The magnetorheological finishing process uses a smart controllable-able fluid known as Magnetorheological polishing fluid, whose yield strength can be controlled externally by varying the magnetic field. The magnetorheological finishing process is capable of providing surface finishing up to the nano-level, but the precision finishing of non-ferromagnetic workpieces like copper and its alloys by using the magnetorheological finishing (MRF) process is challenging. Non-ferromagnetic material repels the applied magnetic field which results in the formation of only one magnetic pole at the tooltip. The magnetic pole at the workpiece surface is distorted by the repelling nature of the non-ferromagnetic materials. So, to finish the surface of nonferromagnetic materials, an axial force is needed to mitigate the repelling effect of nonmagnetic material. In this research paper, a new setup of the Extrusion Based Magnetorheological Finishing process has been designed which can provide the required axial force to the magnetorheological polishing fluid for the precision finishing of the non-ferromagnetic materials.

1. Introduction

The industries foregoing developments have increased the demand for items with precise dimensional accuracy. Copper is an electrically and thermally conductive material that found its major application in the electronics industry. Highly finished copper mirrors are widely used in laser, aerospace, dentistry, and metal optics industries. Conventional finishing processes such as lapping, honing, and grinding, use multiple cutting edges and are not capable of producing surfaces with close tolerances due to the uncontrollable nature of abrading force generated during the finishing operation. Furthermore, they cause subsurface damage as well as an unfavorable residual stress distribution (Khan et al., 2016).

Many advanced fine finishing processes, such as magnetic abrasive finishing (MAF) (Shinmura et al., 1990), magnetic float polishing (MFP) (Komanduri, 1996), magnetorheological jet finishing (MRJF) (Seok et al., 2007), magnetorheological abrasive flow finishing (MRAFF) (Jha & Jain, 2004), and magnetorheological finishing (MRF) (Kordonski & Jacobs, 1996) have been developed in the last decade to precisely control wear forces by the magnetic field. However, because of restrictions on the relative movement of the finishing medium and the workpiece, these techniques are limited to geometries such as concave, convex, flat, and aspherical shapes. For the superfinishing of freeform 3D surfaces, the Ball End Magnetorheological Finishing process (BEMRF) was developed by (Singh et al., 2012).

Magnetorheological finishing is executed by magnetorheological polishing fluid (MRP fluid). MRP fluid consists of micro-sized ferromagnetic particles known as carbonyl iron particles, abrasives, diamagnetic carrier medium like silicon oil, and some additives to avoid the sedimentation of CIPs and abrasives. Under the influence of the magnetic field, the ferromagnetic CIPs of MR fluid align themselves along the direction of magnetic lines of forces and form a chain-like structure with abrasives trapped in between them referred to Fig. 1. The abrasives which are non-ferromagnetic in nature accumulate near

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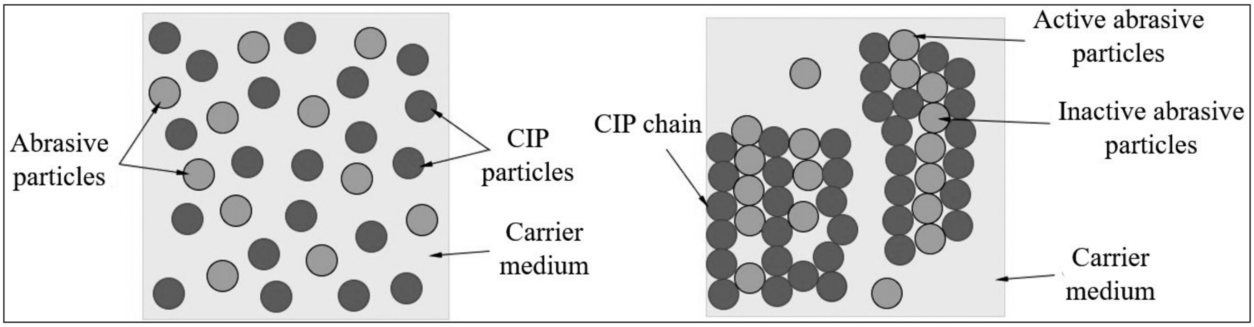

Fig. 1. The schematic diagram of magnetorheological change in MRP fluid.

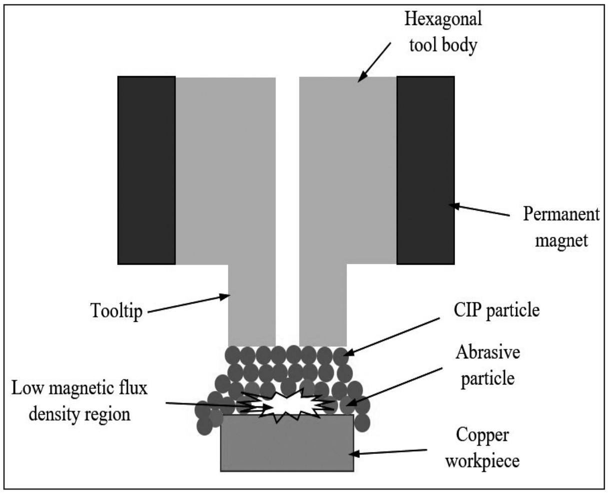

Fig. 2. Repelling effect of the copper workpiece.

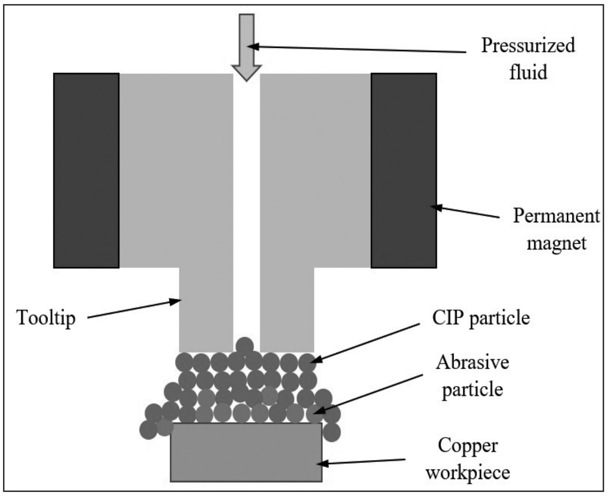

Fig. 3. Finishing of copper in the presence of pressured fluid.

the workpiece surface region as they are repelled from higher magnetic flux gradient toward lower magnetic flux gradient.

In the BEMRF process, while finishing the non-ferromagnetic materials such as copper, only one magnetic pole is established at the tool end and the other magnetic pole at the workpiece surface is distorted due to the diamagnetic nature of the non-ferromagnetic material. This results in poor finishing or no finishing at all. Due to the availability of only one pole, MR fluid is incapable of producing fine surfaces as only shearing force is exerted by the MR fluid on the workpiece surface, refer to Fig.2. Along with the shearing force, an external axial force will also be required to neutralize the repelling effect of non-ferromagnetic material heat transfer.

A new finishing setup for improved finishing of non-magnetic surfaces by Pressurized Fluid Delivery System is developed for superfinishing of non-magnetic materials like copper and its alloys and is also used for ferromagnetic materials. In this process pressurized fluid is supplied to the tooltip, so a pressurized MRP fluid tip is formed at the tooltip which creates axial force while finishing, refer to Fig.3. So, superfinishing of copper is improved.

2. Magnetic Simulation Studies

Ansoft Maxwell 16.0 software is used to study the magnetic flux density distribution. Fig. 4. depicts the magnetic simulation setup consisting of a hexagonal tool body. 5 out of 6 faces of the hexagonal tool body are stacked with a set of 5 neodymium-iron-boron permanent magnets each, and they are separated by an aluminum cover plate.

Fig. 5. shows the magnetic flux density distribution at the tool body. The simulation result shows a higher magnetic flux density all around the tool body and at the tooltip. 5 out of 6 faces of the hexagonal tool body are stacked with a set of 5 neodymium-iron-boron permanent magnets each and they are separated by an aluminum cover plate.

Figure 6 depicts the magnetic simulation result on the copper surface. As discussed earlier the result

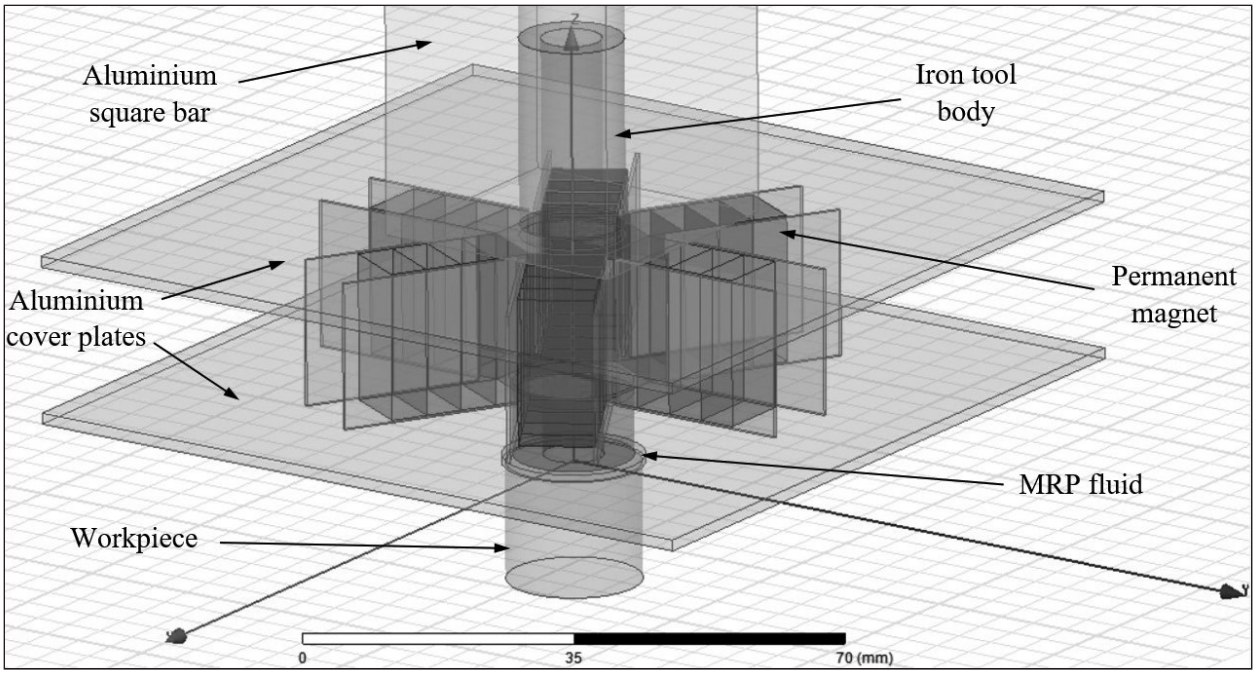

Fig. 4. 3-D model of the extrusion tool with permanent magnets.

shows that the diamagnetic nature of copper repels the magnetic field lines generated by the set of permanent magnets. Only a small ring of magnetic flux density is formed over the top of the copper surface and is very low as compared to the tool body and the tooltip.

3. 3-D Design of Extrusion-Based Magnetorheological Finishing Setup

Based on the simulation studies a new finishing process named Extrusion-Based Magnetorheological Finishing (EBMRF) setup is designed for the superfinishing of non-ferromagnetic materials like copper and its alloys. This is a precision finishing process assisted by magnetic fields. In this process, MR fluid is first pressurized in a pressurizing chamber and is extruded at the tooltip. The continuous pressure supplied to the MR fluid will provide the necessary axial force required for the finishing of non-ferromagnetic materials. Extrusion-based magnetorheological finishing machine setup is divided into three main parts which are MRF tool assembly, Z- slide arrangement, and Pressurized fluid delivery system.

3.1. The MRF tool assembly

The MRF tool assembly is structured on a hollow hexagonal iron piece, five among the six faces of the hexagonal iron piece are stacked with a set of permanent magnets. Neodymium-Iron-Boron

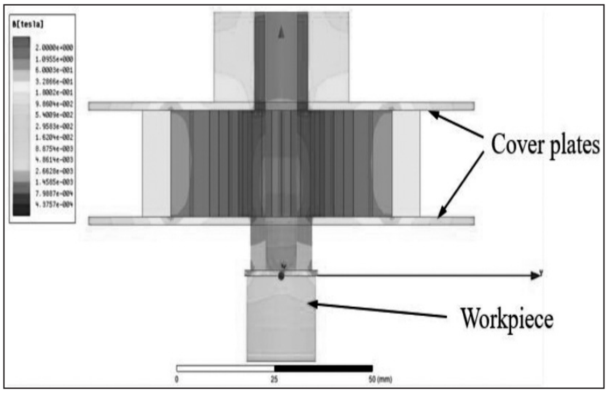

Fig. 5. Magnetic simulation of the tooltip with permanent magnets.

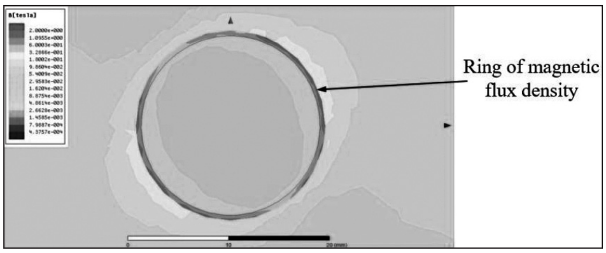

Fig. 6. Magnetic simulation of the copper workpiece in presence of the magnetic field.

Magnet of N52 grade having dimension 20*10*5 mm (l*b*h) is used to generate a generous amount of magnetic flux density at the tooltip. Each set contains five permanent magnets summing up to 25 in total. A magnet casing made up of aluminum plates is provided to separate the set of magnets.

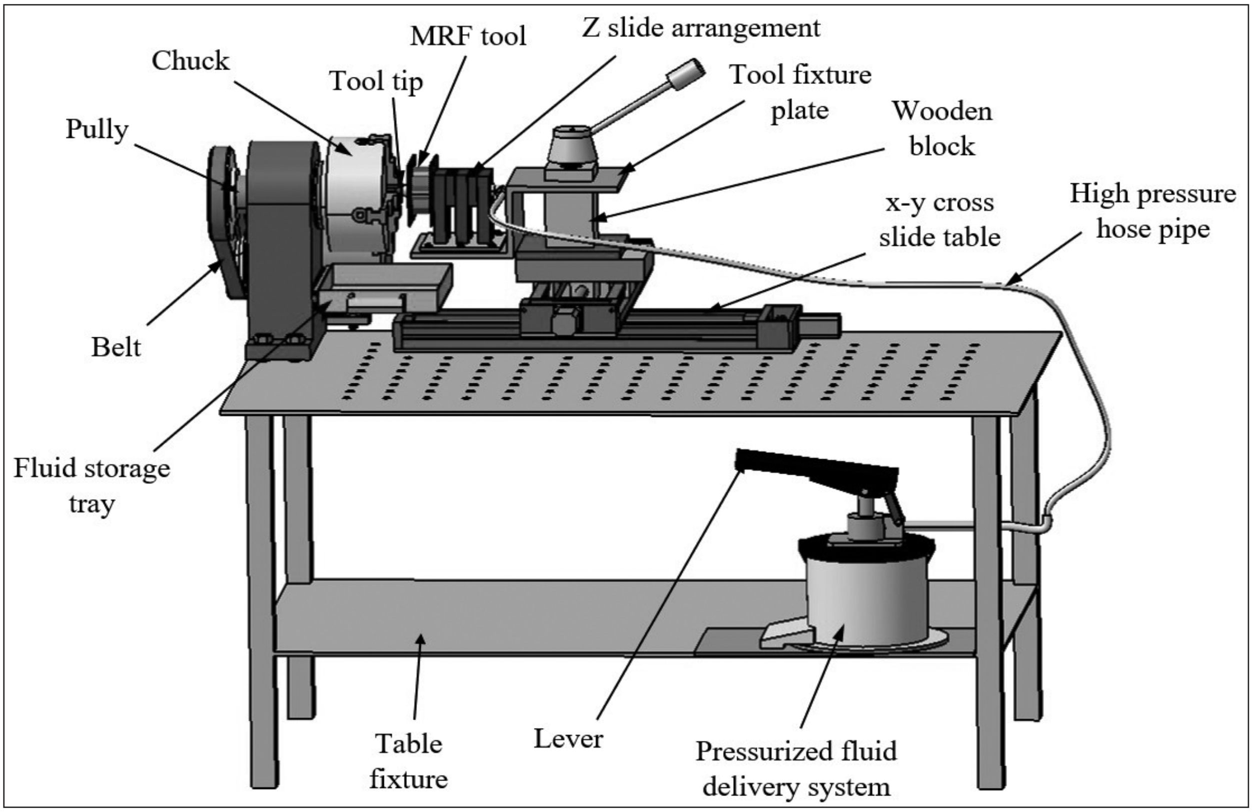

Fig. 7. The extrusion pressure-based magnetorheological finishing setup.

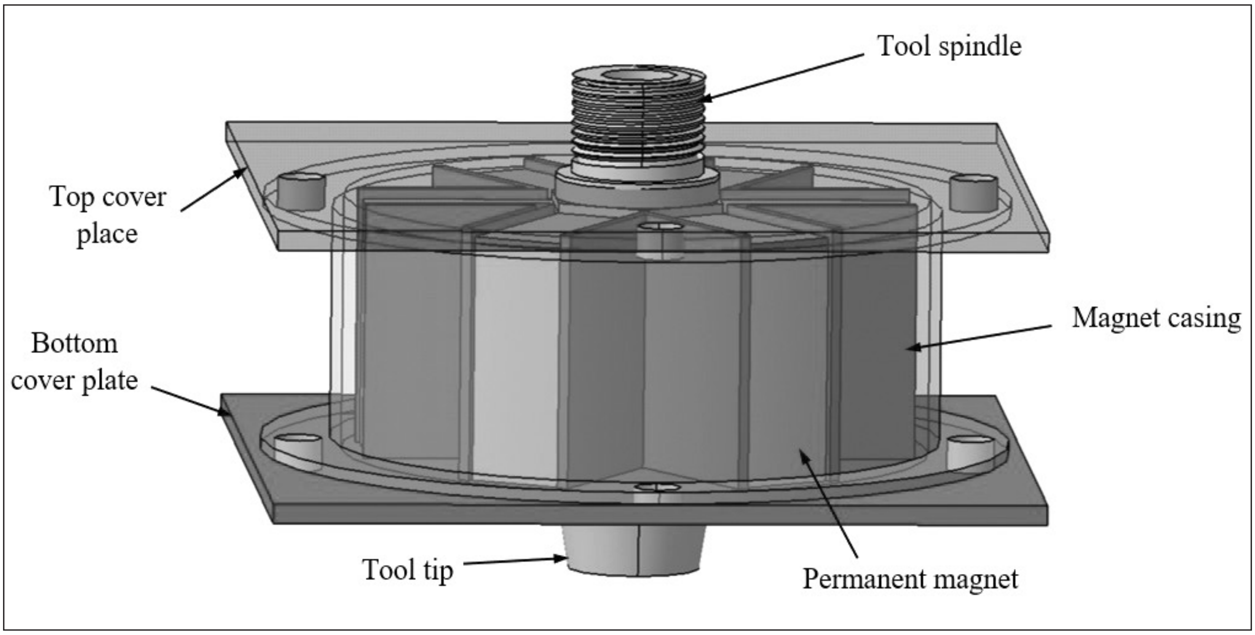

Fig. 8. 3-D model of the tooltip with aluminum brackets and permanent magnets.

3.2. Z- slide arrangement

The z-slide arrangement is designed in such a way that it can be fixed on the tool post end of the lathe machine. The tool fixture plate is made up of aluminum and a vertical stainless-steel structure is erected to support a hollow aluminum square bar that is connected to the MRF tool assembly. The other end of the hollow aluminum square bar is connected to the high-pressure hose pipe which carries pressurized MR fluid. The main purpose of the z slide arrangement is to give movement to the MRF tool in the z-direction so that the tip of the MRF tool can be adjusted as per the requirement.

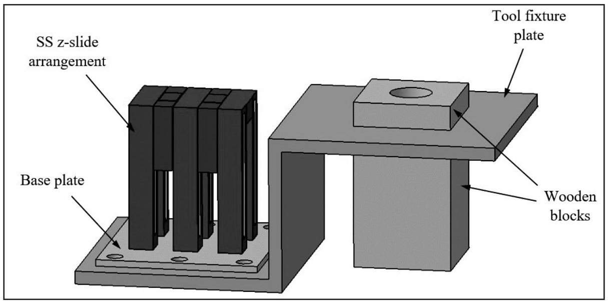

Fig. 9. Z-slide arrangement for the alignment of tool-tip and workpiece.

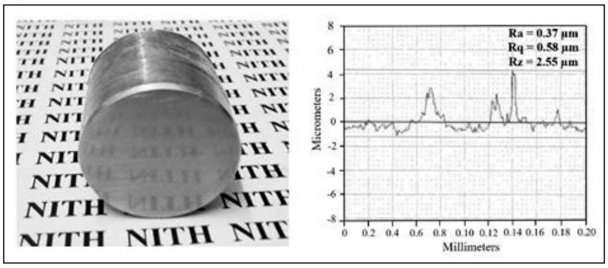

Fig. 10. The reflection of the copper surface and initial surface roughness profile after the polishing action.

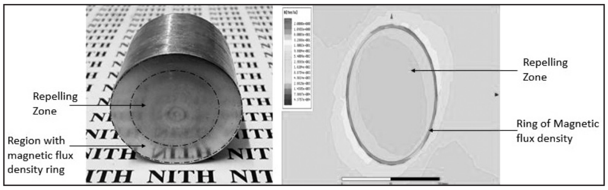

Fig. 11. The face of the copper workpiece after 60 minutes of finishing without extrusion pressure.

3.3. Pressurized fluid delivery system

The novelty of this setup is based on the pressure applied to the MR fluid which is later extruded from the tooltip. A pressurized fluid delivery system is designed to extrude the MR fluid from the tooltip. A pressurized fluid delivery system consists of a hand-cranking trigger mechanism that builds up a back pressure allowing the MR fluid to flow forcefully through the high-pressure hose pipe whose one end is connected to the aluminum square bar. The pressurized MR fluid extruding from the small opening of the tooltip will provide the required axial force necessary for the finishing of non-ferromagnetic materials.

4. Result and Discussion

To analyze the process capabilities of this newly designed setup, preliminary experiments were performed on a copper workpiece of a diameter of 16 mm. The copper workpiece was brought to an initial surface roughness of 370 nm by polishing operation. Figure 10 shows the reflection of the copper surface and initial surface roughness profile after the polishing action.

Table 1
The fixed parameters and conditions were taken during the experimentation.

Parameters	Conditions
Abrasive and Size	Aluminum Oxide, 1000 mesh size
Electrolytic Iron Powder	325 mesh size
Base Fluid	80% Heavy paraffin oil, 20 % grease
Rotational Speed	252 RPM
Working Gap	1.5 mm
Finishing Time	20 Minutes
Finishing Cycle	6

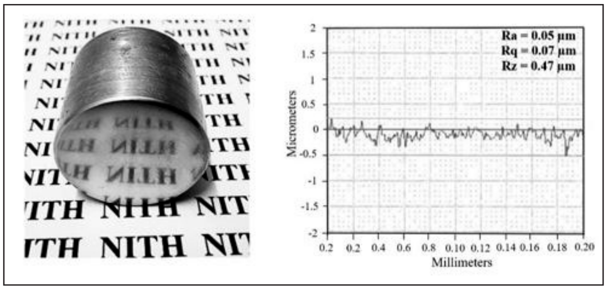

Fig. 12. The reflection of the copper surface and final surface roughness profile after the finishing action.

From a comparison point of view, the experiments were performed with and without pressure. The whole setup is fixed on a lathe machine such that the workpiece is fixed on the chuck of the lathe machine and a manually fabricated tooltip along with the set of permanent magnets is fixed on a z-slide arrangement. Table 1 shows all the fixed parameters and conditions that were taken during the experimentation.

Initially, the experiments were performed without the aid of extrusion pressure in a set of 3 cycles, each compromising of 20 minutes. After the completion of all the 3 cycles, the result obtained on the face of the copper workpiece accurately matches the simulation result. From the simulation result, it is clear that without the aid of extrusion pressure, the diamagnetic nature of copper repels the magnetic flux density generated by the set of permanent magnets, and only a small ring of magnetic flux density is formed on the outer region of the face of the copper workpiece. Figure 11 shows the face of the copper workpiece after 60 minutes of finishing without extrusion pressure.

From the figure, it can be concluded that the central region of the face of the copper workpiece is the repelling zone and the outward portion of the face of the copper is where a ring of magnetic flux density is formed. Reflection of the letters "NITH" can be clearly observed on the outer region of the workpiece whereas there is no significant change in the central region of the workpiece. Also, an average surface roughness value of 80 nm is obtained at the outer region of the workpiece. The next experiment is conducted with the aid of extrusion pressure in a set of 3 cycles, each compromising of 20 minutes. After the completion of all the 3 cycles, a significant amount of change can be observed in the central region of the face of the copper workpiece. From figure 12 it can be observed that after the inclusion of the extrusion pressure to the MR fluid, not only the outward region but also the central region of the face of the copper workpiece indicates a decrement in the surface roughness.

The reflection of the letters "NITH" can be clearly observed on the whole face of the copper workpiece. A final surface roughness value of 50 nm was obtained after the completion of the 3 sets of the finishing cycle.

5. Conclusions

Magnetic simulation studies were performed to evaluate the performance of the permanent magnet in the MRF tool assembly without the presence of pressurized MR fluid. The simulation results show the formation of a ring with a high magnetic flux density over the workpiece surface; however, the magnetic flux density at the inner portion of the ring is negligible. This causes the MR fluid to move towards the region with higher magnetic flux density i.e., toward the outer region of the ring, thus creating a gap between the MR fluid and the workpiece surface. Based on the magnetic simulation studies an extrusion-based magnetorheological finishing setup is designed which can overcome the complication of the repelling effect of the non-ferromagnetic materials by extruding pressurized MR fluid from the tooltip. The result of the initial experiment without the aid of pressure accurately matches the simulation result, which shows the repelling nature of the copper workpiece in the central region, and the finished region on the outward area indicates the presence of a ring of magnetic flux density. The result obtained from the experiment conducted with the aid of extrusion pressure supports the theory of neutralizing the repelling nature of diamagnetic materials with the help of an external axial force aided by providing external pressure. The continuous pressure applied to MR fluid will provide an external axial force that can fill the gap created by the repelling effect of the non-ferromagnetic materials.

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