Comparative analysis of magnetostatic forces in Ball End Magnetorheological Finishing

Abstract— To provide precision to the product geometry and a fine finish to the material of the surface to be used in the industries where there is a demand of high accuracy is very difficult. Also the procedure of providing fine surface finish may lead to sub surface damage. To deal with the problem, a new fine finishing process is developed in which a ball end of magnetorheological fluid is formed at the tool tip to provide the surface finish to the product by controlling the abrasion forces. Ball end magnetorheological finishing process can be used to finish complex geometries, grooves, intricate shapes of the three-dimensional workpiece surfaces. A setup, computer controlled, is formed and an electromagnetic model is developed to perform the simulation of magnetostatic forces acting on the abrasive particle in a ferromagnetic and nonferromagnetic workpiece material by varying the number of carbonyl iron particles. To study the simulations iron is used as a ferromagnetic workpiece material and copper is used as a nonferromagnetic workpiece material.

Index Terms—. **Ferromagnetic, magnetostatic force, magentic flux density, nonferromagnetic.**

I. Introduction

It is difficult to provide a fine surface finish to the intricate shapes, complex geometries, also at certain angles of workpiece due to the restricted movements of the cutting tool and also the workpiece. Traditional processes developed to provide surface finish are limited to certain geometries only, also, the processes such as lapping, grinding, honing may lead to some micro level damages beneath the finishing surfaces. Therefore it is required to control the abrading forces so as to maintain the precision, dimensional accuracy and as a resultant, the product quality. To achieve the controlled abrading forces few processes were developed such as Magnetorheological Jet Finishing (MRJF) [1], Magnetic Abrasive Finishing (MAF) [2], Magntorheological Abrasive Flow Finishing (MRAFF) [3], Magnetorheological Float Polishing (MFP) [4], Magntorheological Finishing (MRF) [5]. The aforesaid mentioned processes utilised the magnetorheological property of the finishing fluid but these process failed to finish the three dimensional workpiece surfaces and the complex geometries. The requirement of finishing the 3D surfaces and highly complex geometries led to the development of ball end magnetorheological finishing process, this has already been reported and demonstrated [6,7]. In this process a stiff ball of magnetorheological fluid is formed at the tool tip by controlling the magnetic field applied to the setup. The MRP fluid is a smart fluid, a type of oil, which has a property that it can increase the apparent viscosity to the point of becoming a viscoelastic solid. MRP fluid is basically the carbonyl iron particles suspended in a base, the base may be oil, water, grease, etc. A computer controlled, three axis motion controller is used to control the horizontal and vertical movements of the workpiece and the MR tool respectively. A very few research have been reported in relation to the magnetic forces acting in the magnetorheological polishing. De Groote et al. observed that drag force and peak removal rate increase linearly with nano diamond concentration upto a certain level in magnetorheological finishing (MRF) process. Further increase in nano diamond particles did not result in increase in drag force or peak removal rate [8]. However Shorey et al. [9] reported contrary to DeGroote's observation, that drag force decrease with increase in nano diamond concentration in the case of sapphire. In the present work Finite element analysis method is used to determine the magnetostatic force and an attempt has been made to do a comparative analysis of the magnetostatic force on the abrasive particle in a ferromagnetic iron and a nonferromagnetic copper workpiece by forming a single chain of carbonyl iron particles attached to the abrasive particle in a linear vertical manner.

II. EXPERIMENTAL SET UP

A. *Review Stage*

The BEMRF set up comprises of a three axis table. X, Y & Z axis. X-Y controls the horizontal movements of the workpiece and Z axis controls the vertical movements of the BEMRF tool. The setup is provided with three stepper motors for controlling the linear motion of X-Y-Z directions. A servomotor drives the MR finishing tool on the Z axis so as to facilitate the tool tip to touch the surface of the material to be finished. Other accessories such as slip ring, ball bearing, timing pulley and rotary valve are place above the MR finishing tool. The MR Polishing fluid runs vertically towards the tool tip as it is replenished after use. A picture of the BEMRF setup is shown in Fig.1.

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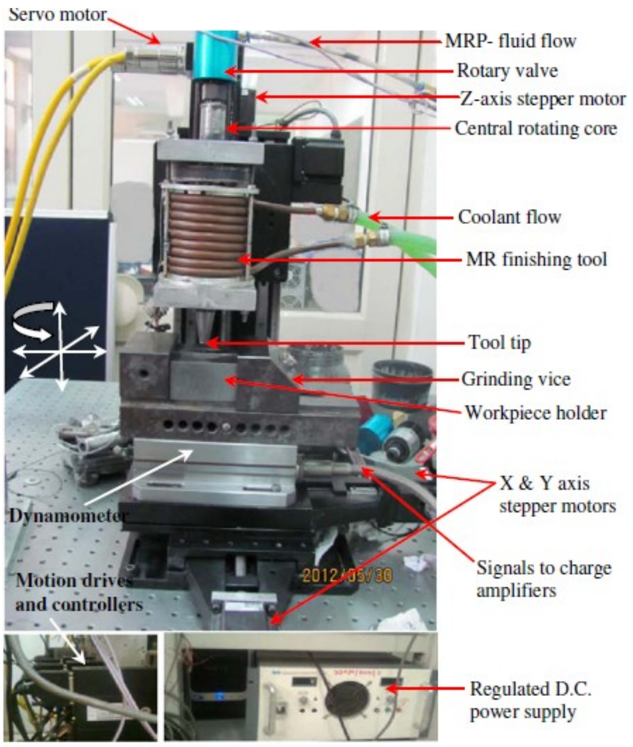

Fig.1.BEMRF set up.

B. *Mechanism of surface Finishing*

In ball end magnetorheological finishing process the surface finish is the result of the abrasion action which is the result of constant interaction of the carbonyl iron particles with the abrasive particles. In BEMRF process the MR fluid runs vertically to the MR finishing tool. As the fluid reaches the tool tip the magnetic field is switched ON. Due to the magnetic flux density the viscosity of the magnetorheological polishing fluid is increased and it stiffens at the tool tip. Hence it forms a stiffened ball end at the tool tip. The abrasive and the carbonyl iron particles adhere to form a single body to perform the surface finishing. The majority of abrasive particles are repelled from the higher gradient of magnetized tool tip surface towards the lower gradient of magnetic flux density (workpiece surface) (Fig.2) [10].

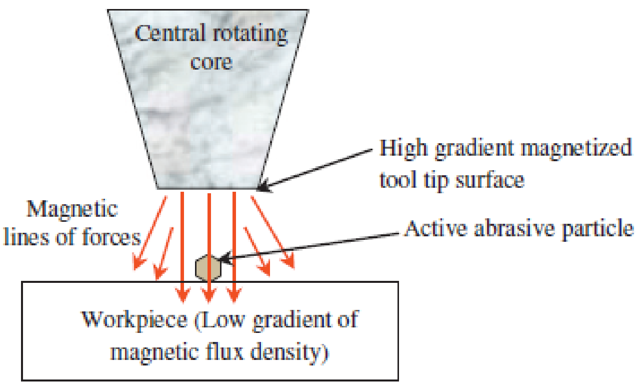

Fig.2 Interaction of abrasive particle with workpiece surface due to repulsion by a high gradient magnetic field.

C. *Electromagnetic Model*

An electromagnetic model is developed by using Maxwell student version software. In the developed model concentric central core, electromagnetic coil and magnetorheological fluid are formed. A workpiece material is placed at the Z axis. The current excitation provided is 2A and 2000 number of turns to the electromagnet. Copper material of relative permeability 0.999991 is used to from the electromagnet. Central core of iron with relative permeability 4000 is used. Further assigned parameters are given in Table.1

Table.1 Electromagnetic model Parameters.

Parameter	**Material**	**Relative Permeability**	**Current**	**No. of turns**
Workpiece	Copper	0.999991		
Central core	Iron	4000		
Electromagnetic coil	Copper	0.999991	4A	2000
MR Polishing Fluid	MR Fluid	5		
Abrasive Particle	Al92pct	1		

III. Finite Element Analysis for Magnetostatic Force on Abrasive Particle on a Ferromagnetic Iron Workpiece

A ferromagnetic iron workpiece is used to determine the magnetostatic force on abrasive particle by forming a linear chain of carbonyl iron particles attached to the abrasive particle on the surface of the work piece. The magnetostatic force on the abrasive particle without any CIP is noted down after running the simulation and is found to be 0.003365N. After this one CIP is added and the force is found to be0.001467N. In the similar manner the carbonyl iron particles are added upto a number of five particles and the magnetostatic force on the abrasive particle when a chain of five CIPs attached to the abrasive is formed is found to be 0.012268N. Detailed results of simulations are given in Table2. The pictures are given in Fig.3 representing the formation of the chain like structure by adding CIPs one by one. Also the changing magnetic flux density by performing the above process is studied and shown in Fig.4.

Table2. simulation results for ferromagnetic Iron work piece.

Number of CIPs	Magnetostatic force (N)
No CIP	0.003365
1 CIP	0.001467
2CIP	0.0070966
3CIP	0.00098186
4CIP	0.010564
5CIP	0.012268

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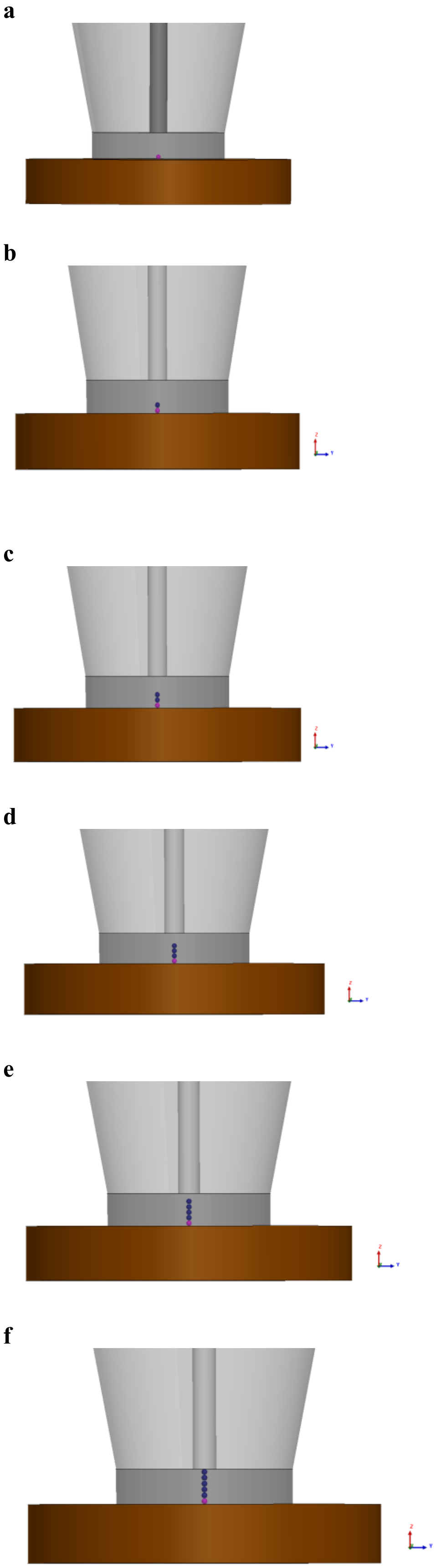

Fig.3 represents the chain formation of CIP with increasing number of CIPs (a) when no CIP, (b), (c), (d), (e), (f) with 1,2,3,4,5 number of CIPs added repectivley.

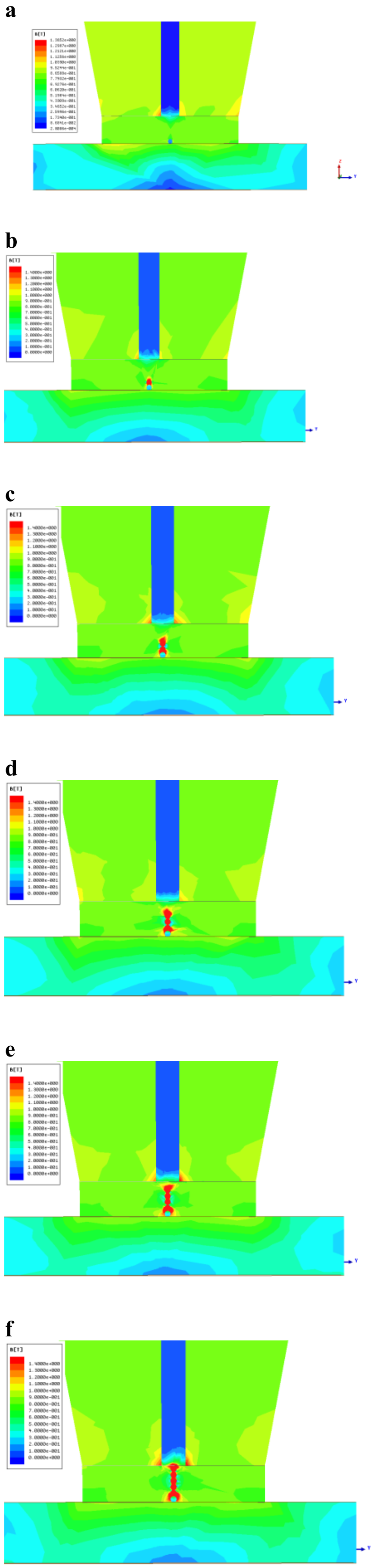

Fig.4 (a) shows the magnetic flux density for a ferromagnetic workpiece with (a) no CIP, (b), (c), (d), (e), (f) with 1,2,3,4,5 CIPs.

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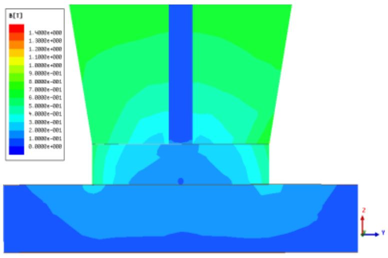
IV. Finite Element Analysis for Magnetostatic Force on Abrasive Particle for Nonferromagnetic Copper Workpiece

The magnetostatic force on abrasive particle is noted down on a nonferromagnetic copper workpiece by assigning the force parameter . After running the simulation without any CIP, the magnetostatic force is found to be 0.00017491N. After this a carbonyl iron particle is attached to the abrasive particle, a simulation is run for refinement of the results and the magnetostatic force is calculated to be3.2207E-005N. In the similar manner one more CIP is added and like this a linear vertical chain of CIPs is formed and the forces are noted down the magnetostatic force on adding upto 5 CIPs in nonferromagnetic copper is 0.00023827N. The simulations results are shown in Table3. The magnetic flux density with varying number of CIPs is shown in Fig.5

a



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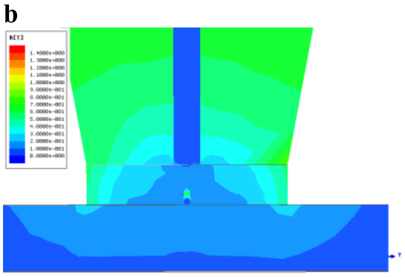

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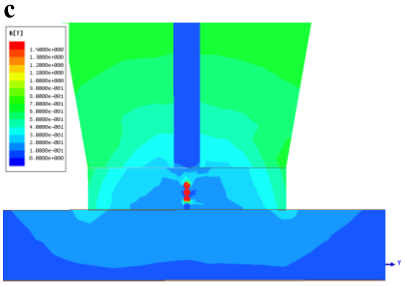

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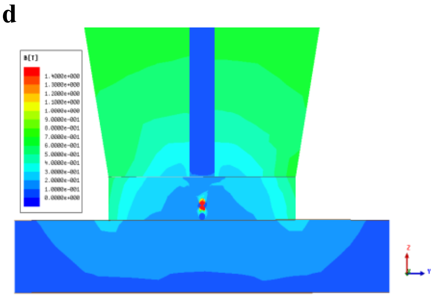

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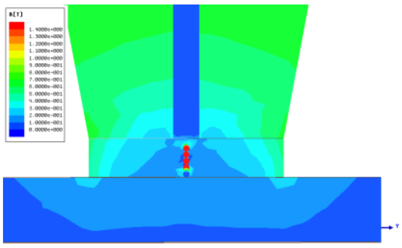

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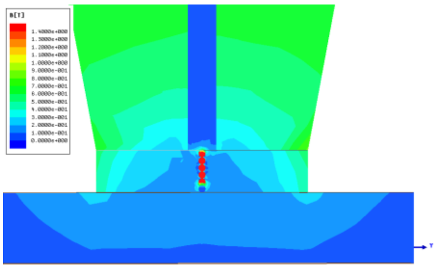

Fig.5 Shows the magnetic flux density on a copper workpiece (a) without any CIP, (b), (c), (d), (e), (f) with 1,2,3,4,5 CIPs added respectively.

Table3. Results of simulation for nonferromagnetic copper.

Number of CIPs	Magnetostatic Force(N)
No CIP	0.00017491
1 CIP	3.2207E-005
2 CIP	0.0006243
3CIP	3.5568E-005
4 CIP	0.00056304
5 CIP	0.00023827

V. RESULTS AND DISCUSSIONS

1. The magnetostatic force on abrasive particle by increasing the number of carbonyl iron particles for a ferromagnetic iron and nonferromagnetic copper material is analysed, also the magnetic flux density is studied for the same conditions.
2. The value of magnetostatic force is increased by increasing the number of carbonyl iron particles but upto a certain level and then it fluctuates for ferromagnetic as well as for nonferromagnetic material.
3. The comparative analysis of magnetostatic force shows that the value force for similar number of CIPs attached to an abrasive is higher for a ferromagnetic work material and lower for a nonferromagnetic material, e.g., Magnetostatic force for no CIP and 1 CIP in a ferromagnetic material is 0.003365N, 0.001467N respectively and for nonferromagnetic copper the magnetostatic force is 0.0017491N, 3.2207E-005N for 0 and 1 CIP respectively.
4. The magnetic flux density is found to be higher for ferromagnetic workpiece and comparatively lower for a nonferromagnetic workpiece. The magnetic lines of force were more uniform for the ferromagnetic material in comparison to nonferromagnetic copper.

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VI. CONCLUSIONS

The work done reveals the varying magnetic flux density for the ferromagnetic and nonferromagnetic workpiece. The magnetostatic forces are calculated by using the developed electromagnetic model for ferromagnetic and nonferromagnetic material. The magnetostatic forces were found to be increased upto a certain number of CIPs added and then fluctuates. The more accurate results may be found by increasing the value of current and magnetic field.

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