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Development of Magnetorheological Finishing (MRF) Process for Freeform Surfaces

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Abstract:

One of the newly developed methods for obtaining super finished surfaces for freeform is Magnetorheological finishing (MRF). MRF is an advanced finishing process in which the grinding force is controlled by magnetic field. The material removal in MRF is governed by the magnetorheological fluid which mainly consists of carbonyl iron (CI), abrasives particles, carrier fluids and additives. MRF process is capable of giving nanometer-scale surface finish. The process makes use of a magnetorheological fluid as a tool that acts as a flexible magnetic abrasive brush (FMAB) that provides finishing action. The relative motion between the finishing medium and the workpiece can be obtained either by rotating the workpiece, rotating the finishing medium, or both.

In the present work, a setup has been developed for MRF application using a pillar drilling machine. Experiments were conducted to finish free form jobs of copper material using the developed setup. The effects of various process parameters viz. composition of the MR fluid, rotational speed of work and vessel containing MR fluid, mesh size of abrasives on surface finish were explored.

Keywords: MR fluid; Magnetorheological finishing (MRF); Freeform work; Surface finish

Introduction

In today's advanced engineering industries, the designers' requirements on the components are stringent, for example, extraordinary properties of materials, complex shaped 3D components, miniature features, and nano-level surface finish on complex geometries are not feasible to achieve by any traditional methods [3]. Some advanced finishing processes like abrasive flow machining (AFM), magnetorheological finishing (MRF), Magnetorheological abrasive flow finishing (MRAFF), magnetic abrasive finishing (MAF), and magnetic float polishing (MFP), have been evolved in the last few decades [1,2]. A new magnetic abrasive medium, using silicone gel to mix with steel grits and silicon carbon, to enhance the efficiency of MAF was proposed [4].

This paper is divided in to four sections i.e introduction, development of (MRF) experimental setup, MRF Experiments with results and conclusions. General introduction to some of the magnetic assisted finishing process is given in section 1. In section 2, all the processes involved in developing and fabricating the MRF setup are given. In the next section i.e., section 3, results of the experiments conducted and conclusion obtained on the developed MRF setup are given.

Development of Magnetorheological finishing (MRF) setup

MR fluid

The MRF process relies on a unique "smart fluid", known as Magnetorheological (MR) fluid. MR fluid consists of Magnetizable particles such as CIPs (Carbonyl Iron Particles), Non-magnetic carrier medium (like silicone oil, mineral oil etc.), Abrasive particle (like Silicone carbide, aluminum oxide, cerium oxide etc.), Additives such as grease.

On application of external magnetic field, the iron particles in carrier fluid aggregate into columnar chains aligned in the field direction. A calibrated measuring glass tube is used to measure the volume percentage of CI particles, abrasives and engine oil. MR fluid was prepared by mixing the compositions as per the pre-determined percentage volume given in table 2. The fine carbonyl iron (CI) powder is collected from the saw dust of pure iron by sieving.

Design of experimental setup

To develop a MRF setup, a pillar drilling machine is used. The basic purpose of using a drilling machine in the MRF setup is to get a basic structure and place on which it can be erected and second and the most important is to obtain the relative motion (rotational) between the workpiece and the MR fluid contained in the vessel as shown in Fig. 1.

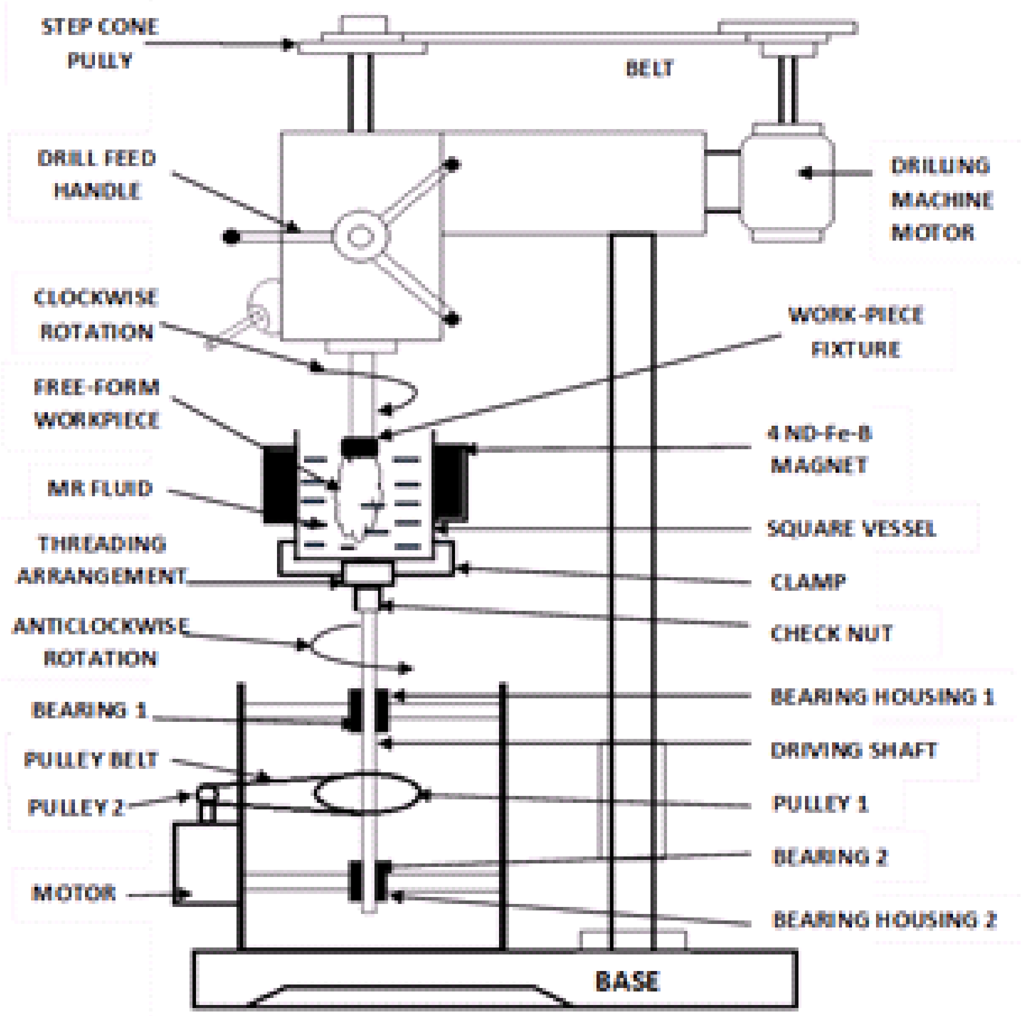


Fig. 1. Schematic Diagram of the MRF setup

Fabrication of MRF setup

Thin steel channels were taken to fabricate the structure of the equipment using nuts and bolts as fasteners. At the middle portion of the frame, 2 bearings of same dimensions are clamped with the help of the bearing housing. Steel rod which is used for construction purpose is taken to prepare the driving shaft of the setup. Shaft is made with dimensions in accordance with that of bearings.

Motor of the required specifications is mounted on this frame as shown in the Fig. 2. Main vessel of the setup to contain the MR fluid is of square shape of 150mm×150mm×150mm. The complete setup of MRF process which can finish any free-form nonmagnetic job is shown if Fig. 3. Free-form job is clamped through workpiece fixture in the drill chuck of the drilling machine. The speed of the motor was 950 RPM, hence a regulator is used to lower down the speed because at high speed the chances of spilling out of MR fluid from the container may arise.

Fig. 2. The pulley and belt system attached with the motor

Fig. 3. Developed experimental setup of MRF process

Setting of the magnets and freeform workpiece

In MRF experiments, permanent magnets are distributed symmetrically on the sides of a nonmagnetic container. The experimental setup consisted of mounting two pairs (4 nos.) of Nd-Fe-B magnets of N35 grade placed on each side of the container with diametrically opposite poles. It was observed that for this magnetic configuration, the CIPs chains are more uniformly distributed.

The workpiece material considered for all the experimentation is copper alloy of non-magnetic nature. The detailed chemical composition of the copper alloy used as a workpiece in the present study is given in table 1.

Initially turning and facing operation was performed on the job by the lathe machine to remove the outer layer of the workpiece. Then to convert it to a free-form job, a portion is removed from the bottom end by sawing operation as shown in the figure 4. As a result of which the job is now a combination of two surfaces i.e., flat and cylindrical.

Table 1: Composition of the copper alloy (C70600) used as a workpiece

Constituents	Percentage
Copper	86.2
Nickel	11
Iron	1.8
Manganese	1

Fig. 4. Workpiece fixture with free-form job fabricated from copper alloy

Working of the MRF experimental setup

To machine external surfaces, workpiece is rotated in MRF solution, to obtain the required surface finish. In the present work, the job is submerged in the MR fluid and at the same time, polishing medium is rotated by imparting a rotational motion to the vessel also. By superimposing these two motions, smooth mirror finished surface can be achieved in comparatively less time.

Experiment 1 was conducted with the rotation of job only in the clockwise direction. Experiments 2 and 3 were conducted with rotation of job in the clockwise direction as well as rotation of vessel also in the anticlockwise direction which is an innovative feature of the system reduced the time of surface finish to a great extent.

MRF Experiments and Results

In the present work, three different sets of selected process parameters are considered to conduct three experiments respectively as shown in table 2.

Table 2: Composition of the MR fluid kept in different experiments

Parameters	Experiment 1	Experiment 2	Experiment 3
Abrasive particle	20% volume, 80 SiC	30% volume, 46 SiC	36% volume, 46 SiC
Engine oil	48% volume	30% volume	27% volume
Grease	12% volume	10% volume	7% volume
CI particles	20% volume	30% volume	30% volume
Duration of run	4hours	4hours	4hours
Rotation	Rotation of job in MR fluid	Rotation of job in MR fluid &rotation of container	Rotation of job in MR fluid & rotation of container
RPM of job	440	440	790

The surface finish was measured using a surface roughness tester, Taylor-Hobson Surtronic 4+. The surface finish value was taken at four different palaces before and after on the same workpiece in a particular experiment and was averaged to represent the actual surface finish of the workpiece as shown in Table 3.

The results in terms of percentage improvement in surface finish are tabulated in table 4. Here %ΔRa is taken as response and has been calculated using:

$$\%\Delta Ra = \frac{RaINTIAL - RaFINAL}{RaINITIAL}$$

Table 3: Experimental results obtained from the MRF experiments

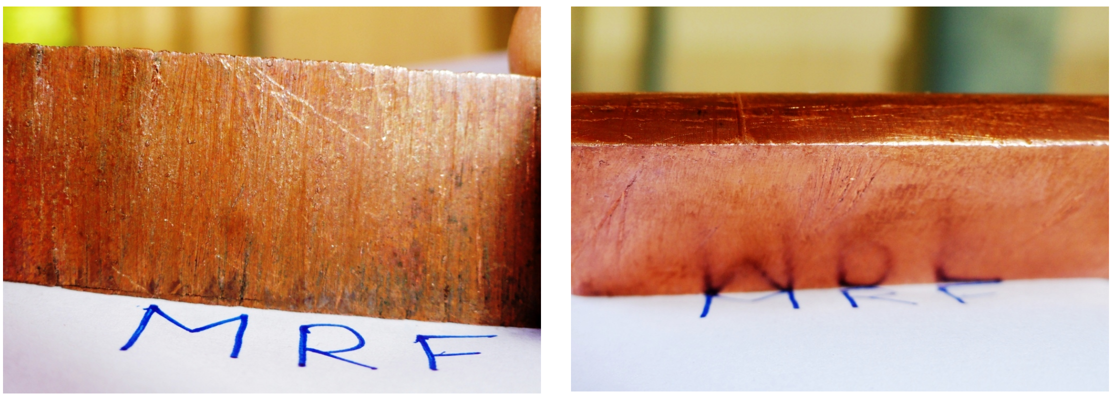
	EXPERIMENT 1 Surface Finish (µm)		EXPERIMENT 2 Surface Finish (µm)		EXPERIMENT 3 Surface Finish (µm)	
	Before	**After**	**Before**	**After**	**Before**	**After**
FLAT	1.9	0.7	2.3	0.5	2.8	0.5
	2.0	0.6	3.0	0.6	2.1	0.4
	1.9	0.5	3.1	0.8	2.0	0.5
	1.9	0.6	2.9	0.9	1.8	0.5
AVERAGE	1.9	0.6	2.8	0.7	2.2	0.5
	68% Improvement 1.9 → 0.6		75% Improvement 2.8 → 0.7		77% Improvement 2.2 → 0.5	
CLYNIDRICAL	0.6	0.3	1.0	0.3	0.5	0.3
	1.2	0.3	0.5	0.3	0.5	0.2
	0.8	0.4	0.7	0.3	0.6	0.3
	1.0	0.4	1.2	0.4	0.5	0.3
AVERAGE	0.9	0.4	0.9	0.3	0.5	0.3
	56% Improvement 0.9 → 0.4		67% Improvement 0.9 → 0.3		40% Improvement 0.5 → 0.3	

The surface finish of the specimen obtained with the MRF experiments are shown in the figure 5, the surface finish of the work has significantly improved by the MRF process.

After cleaning the finished job with paraffin agent (petrol) the improvement in the surface finish can be observed by naked eye as the mirror image of texts formed on the reflective surface of the finished copper job as in the shown Fig. 6.

i ii

Fig. 5. Workpiece before and after the experiment (i) cylindrical (ii) Flat



i ii

Fig. 6. Reflection of texts on the flat surface of finished job (i) before (ii) after

3. Conclusions

After clearly observing the results of all the experiments, it can be concluded that the improvement in the surface finish of flat portion is better than cylindrical surface.

Probable Reason – It is due to the fact that while rotating the job in the MR fluid in clockwise direction and the container containing the MR fluid in the anticlockwise direction the obstruction by the flat surface to the abrasive grains is more than that of cylindrical portion. Due to this obstruction the material removal or grinding action is prominent in the flat portion. In experiment 1, the improvement in the surface finish of flat portion was 68% while in experiment 2 this improvement was 75%. Similarly in experiment 1, the improvement in the surface finish of cylindrical portion was 56% while for experiment 2 this improvement was 67%. So it can be concluded that experiment 2 is giving better results compared to experiment 1.

Between experiment 2 and 3, there was a slight improvement in the surface finish of flat surface from 75% to 77% but a substantial reduction in the improvement in the surface finish of cylindrical surface from 67% to 40%. It is due to the fact that by increasing the speed of rotation of the job from 440 RPM (experiment 2) to 790 RPM (experiment 3), might have less finishing effect on the cylindrical surface.

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