PARAMETRIC EVALUATION OF CYLINDRICAL MAGNETIC ABRASIVE FINISHING PROCESS

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Abstract. *On this paper, a study is done to evaluate the dependency of work parameters on the final results of cylindrical Magnetic Abrasive Finishing (MAF) process. MAF is a relatively new finishing process, with related studies carried on several research centers around the world. In this manufacturing process, a cylindrical workpiece (ABNT 1045 steel) is machined by a magnetic brush, which is a mixture of magnetic (iron) an abrasive (aluminum oxide) powder, and structured by the action of a magnetic field. The studied parameters were the workpiece rotation speed, processing time, and the grain size of both magnetic and abrasive powder. Project of experiments were used to improve the quantity of results, and variance analysis showed rotation speed, processing time and abrasive powder grain size to have a significant influence on the variation of surface roughness. It wasn't found statistically relevant influence of magnetic powder grain size on the roughness of processed parts. Through the experiments carried on, it was evident the efficiency of magnetic abrasive finishing, since previously machined workpieces were able to reduce surface roughness from 2,5 μm* Ra *to 0,7 μm* Ra.
Keywords*: magnetic abrasive finishing; polishing process; magnetic abrasive brush; magnetic abrasive powder; Surface finish.*

1. INTRODUCTION

A relatively recent manufacturing process, magnetic abrasive finishing (also known as magnetic abrasive process), has been formerly described on a 1938 patent, on the name of Harry P. Coats. It consists on an abrasive process, with undefined geometry and form, and is able to efficiently achieve surface quality of the order of few nanometers on flat surfaces as well as internal and external surfaces of tube type workpieces (Jain et. al., 2001). It is also applicable on burr removal and to correct geometric errors.

It is more efficient, and produces better surface finish than traditional machining processes, such as grinding, burnishing, sanding and polishing (Kremen et. al, 1994). However, it has poor representation on the industry, with its application mostly restrained to research.

On this process, the tool part is played by a flexible magnetic brush (FMaB), formed by a magnetic abrasive powder (MAP), whose form is sustained through the action of a magnetic field. This way, the tool acquire the shape of the workpiece, with the advantage of being self sharpening, thus dispensing complementary process such as dressing.

There are two main geometric variations of MAF, whose are cylindrical and plane magnetic abrasive finishing. The cylindrical MAF can be internal or external.

On internal cylindrical magnetic abrasive finishing, the workpiece, under rotation, is kept between two magnetic poles, and machined by the flexible magnetic brush, which is sustained on the air gaps by a magnetic field, generated by an electromagnet (Fig. 1).

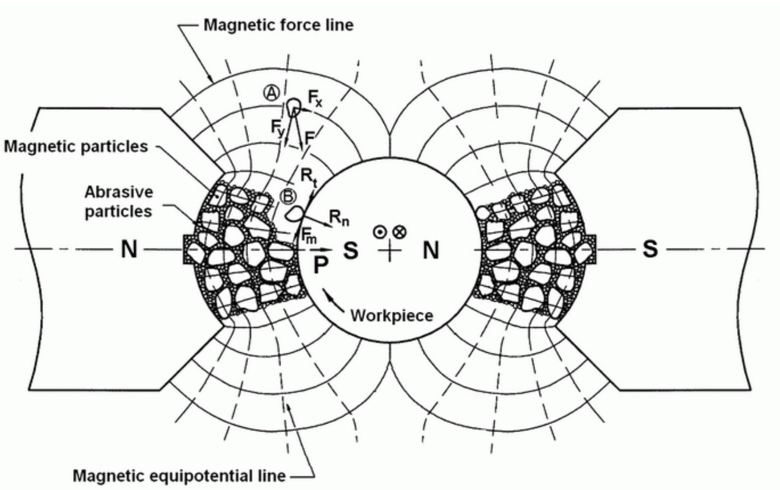


Figure 1. Cylindrical magnetic abrasive finishing.

The main process parameters are the magnetic flux density *B*, controlled by the input current on the magnet, the air gaps between magnetic poles and workpiece, cutting speed, grain size of magnetic and abrasive particles, processing time and the existence or not of mechanical vibrations.

Several studies has been done concerning the influence of the process parameters on magnetic abrasive finishing results. Jain et. al, 2001, has evaluated the effect of the working gap and circumferential speed on material removal and improvement on surface finish, showing that the highest the speed and smaller the working gaps, better the surface finish. Exceptions were found for working gaps smaller than 0.5 mm, due to the restrained space, that compromises abrasive renovation. The effect of circumferential speed is related to the longer distance traveled by each abrasive particle on the workpiece surface on the same time. However, the results shown that a saturation point occurs at high speeds, attributed by the authors to the accelerated wear of abrasive powder.

Several authors had studied MAP characteristics. Shinmura et al., 1987, concluded that finer grain sizes (magnetic and abrasive), allow better surface finishes, and larger magnetic grains cause higher material removal rates. On the other hand, Chang et al., 2002, studied different magnetic abrasive powders, focusing on grain size of magnetic and abrasive particles and on the magnetic material, and found that larger magnetic powder particles allow not only high material removal, but also better surface finish. The authors also compare the use of iron grit and steel grit as magnetic powder, and found better surface finish and higher material removal for the MAP with addition of steel.

The fact that each author carries out his experiments on home-made equipments, and with different parameters, summed with the multidisciplinary profile of MAF process and the limited knowledge on the field facilitates discrepancies between different papers. This work inserts itself on the necessity of a wider study, considering not only the most reviewed parameters, but the possible interactions between them.

2. EXPERIMENTAL PROCEDURE

The experiments were carried out with the equipment developed by Leonhart and Amorim, 2004, on the Machining and Automation Laboratory of the federal university of Rio Grande do Sul (Fig. 2). The equipment consists on an electromagnet, adapted to a mechanical lathe, and supplied by a DC power supply.

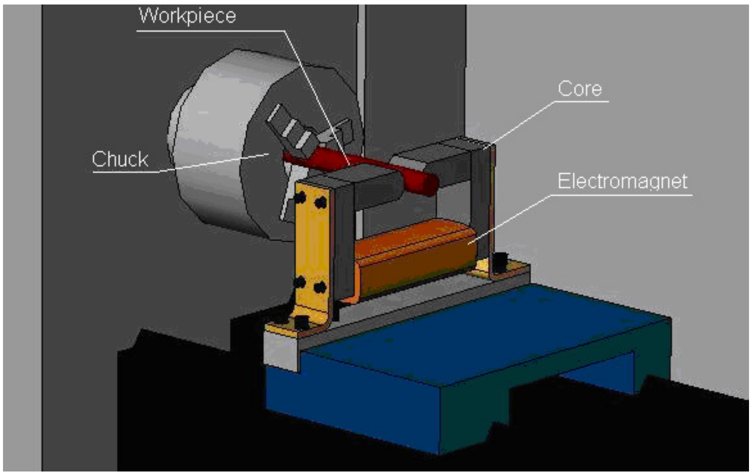


Figure 2. Experimental apparatus.

Tests were done with ABNT 1045 rolled bar steel, and the parameters tested were iron and aluminum powder grain size, rotation of the workpiece and processing time. Each tested body was processed for thirty minutes, with periodic pauses for measuring of the surface roughness and replacement of magnetic abrasive powder (this replacement has to be done, in order to clean up the components for roughness measuring). Table 1 shows the fixed test conditions.

Table 1. Fixed parameters adopted on the tests.

Parameter	Value
Tension (V)	12V
Current (i)	2.85A
Fe/Al_2O_3 proportion	4:1
Working gap	1 mm
Vibration	NO

The adopted experimental conditions aims to study the combined effect of grain sizes of magnetic and abrasive particles, workpiece rotation speed and processing time on the surface finish of processed components. The MAP developed consists on a loosely bounded combination of iron and aluminum oxide, on 4:1 mass proportion, with addition of lubricating oil, to achieve the bounding and improve the particles cohesion. Two different grain sizes of aluminum oxide (#200 and #400 – 0,074 and 0,037 mm, respectively) and tree of iron grit were used, (#60, #48 and #28 – 0,250, 0,360 and 0,710 mm). Tests were done at 400 and 800 RPM. Table 2 shows the studied conditions. Factorial design of experiments was used, in order to improve the quality of obtained data.

Table 2. Tested parameters.

Iron grit average particle size	#60 (0,250mm); #48 (0,360 mm); #28 (0,710mm)
Al_2O_3 powder grain size	+ 200 # (0,074mm); + 400 # (0,037mm)
Rotation	400 RPM; 800 RPM
Cutting speed	0,54 m/s; 1,08 m/s
Total time	30 min
Measuring interval	5 min
Working gap	1 mm
Tested material	ABNT 1045 steel
$Fe:Al_2O_3$	4:1
Lubricant	SAE 20W40 oil
MAP weight	10,5 g

The tested bodies of had diameter of 26 mm, and equal total length of 80 mm. The process was applied on a length of 40 mm from the right extremity of the part, in a way that portion of the workpiece rests not finished, for visual comparison. As the initial condition of the workpieces was turned, it was not possible to guarantee the same initial state of surface finish for all of them. So, several results are better represented on terms of surface finishing improve (ΔRa) or percent improvement on surface finish.

3. RESULTS

There were studied the effects of process parameters on surface finish (Ra) and the change of surface finish (ΔRa). The ΔRa value is defined as the difference between surface finish values before and after magnetic abrasive finishing. Thus, a positive value of ΔRa means that the surface finishing has become better, while a negative value shows its deterioration.

Anova results for ΔRa (Table 3) showed high significance for the effects of processing time (factor A), aluminum oxide grain size (factor B) and workpiece rotation (factor C), while iron grit grain size (factor D) were found to be no significant at α=0,05. These results agree whit the study carried out by Amorim et al., 2006, for short time application of MAF.

Table 3. ANOVA results for ΔRa.

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Squares**	**F**	**F_{cr}**	**Significant?**
SQA	24,31	5	4,86	57,19	2,28	**YES**
SQB	0,42	1	0,42	4,95	3,92	**YES**
SQC	0,42	1	0,42	4,99	3,92	**YES**
SQD	0,06	2	0,03	0,37	3,07	**NO**
SQAB	1,37	5	0,27	3,23	2,28	**YES**
SQAC	2,27	5	0,45	5,33	2,28	**YES**
SQAD	0,59	10	0,06	0,69	1,91	**NO**
SQBC	0,13	1	0,13	1,51	3,92	**NO**
SQBD	0,02	2	0,01	0,12	3,07	**NO**
SQCD	0,67	2	0,33	3,94	3,07	**YES**
SQABC	0,39	5	0,08	0,92	2,28	**NO**
SQABD	0,82	10	0,08	0,97	1,91	**NO**
SQ ACD	2,98	10	0,30	3,51	1,91	**YES**
SQ BCD	0,21	2	0,10	1,23	3,07	**NO**
SQ ABCD	1,49	10	0,15	1,76	1,91	**NO**
Error	12,24	144	0,09			
Total	48,40	215				

The significant interactions that were found have shown the complex nature of the magnetic abrasive finishing process. Despite the fact of iron grit grain size is not statistically significant at the confidence interval studied, a significant difference was found for the #28 average grain size (called Fe_3). This larger particle has permitted to obtain greater surface finishing than the others. This agrees with results found by Chang et. al., 2002. Figure 3 shows the results of Ra as a function of workpiece rotation for different magnetic particles grain size. The finer magnetic powder is named Fe_1, while Fe_3 is the largest particle.

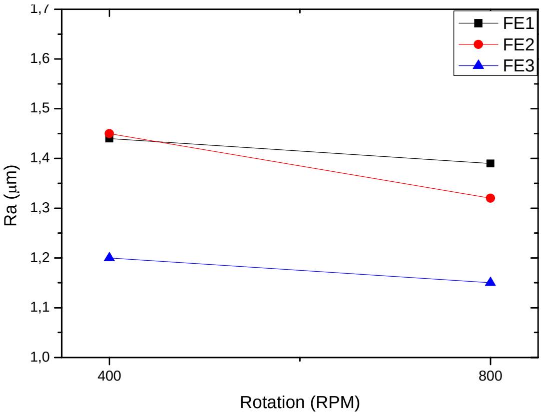
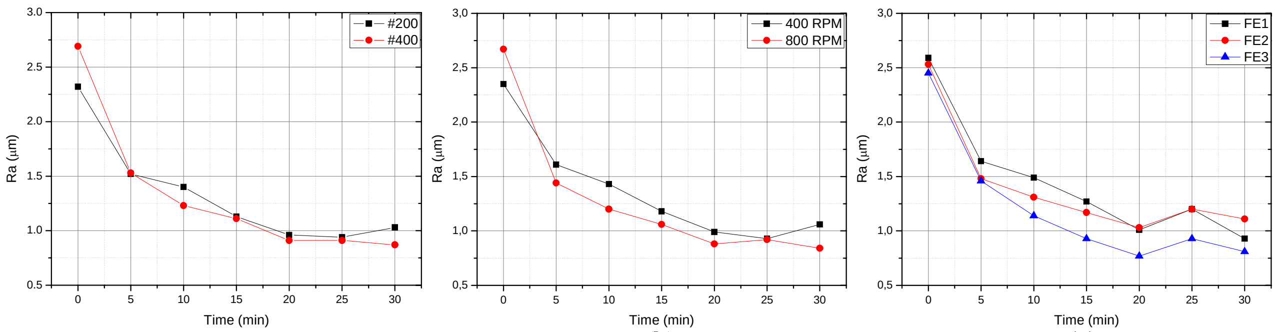


Figure 3. Results of surface roughness as a function of workpiece rotation for different iron grit grain sizes.

Figure 4 shows the results of surface roughness as a function of processing time. As seen on Table 2, processing time has strong influence over obtained surface roughness. However, its influence tends to weaken with processing time. Therefore, as shown on Fig. 4 a-c, strongest effect is verified on the first time interval. As a matter of fact, the average changes on surface roughness on the first five minutes of magnetic abrasive finishing were superior of the finishing obtained from five to thirty minutes. Also, results showed that a saturation point, from what there is few or none surface quality gain, happens when processing time reaches twenty minutes. From this point on, there is even deterioration of the surface finishing.



(a) (b) (c)

Figure 4. Results of surface roughness as a function of processing time.

Figure 4 (a) shows the effect of time for different aluminum oxide grain sizes. It is found that finer particles allow the attainment of better surface finishing, what agree with results found by several authors (Chang et al., 2002; Umehara & Komanduri, 1996; Yamaguchi & Shinmura, 2003). This happens because of finer particles tend to generate smaller indentations on the surface, thus resulting on smaller surface roughness. On Figure 4 (b), results for different workpiece rotations showed better results for higher rotation, what agree with results found by Jain et al., 2001, who suggest that it only happens because, at higher cutting speeds, the same abrasive particle covers a greater distance over the workpiece. On Figure 4 (c), there is observed similar behavior for tests done for different iron grit sizes, except for FE3 (#28), what confirms results showed on Fig. 3.

Except for the iron grit particle size, each one of the studied effects was found to be statistically signifficant at the desired confidence interval (α=0,05). That means that a change in any of these parameters will affect the resulting surface finishing. Figure 5 (a) presents the results of surface roughness as a function of aluminum oxide grain size, for both rotation speeds, and makes clear the superiority of higher rotation speeds. Figure 5 (b) shows the results of surface roughness variation (ΔRa) as a function of aluminum oxide grain size. It clarifies the positive influence of both a finer grain size and higher rotaton speed on surface finish. Significant interactions were found between effects A and B (time-Al_2O_3 grain size), A and C (time-rotation speed) and C and D (rotation speed and iron grit grain size), and third order interaction between ACD.

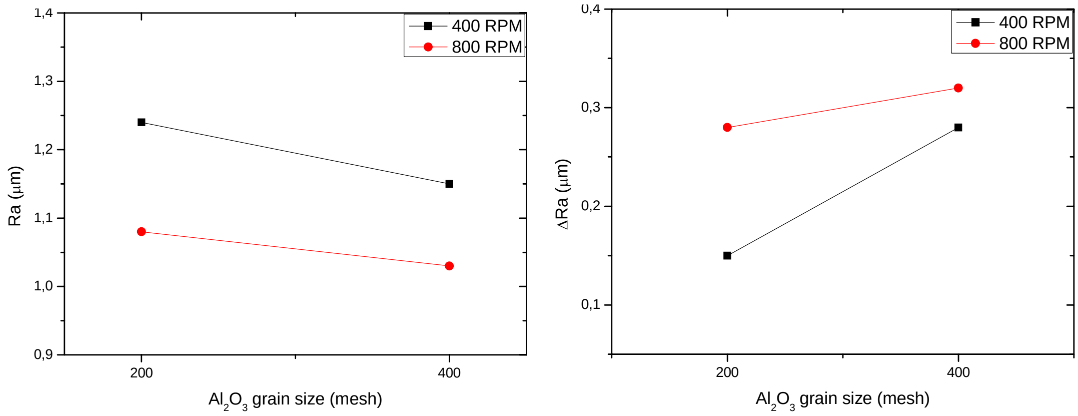


Figure 5. Results of (a) surface roughness and (b) surface roughness variation as a function of Al_2O_3 grain size.

Figure 6 presents the results of both surface roughness (a) and its variation (b) as a function of rotation speed for both abrasive grain sizes, and shows better results for both finer Al_2O_3 particle and higher cutting speed.

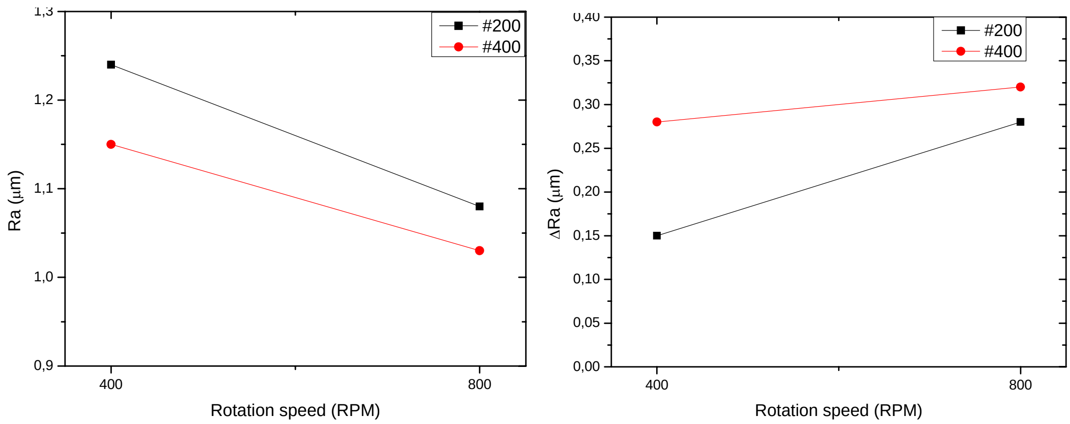


Figure 6. Results of (a) surface roughness and (b) surface roughness variation as a function rotation speed.

4. CONCLUSIONS

Through analysis of the obtained results, it is possible to conclude:

- Processing time is the most effective parameter for magnetic abrasive finishing. However, its influence tends to weaken on direction of saturation. After this saturation point, surface finish can even present deterioration.
- Other effective parameters are abrasive grain size and rotation speed. Both higher rotation speed and smaller abrasive grain size allowed the obtaining of smaller surface roughness.
- Despite of the non-significant result shown by ANOVA test, magnetic gain size had shown statistically significant difference for the largest particle size (#28, or 0.710mm average diameter). Tests carried out with magnetic abrasive powder containing this magnetic particle showed better surface finish than the others.
- Even on the absence of excited vibrations, magnetic abrasive finishing is an effective tool for obtaining high surface finishing.

5. REFERENCES

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