Development of Sintered Magnetic Abrasive Media for Flat and Cylindrical Components Finishing by Magnetic Abrasive Finishing

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Abstract

Magnetic Abrasive Finishing process is a nanofinishing process using relative motion between magnetic abrasive and workpiece under influence of magnetic field to finish the surface of the work piece to a super finishing level. The finishing force is the result of the magnetic field developed between the magnetic poles & magnetic abrasive. Abrasive particles are non-magnetic in nature and cannot induce magnetism whereas iron particles being magnetic in nature can induce magnetism. Hence both are mixed together to give dual effect i.e. magnetism & abrasiveness. The advantage of this technology in cylindrical components finishing is that it can finish both inner diameter & outer diameter of the tube. After decades of research, since there are challenges in developing magnetic abrasive media. The technology has not gained much attention in industrial application. There are several methods for developing magnetic abrasive media but sintering process is considered as one of the best methods for developing magnetic abrasive media. The bonding strength also depends on the composition of materials used in preparing media. In this paper, development work on magnetic abrasive media by using iron particles & diamond powder has been come out and experimented on flat & cylindrical surfaces.

Keywords: Magnetic abrasive particles, Surface Morphology, Magnetic Abrasive finishing, Inert Atmosphere.

1. INTRODUCTION

Precision components used in aerospace, automotive, biomedical require nano-finished surface and processes like magnetic abrasive finishing [1, 2] can achieve it in very short time. Simplest way of preparing magnetic abrasive is by mixing iron and abrasive powder with fluid known as unbounded abrasives but it doesn't have enough bonding strength during the finishing operation. Sintered abrasives [3, 4] have much better bonding strength as they are compacted under high load & later heated up to their sintering temperature, which causes bonding by diffusion.

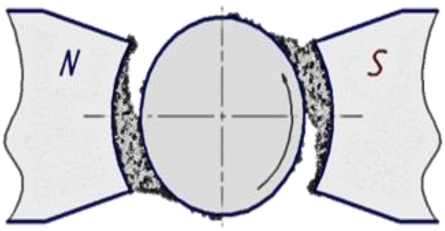

Fig.1 Finishing of Cylindrical Component by abrasive finishing

The bonding strength also depends on the composition of materials & sintering parameters. Under the effect of magnetic field, magnetic abrasives are arranged orderly along the magnetic line to form a flexible abrasive brush [5]. Magnetic abrasives finish the workpiece when there is relative motion between the magnetic abrasive brush and the workpiece as shown in fig.1 & fig.2. [1]

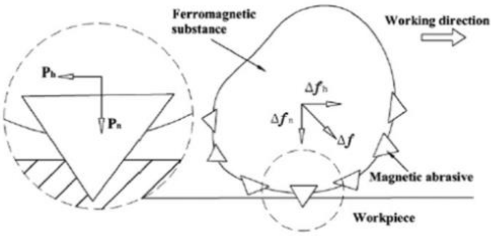

Fig.2 Schematic diagram of magnetic abrasive particle

2. DEVELOPMENT WORK FOR PREPARATION OF MAGNETIC ABRASIVE

Sintered components with metallic & ceramics powders are manufactured by heating the green compact up to their semi-solid state under inert gas atmosphere to prevent oxidation. Magnetic Abrasive Particles are a combination of ferrous particles like iron, steel, etc with fine abrasive particles like Al_2O_3, SiC, diamond powders. Magnetic abrasive particles are produced by different methods of sintering like conventional sintering, plasma sintering etc. The ferromagnetic phase and the abrasive phase of magnetic abrasive prepared by sintering process are bonded more firmly. Magnetic abrasive media is crushed to get magnetic abrasive particles after the sintering process. Conventional sintering process leads to oxidation of materials, low-density problem, and abrasive particles easily fall off during finishing. In order to reduce the problems associated with un-bonded magnetic particles, the gel or oil is mixed with the un-bonded magnetic abrasive particle which is called loosely bonded magnetic abrasives. The particle has been selected from a range of 80 microns to 120 microns for iron powder particles whereas the size of the abrasive particle was in the range of 40 microns to 60 microns. Before the compaction of powders, it was thoroughly mixed along with PVA for 30 minutes in blending machine. The rate of heating, sintering temperature, binders & holding time are the crucial factors in processing as after sintering, the billets will be broken into fine powders by mechanical methods. Better the bonding, the lifetime of abrasive media will be better. Comparing un-

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bonded and bonded magnetic abrasive particles, bonded magnetic abrasive particles have both durability and enhanced working life. According to size & mass ratio, the size of the Fe particles should be 2.5 times of the abrasives. If the mass ratio is too low, Fe particle cannot hold the abrasive particles during the finishing process. The ratio of magnetic material & abrasive should not be less than 60:40. If the size ratio is too high, then finishing process will not take place by magnetic abrasive particles instead it will simply rotate in the magnetic field. For the experiment, iron & abrasive material ratio kept between 70:30 shown in table 1. The alloying elements are usually added in the powder metallurgy process for improvement in the bonding between two different powder materials. Copper improves adherence between Fe particles and abrasive. The copper usage is about 3% to 5%. A small percentage of the Tin & Titanium added to get required surface tension & angle of contact. Fine hard abrasive particles such as SiC, diamond, etc are not free flowing or have poor flowability and very difficult to press [6]. In order to overcome these challenges, the binders are used during blending and it helps in improving compaction of powder. In this experiment, Polyvinyl Alcohol used as the binder, (Table 1), mixing of large size and small size particles with different density is very difficult compared with the mixing two different types of particles with the similar size and density. As to avoid the agglomeration and aggregation during mixing, we required shear action in the mixture. The compaction time is also optimized only through experiments. Diamonds powders are not stable at higher temperatures and will undergo graphitization resulting in weaken of bond with iron particles & get separated. Some alloying materials like Ti for the improved angle of contact, Sn for improved surface tension and Cu for better packing density are added during sintering to achieve better bonding strength From the experiment, we conclude that 800-850Mpa gives required strength to the pellets.

Hydraulic Press Specification (fig.3):
Maximum capacity: 15 ton
The diameter of the press: 15mm.

The blending of iron & diamond powder has been done in proportional amount. The variation of time is between 20 minutes to 60 minutes based on the abrasive powder volume and magnetic materials. The samples were mixed in the ratio of 70:30 and alloying elements i.e. Tin & Titanium added from a range of 0.5% to 2%. The samples were compacted by the compaction machine shown in above fig.3 & sintered in tubular vacuum furnace on the design of experiment basis. After sintering, samples were broken into fine powders for sieving for uniformity in magnetic abrasive powders. Sintered billets showed different strength after sintering depending on their alloying composition. The compacted magnetic abrasive materials were given soaking for 10 hours at 500°C at a rate of 5°C per minute. After soaking, billets were sintered in the argon atmosphere at 1050°C & furnace cooled to room temperature [7, 8].

Fig.3 Hydraulic Press

Fig.4 Sintered Billets

Fig.5 Sintered Abrasive

Table 1 Optimized parameters for powder blending

Abrasive	Diamond powder(22µm)
Iron Particle size	85µm
Binder	PVA,
MAP Mixture	70:30
% of Binder	5%,

3. RESULTS

After the sintering process, the different types of magnetic abrasive particles were characterized using SEM. The SEM image provides the detailed understanding about the distribution of abrasives in magnetic particles and shows the bonding between magnetic particles and abrasive in magnetic abrasive process. SiC & Al_2O_3 abrasives powders were also sintered with same parameters (Table 1) as the diamond powders for study purpose. The cylindrical rod has been finished & tested (Table 1). The SiC particles are completely bonded between Fe particles. There is no segregation of SiC particles (fig.6) & it's uniformly distributed. Similarly, abrasive Al_2O_3 (fig.7) also bonded with iron uniformly. In Comparison of abrasive SiC & Al_2O_3 with diamond powder, diamond powder always has edge over these two abrasive. It takes lesser time in finishing the component & final value of surface roughness (Ra**)** of finished components are 0.100 µm(Table3).The diamond powder abrasive billets are not strong & became fine powders in short time. Titanium & Tin (Table 3) were added to give good strength at the time of finishing & to prevent graphitization at the time of sintering.

Magnetic Abrasive media using SiC

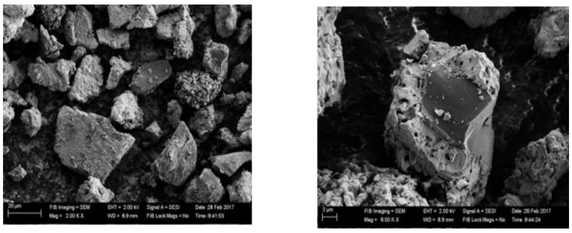

Fig.6 Fe and SiC Sintered SEM Images.

Magnetic Abrasive media using Al_2O_3

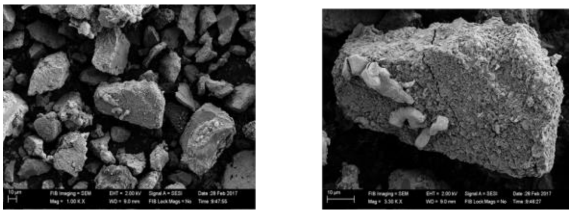

Fig.7 Fe and Al_2O_3 Sintered SEM Images

Magnetic Abrasive media using Diamond

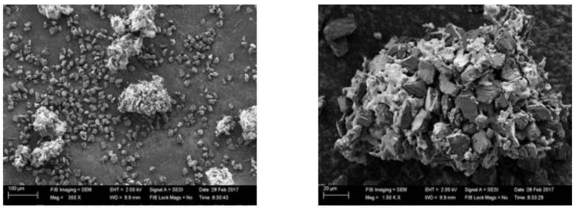

Fig.8. Fe and Diamond Sintered SEM Images

Figure 9 Super Finished Cylindrical Rod.

4. EXPERIMENTAL WORK

The initial Ra value of the workpieces was observed as 0.21 µm. After the Magnetic abrasive finishing process, the Ra value of workpieces was checked by surface roughness tester (Table 2). The final Ra value of the workpieces is given below.

Table 2 Experimental Work Details

Material	Stainless Steel 304
Sample Size	100mm*40mm*7mm
Machine	Vertical Machining Centre (HMT VTC 800)
Flux Measurement	Magsys Gaussmeter
Viscosity Measurement	Brookfield Viscometer
Surface Profilometer	Veeco (Wyko NT 9100)
Surface Roughness Tester	Taylor Hobson (Talysurf Series 2)

Table 3 Experimental Results

Sample No	Abr %	Ti %	Sn %	Initial Ra(µm)	Final Ra (µm)	Change in Ra (µm)
1	30	0.5	1	0.2	0.088	0.113
2	30	1	2	0.2	0.168	0.032
3	30	2	3	0.2	0.114	0.086
4	25	0.5	2	0.2	0.137	0.063
5	25	1	3	0.2	0.17	0.03
6	25	2	1	0.2	0.075	0.125
7	20	0.5	3	0.2	0.127	0.073
8	20	1	1	0.2	0.098	0.102
9	20	2	2	0.2	0.106	0.094

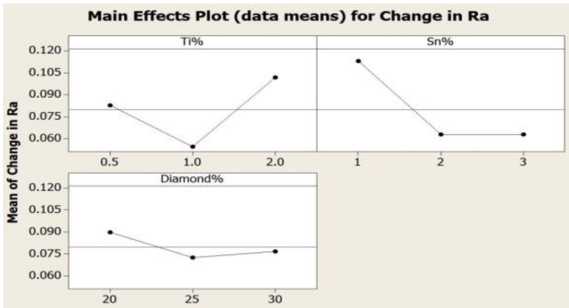

Fig.10 Main effect plots

From the main effect plot, it is observed that Titanium at 2% and Tin at 1% has more influence in the change in Ra value. The percentage difference in diamond does not affect the Ra value significantly.

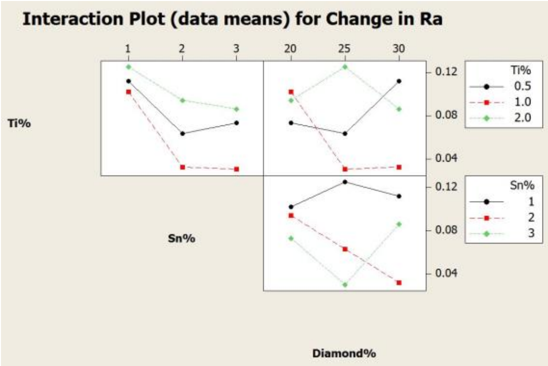

Fig.11 Interaction plot

From the interaction plot (fig.11), it shows that Titanium-Diamond & Tin-Diamond has more interaction whereas Titanium-Tin has least interaction. It shows that titanium and tin are independent factors.

5. ANOVA

The analysis of variance for change in surface roughness (R_a) has been depicted in table 4

Table 4 ANOVA Results

Source	DF	Seq SS (10^{-3})	Adj SS (10^{-3})	Adj MS (10^{-3})	F	P
Ti	2	3.35	3.35	1.68	43	0.023
Sn	2	5.00	5.00	2.50	64.1	0.015
Diamond	2	0.470	0.470	0.237	6.08	0.141
Error	2	0.078	0.078	0.039		
Total	8	8.91				

From the ANOVA analysis, considering P factor Tin has much significance and Titanium has the least significance in the experiment.

6. CONCLUSION

Development of magnetic abrasive media i.e. iron & diamond powder for magnetic abrasive finishing process has been carried out & optimized. The result involved the optimized ratio of magnetic particles and abrasives, mixing time, sintering parameters to achieve good bonding strength. The SEM images of abrasive after sintering have been done to compare bonding strength results to evaluate the media. The process can finish the job with surface finishes (R_a) less than 0.100 µm. The amount of tin at 1% has high significance. By using DOE, magnetic abrasive media prepared from diamond powder & iron by varying mass ratio, the percentage of Titanium and Tin. Process parameters like amount of binder, mixing time, pre-sintering temperature, sintering temperature, sintering duration and sintering atmosphere were kept constant for all nine experiments.

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