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Analyzing Effect of Interactions of Process Parameters on Surface Finish of SUS304 Steel Roller Using RSM Technique

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***Abstract* - Finishing of cylindrical workpieces of SUS304 steel has been done using loosely bonded diamond based magnetic abrasives prepared by homogeneous mixing of magnetic powder (Fe powder of 300 mesh size (51.4µm)), abrasive powder (Diamond particles of 200 mesh size (41µm)), and lubricant. A central composite design involving four variables has been employed using RSM techniques to establish a mathematical model between parameters and response (percent improvement in surface finish), a series of experiments have been conducted using in-house fabricated setup. It has been found that magnetic flux density, quantity of magnetic abrasives, rotational speed of workpiece and percentage of abrasives in magnetic abrasives has significant effect on PISF. The maximum percentage improvement in surface finish was found to be 81% (0.04 µm Ra) at 1.0 Tesla of magnetic flux density, 40 mg of magnetic abrasives, 800 rpm as rotational speed of workpiece and 40% of abrasive. Scanning Electron Microscope (SEM) photographs shows that the surface generated by turning on lathe consists of deep scratches. The peaks have been sheared off to much smaller heights by MAF resulting in improved surface finish, but fine scratching marks produced by MAF appear on the surface.**

***Keywords*: Magnetic Abrasive Finishing (MAF), Scanning Electron Microscope (SEM)**

I. Introduction

Magnetic Abrasive Finishing is one of the super polishing processes involving extremely small amount of material removal even to the extent of an atomic cluster. This process uses magnetic force for material removal. The cutting forces of extremely small magnitude are applied on the workpiece surface. These forces are uniformly distributed on the work surface and are easily controllable. Hence there is negligible damage to the surface of workpiece. The process is capable of achieving surface roughness of the order of nanometric level.

From the literature survey it is observed that considerable research work has been done using different types of magnetic abrasives. Different techniques used for preparing magnetic abrasives are:

a. Sintering
b. Adhesive Based (Glued)
c. Plasma Based (Powder Melting/ Plasma Spraying)
d. Mixing (Loose Bonding/Unbonding)

Kim (2003) used sintered magnetic abrasives for internal finishing of SUS304 stainless steel tubes. It has been found that surface finish and material removal was affected by grain size, weight of magnetic abrasives, flux density, speed of workpiece, machining fluid and machining time. The optimal working conditions were 90%, 12 gm, 0.4 Tesla, 112m/min, 1ml and 15min. respectively and a surface finish of 0.05 µm (Ra) was obtained. Yamaguchi (2003) applied magnetic abrasive finishing process to SUS304 stainless steel bent tubes. Aluminium oxide composite magnetic abrasive with a mean diameter of 80 µm was used for the process. It contains aluminium oxide with grain size less than 10 µm sintered with iron in an inert gas atmosphere with high pressure and temperature. A two phase finishing process controlling the size of the ferrous particles was proposed to achieve efficient fine surface finishing. In particular, the use of 150 µm iron particles after 330 µm iron particles was found to be effective. Lin *et al.* (2007) prepared the magnetic abrasives by typically mixing iron powder (60 wt %) and Al_2O_3 (40 wt %) with average size of 50µm and compressing mixture into the cylindrical shape. These compacts were sintered into a vacuum furnace. After sintering process, these cylinders were crushed to produce magnetic abrasives of average size 150 µm. The ball-shaped magnetic pole with special grooves was used with these magnetic abrasives. It was found that the design increased the finishing efficiency and created a good surface finish for the non-ferromagnetic material, SUS304. The best surface finish was obtained at a working gap of 2.5 mm, a feed rate of 10 mm/min, and an abrasive mass of two grams.

Feygin *et al.* (1998) prepared magnetic abrasives by mixing iron powder, Al2O3 and glue as adhesive (commercially known as industrial crazy glue). Iron and abrasive particles were strongly bonded with each other by the glue. They reported that this method was simple as compared to the other methods for preparation of the magnetic abrasives. MRR was higher as compared magnetic abrasives prepared by other methods. Kremen et al. (1999) also developed magnetic abrasives using an adhesive to bind magnetic component (iron powder) with abrasive component (diamond powder). All the three components were mixed thoroughly, dried and crushed into small particles of desired size for machining. Then, using these glued magnetic abrasive powder and keeping magnetic flux density 0.4 Tesla, machining time five minutes and 4% boric acid in water used as cooling fluid, investigated the effect of powder grain size on the surface roughness and MRR of a silicon wafer and tube.

Handa *et al.* (2008) also developed spherical iron-based composite powder with carried diamond particles using a plasma spraying technique. Spherical carbonyl iron powder with 7.2 µm in average and diamond particles with 0.3 µm in average were mechanically mixed and then were plasma-sprayed at various plasma currents, and the spherical iron-based composite powders with carried diamond particles which have a particle size less than 10 µm were obtained. These fabricated spherical magnetic abrasives were used for finishing of SUS304 plate on setup in dry conditions.

Yin and Shinmura (2004a, b) finished three different materials with loosely magnetic abrasives (4 gm iron particles of size 330 µm mixed with 1gm of Al_2O_3 of size 80 µm and 2 ml of straight oil type grinding fluid). It was reported that volume removal rate of magnesium alloy was more as compared to stainless steel and brass. Wang et al. (2005) also used loosely bonded magnetic abrasives (mixer of 1.5 gm iron of size 510 µm, 1.5 gm Cr2O3 of 3µm size and 0.5 ml distilled water). They reported that wet finishing gives better surface finish as compared to dry finishing. Singh et al. (2005) used UMA prepared by homogeneous mixing of 25% SiC abrasives (mesh no. 400) and 75% iron particles (mesh no. 300) in 3% oil (SAE30) for finishing of alloy steel tubes. The surface roughness of the workpiece was decreased from 0.58 µm Ra to 0.11µm Ra.

Amongst all the available varieties of magnetic abrasives, the sintered magnetic abrasives give highest surface finish on most of the work materials. Cost involved in manufacturing sintered abrasives is high. Irrespective of type of magnetic abrasive used, the percentage improvement in surface finish over original finish of the surface varies in 75% to 99%. Only few researchers have used diamond as abrasive component in loosely bonded/unbonded magnetic abrasives.

The gaps in the existing research of MAF are as under:

1. Most of the abrasive manufacturing methods are either proprietary or difficult.
2. In case of unbounded/loosely bonded magnetic abrasives few researchers have used diamond as abrasive component.

The present work is aimed at studying the effects of finishing parameters such as polishing speed, magnetic abrasive supply, abrasive material, magnetic abrasive manufacturing processes and particle size on change in surface finish, percent improvement in surface finish and material removal rate (MRR) on the three kinds of materials tubing. The MAF setup has been designed and fabricated.

II. Experimental Setup

The experimental setup has been designed and developed to carry out the present research work, keeping in view the objectives and various design considerations and constraints. The fabricated setup has major components like electromagnet (12 k Gauss), control unit, dc motor with three jaw chuck, variable dc supply and magnetic abrasive particles (diamond + iron).

A schematic view and a photograph of the setup are shown in the Figure 1 and Figure 2. MAPs through magnetic pressure finish the workpiece. Abrasive particles (diamond) and magnetic particles (iron) are loosely bounded together by lubricating oil to have composite particles (or conglomerate). For the present work, the magnetic abrasive powder was prepared through homogeneous mixing of magnetic powder (iron powder of 300 mesh size,51.4µm) and abrasive powder (diamond powder of 200 mesh size,74 µm).

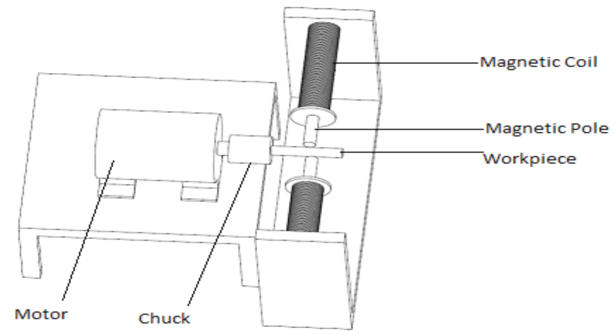

Fig.1 Block Diagram of the Experimental Setup

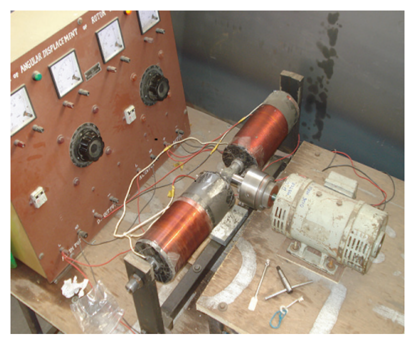

Fig. 2 Setup for Magnetic Abrasive Finishing

III. Experimental Procedure

Table I Maf Parameters For Experimentation

Parameter	Range	Mode of Selection
Pole work-piece gap	1 mm	Literature
Grit size of diamond abrasive	74 µm	Literature
Machining time	30 Min	Experimentation
Lubricating oil	5% by wt. of MA	Literature
Rotational speed of work piece	400-2000rpm	Experimentation
Quantity of magnetic abrasives	10-50 gm	Experimentation
Percentage of diamond abrasives in MA	10-50 %	Experimentation
Magnetic flux density	0.4-1.2 Tesla	Experimentation

Table II Coded And Real Levels Of Independent Variables

Input Process Parameter	Abbreviation	Coded Parameter	Level I	Level II	Level III	Level IV	Level V
			-2	-1	0	1	2
Magnetic Flux Density (Tesla)	MFD	A	0.4	0.6	0.8	1	1.2
Quantity of MA (gm)	Quantity	B	10	20	30	40	50
Rotational speed (rpm)	Speed	C	400	800	1200	1600	2000
Percentage of abrasives in MA	% Abrasive	D	10	20	30	40	50

Finishing of cylindrical workpieces has been done using loosely bonded diamond based magnetic abrasives prepared by homogeneous mixing of magnetic powder (Fe powder of 300 mesh size (51.4μm)), abrasive powder (Diamond particles of 200 mesh size (41μm)), and lubricant. A central composite design involving four variables has been employed to establish a mathematical model between parameters and response (percent improvement in surface finish), a series of experiments have been conducted using in-house fabricated setup.

Important input process parameters and their working range have been selected on the basis of preliminary experiments conducted using the experimental setup developed for the present work and literature available. The different MAF parameters and their range are tabulated in Table I.

The input process parameters and their levels are tabulated in Table II.The range of input parameters was selected on the basis of preliminary trial experimental results. The finishing characteristics of magnetic abrasives were analysed by measuring the surface roughness, which was measured at four points before and after finishing using a Mitutoyo surface roughness tester (SJ-210P) having a least count of 0.001 μm (cut off length = 0.8 mm) and averaged. Also surface finish was analysed using Response Surface Methodology (RSM). Therefore finishing characteristics in terms of PISF (Percentage Improvement in Surface Finish) were analysed.

V. Results And Discussions

The effects of interactions of different process parameters such as circumferential speed of the work piece, magnetic flux density (MFD), abrasive grit size and quantity of abrasives on percent improvement in surface finish (PISF) were analyzed using Response Surface Methodology (RSM).

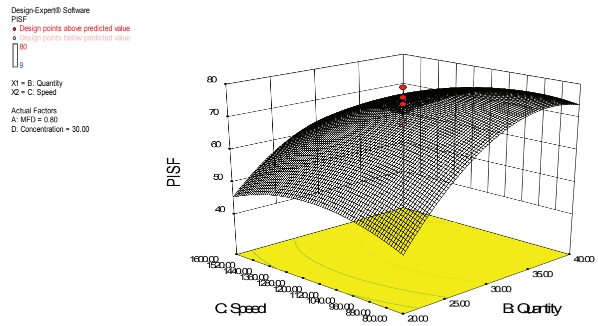

Figure 3

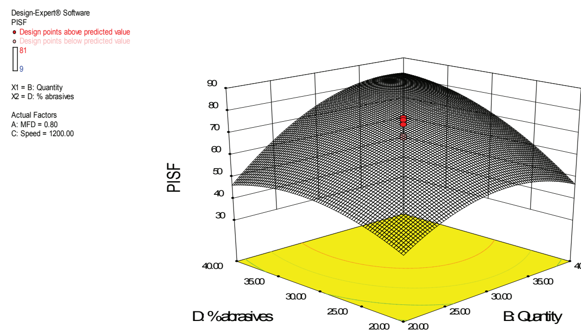

Fig. 4

Figure 3 shows the effect of simultaneous variation of quantity of magnetic abrasives (B) & rotational speed (C) on PISF. At all levels of rotational speed, the increase in quantity of magnetic abrasives leads to increase in PISF upto 35 gm then there is no change in PISF. Similarly for small quantity of magnetic abrasives increase in speed has very small effect on PISF, but for large quantity of MA with increase in speed PISF decreases.

The effect of simultaneous variation of quantity & percentage of abrasives on PISF is shown in Figure 4. PISF increases, at all levels of quantity of magnetic abrasives, with increase in percentage of abrasives. Also with increase in quantity of magnetic abrasives, PISF increases at all levels of percentage of abrasives.

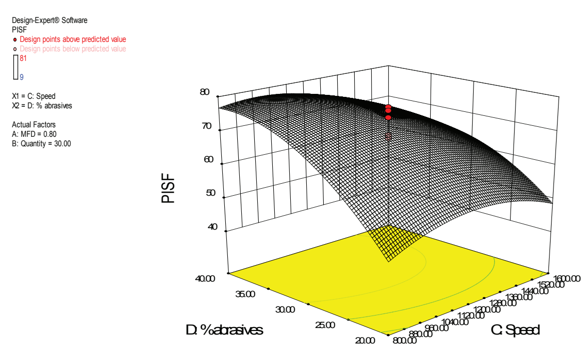

Fig. 5 The effects of rotational speed (C) and percentage of abrasives (D) on the PISF

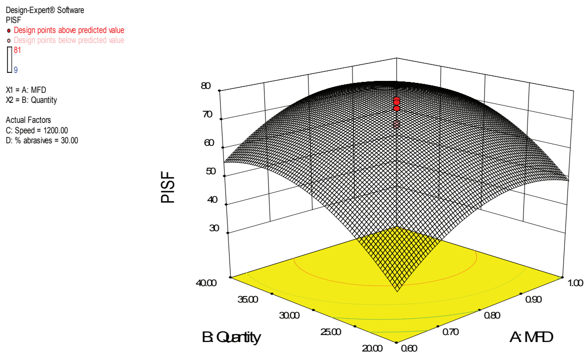

Fig. 6 All levels of MFD

Figure 5 shows the effects of rotational speed (C) and percentage of abrasives (D) on the PISF. It can be seen that all low levels of speed with increase in the percentage of abrasives the surface finish improves while it decreases at high levels of speed.

Figure 6 show that all levels of MFD, with increase in quantity of magnetic abrasives PISF increases. Similarly at all levels of quantity, with increase in magnetic flux density, PISF increases till the mid value and then starts decreasing.

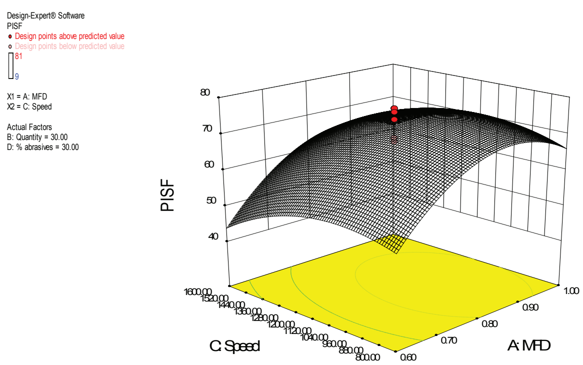

Fig. 7 The relationship between the MFD & speed

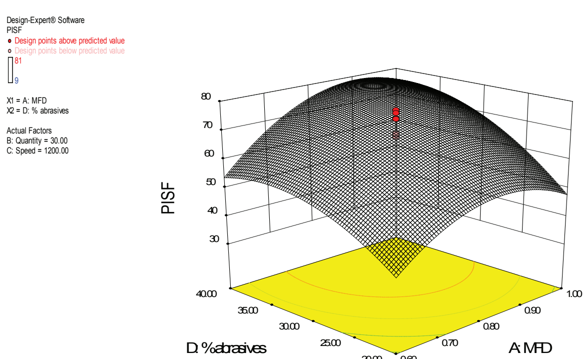

Fig. 8 All levels of MFD, with increase in percentage of abrasives

Figure 7 shows the relationship between the MFD & speed, keeping the value of Quantity & percentage of abrasives to a constant level. At low level of speed as the value of MFD increases the surface finish improves and then becomes saturated. While at all levels of MFD, with increase in speed the PISF slightly increases then starts decreasing.

Figure 8 shows that at all levels of MFD, with increase in percentage of abrasives PISF first increases than attains a constant value. The combined effect shows that increasing the value of MFD & percentage of abrasives the value of PISF goes on increasing at different rates, reaches maximum value before it starts decreasing.

VI. Microstructure Examination

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

The figures below show typical SEM micrographs of as received turned surface and magnetic abrasive finished surfaces. The surface generated by turning consists of deep scratches produced by the interaction of abrasive cutting points with the workpiece surface. The initial surface profile has periodic peaks and valleys generated by turning. The observations reveal that the finishing of workpiece surface in this process is done by scratching / micro-cutting. However marks due to turning, pits and digs, shown in Figure 9 disappear after magnetic abrasive finishing as shown in Figure 10, but fine scratching marks produced by MAF appear on the surface. Most of the peaks have been sheared off to much smaller height by MAF resulting in improved surface finish.

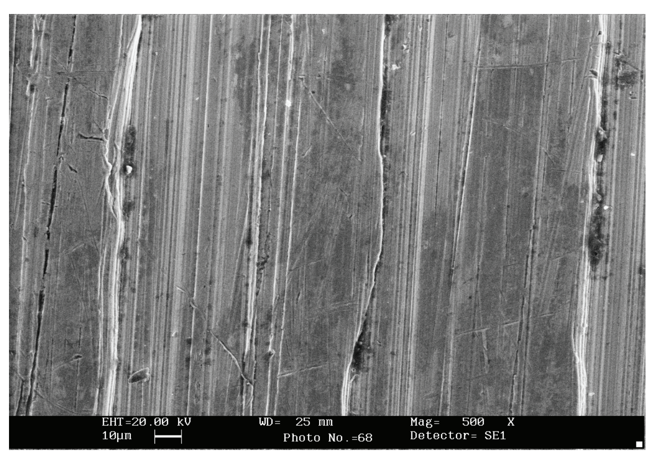

Fig. 9 SEM microphotograph of surface

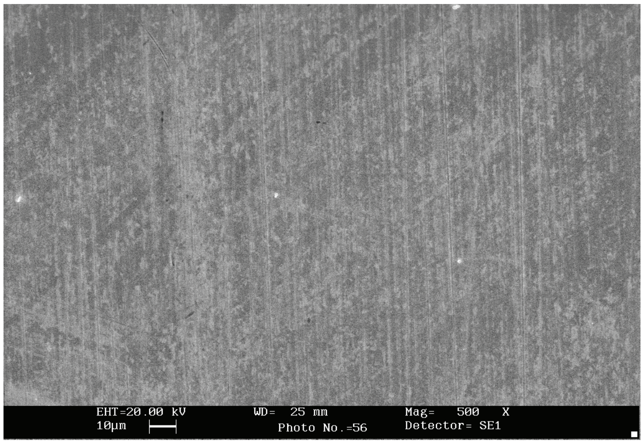

Fig. 10 SEM microphotograph of surface finished by turning finished by MAF

VII. Conclusions

In the present work, MAF setup has been designed and fabricated. The performance of loosely bounded MAPs has been studied on non-magnetic stainless steel. The conclusions drawn from this research can be summarized as follows:

1. Magnetic flux density, quantity of magnetic abrasives, rotational speed of workpiece, percentage of abrasives, interactions between (a) quantity of magnetic abrasives & rotational speed, (b) quantity of magnetic abrasives & percentage of abrasives, (c) rotational speed of workpiece & percentage of abrasives and quadratics of magnetic flux density, quantity of magnetic abrasives, rotational speed of workpiece, percentage of abrasives have significant effect on percentage improvement in surface finish.
2. The SEM micrographs show that tool marks and scratches are removed by MAF.
3. The process yielded best results at magnetic flux density (A) = 1.00 Tesla, quantity of magnetic abrasives (B) = 40gm, rotational speed (C) = 800rpm and percentage of abrasives in MA (D) = 40% for PISF.

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