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SURFACE ROUGHNESS ON METAL POWDER INJECTION MOULDING AISI 316L STAINLESS STEEL BY ABRASIVE BELT GRINDING

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ABSTRACT

Grinding removes surface material to improve the surface by sandpaper to give a specific or desired roughness behind the grinding. The ultra-precision turning may enhance the surface roughness of the workpiece to Ra 10 nm, but the cost of this turning process is higher than the one of the traditional grinding and polishing processes. The wear devices such as the iwatch of Apple and Galaxy Gear of Sumsung use the stainless steel cases to increase the luster and the noble sense. The metal powder injection molding is therefore applied to fabricate the stainless steel cases in mass production. The grinding is essential for these MIM stainless steel cases to minimize the surface roughness and then eliminate the voids on the surface which are lead during the sintering of MIM. The mechanism of the abrasive machining includes the sliding, plowing and cutting while the previous two are preferred during grinding. By abrasive belts from #800 , #1200 and #2000, the MIM stainless steel cases are polished. The control factors of tangential velocity of abrasive belt, normal force acting on the workpiece, grinding time and the abrasive grit number varied under Taguchi method to derive the suitable parameters for minimizing surface roughness of workpiece. The surface roughnesss of the MIM stainless steel cases are measured by the surface stylus and the white light interferometers. The morphologies of the workpieces are examined by the SEM. By the Taguchi experimental design of three levels and four factors in $(3)^8$, results show that the morphologies of workpieces indicate the voids of the MIM parts are covered thanks to the mechanism of plowing gives the plastic flow while the individual abrasive acting on the workpiece exceeds to the yielding strength. Etching of the workpiece may reveal the voids under the polished surface. Experimental results further indicate that the lowest surface roughness in grinding by abrasive belts is Ra 97 nm and show this grinding process is perfect to derive the semi-bright surface for the MIM stainless steel.

Keywords: ***Surface Roughness, Belt Grinding, Stainless Steel, Metal Powder Injection Molding***

1. INTRODUCTION

Belt grinding is a general machining process where the workpiece is pushed with a defined force against the running abrasive belt. The traditional abrasive belt consists of three main components:the polyester backing, the abrasive grits (Al_2O_3 or SiC) and the resin bond. The the size of the abrasive grits is usually between 9μm and 100 μm with granularities of 320, 600 and 800 of abrasive belts. Differing from the grinding which gives high temperature associated with the thermal damages to the sub-surface, leading to micro-cracks and residual stresses, the belt grinding process is an effective one to remove the materials from the workpiece with complex form[1].

Metal powder injection molding (MIM) allows designers to construct various net-shape from metals. This technology is good for mass production, and thus resulting in a high cost-effectiveness. AISI 316L, one of the austenitic stainless steel, is chosen to fabricate the metal case of the jewellery due to the highest corrosion resistance and mechanical properties for versatile applications. The sintered MIM workpieces are rough of about Ra 3 μm without surface finishing. To enhance the luster of the AISI 316L, the surfaces of the MIM parts may be polished [2]. The grinding process is thus essental for the previous metal case of jewellery to derive a suitable surface for lowering surface roughness. However, before polishing the belt grinding is an essential process

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for the sintered AISI 316L workpiece to lower the surface roughness.

Since the complex shape of the workpiece is sintered by MIM process, the abrasive belt associated with the rubber roller is therefore used to polish the previous workpiece. The elastic foundation of these abrasive and rubber roller gives diversity of grinding. However, the integrity of the MIM parts may affected by the porous within the parts and the mechanical properties. In this paper, the grindability of AISI 316L stainless steel in relation to grinding systems is normally tested on flat specimens using the predefined abrasive numbers of abrasive belts, a defined tangential velocity, a defined grinding time and a predefined grinding load.

In this study, grinding experiments have been performed to study the formation of surface roughness of AISI 316L workpiece by abrasive belt, mutual relationships between surface roughness and parameters during grinding. By the Taguchi experimental design of three levels and four factors in $(3)^8$, the goal of the present study is to evaluate four factors of three different level with regard to the following aspects: (1) the influence of the press-on force on the integrity of grinding results, (2) the influence of the grinding time on the surface roughness of AISI 316L stainless steels. (3) to compare of these results with the results of optimally polished specimens.

2. EXPERIMENTAL SETUP

The abrasive belt polisher of Kingkong as shown in Figure1 with inverter used in the experiments for the MIM AISI 316L workpieces, the workpiece is shown in Figure 2. To conduct the experiments the workpieces are original from the sintered process of 30 mm in length, 18 mm in width and 2mm in thickness. A piezoelectric transducer based dynamometer of type Kistler 9257B associated with the amplification is used to measure the grinding forces. The abrasive belts as Figure 3 with granularities of 800, 1200 and 2000 act on the MIM parts to process the grinding. The non-contact 3D surface roughness measurements are conducted with the Chroma 7503 3D Optical Profiler which Uses white light interference measurement technique to do nondestructive and rapid surface texture measurement and analysis. The height resolution for measurement of the Chroma 7503 3D Optical Profiler is up to 0.1 nm.

Figure 1 Kingkong abrasive belt grinder

Figure 2 AISI 316L MIM workpiece

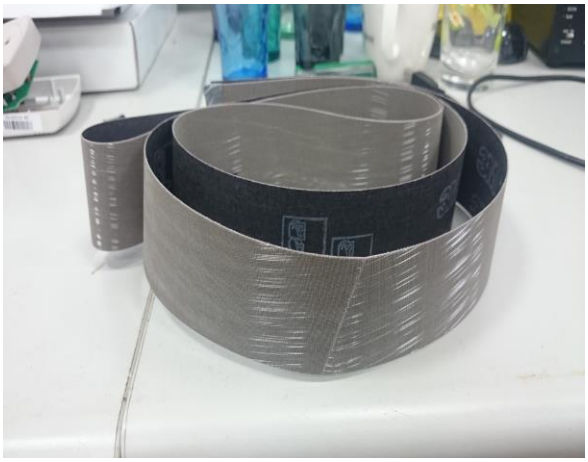

Figure 3 abrasive belt

Surface roughness of grinding is as a function of press-on force. The surfaces of the workpieces are roughened using a grinding device with a rotation speed of 1200 , 1600 and 2000 r/min under the press-on force of approximately 5, 10 and 20 N and

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#800 , #1200 and #2000 grit abrasive belts. The fixture is used to mount and fix the MIM workpiece with a constant force. The grinding fixture is placed on the workpiece in a vertical direction and force is exerted against the incoming air pressure and kept at a constant level over a distance of 10 millimeter , verified by the lower and upper positions of the specimen holder. The surface roughness is only measured before and after all three grinding steps were completed. Surface roughness after grinding is as a function of grinding time. The mean surface roughness is measured at intervals of 1 s until a grinding time of up to 7 s was achieved. Ra (arithmetical mean of the profile deviations from the center line Z mean roughness), R_t (total height of profile Z vertical distance from the deepest valley to the highest peak of the roughness profile)

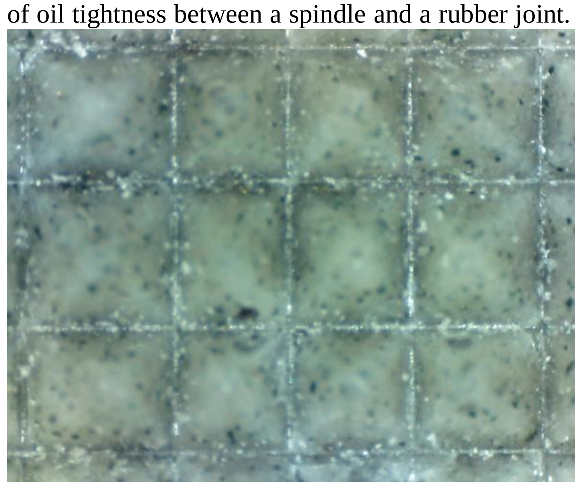
Table 1 L9(3^4) experimental plan

Factors \ Levels	Level 1	Level 2	Level 3
(A)abrasive belt (#)	#800	#1200	#2000
(B) time(sec)	3	5	7
(C) normal force(N)	5	10	20
(D) rotation speed(rpm)	1200	1600	2000

Some parameters for grinding process, having significant effects on surface roughness, were investigated using Taguchi's method. The *L*9 orthogonal array was selected to conduct the matrix experiment to determine the optimal grinding process parameters as shown in Table 1. Engineering design problems can be divided into the smaller-the-better type, the nominal-the-best type, the larger-the-better type and the signed-target type [3]. The signal-to-noise (S/N) ratio is used as the objective function for optimizing a product or process design. The surface roughness value of the ground surface via adequate combination of grinding parameters should be smaller than that of the original surface. Consequently, the grinding process is an example of a smaller-the-better type problem [3]. The repeatability and improvement are ideal once the predicted one is very close to the experimental result under the optimal conditions. As a result, there is no interaction between the factors. Five hypotheses have been formulated in this study: (1) The press-on force has an influence on the surface roughness in every material; (2) the grinding time has an influence on the surface roughness; (3) the endpoint of grinding is comparable to an optimally polished surface; (4) the metal matrix creates a smooth surface; (5) there is a close relationship between the mean surface roughness.

3. RESULTS AND DISSCUSSIONS

The belt grinding operation tends to improve the reliability of the quality of the cut surface roughness. The 3M abrasive belt [4] associated with the rubber roller is therefore used to polish the previous workpiece in order to deriving the luster surface. The elastic foundation of these abrasive and rubber roller gives diversity of polishing. However, the 3M™ Trizact™ structured abrasive are formed by the epoxy on the belt. The glass transition and degradation temperatures of epoxy are about 150 and 250 degrees, respectively. The epoxy may be worn under the polishing process thanks to the character of the higher specific machining energy in abrasive machining. A global analysis of the surface topography of the 3M abrasive belt (Figure 4) reveals that the belt grinding operation has completely deleted the helical surface topography. This new topography is of interest in some applications, such as problems of oil tightness between a spindle and a rubber joint.



(a) top view

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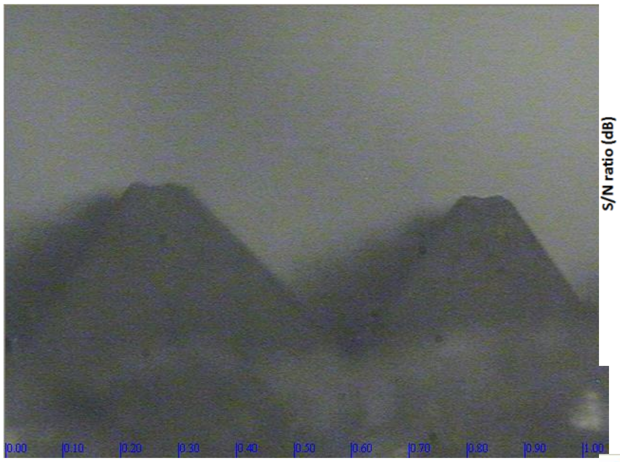

(b) side microscope view

Figure 4 3M abrasive belt of #800

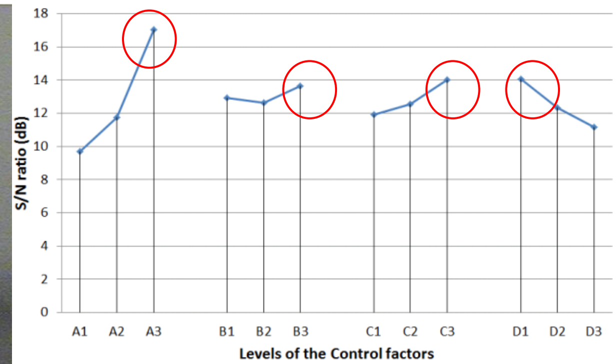

Figure 5 S/N ratio of L9 orthogonal table

Table 2 roughnesses of MIM workpieces by L9(3^4)

number	A	B	C	D	Measured Ra(μm)
1	1	1	1	1	0.31
2	1	2	2	2	0.40
3	1	3	3	3	0.28
4	2	1	2	3	0.29
5	2	2	3	1	0.22
6	2	3	1	2	0.28
7	3	1	3	2	0.13
8	3	2	1	3	0.19
9	3	3	2	1	0.12

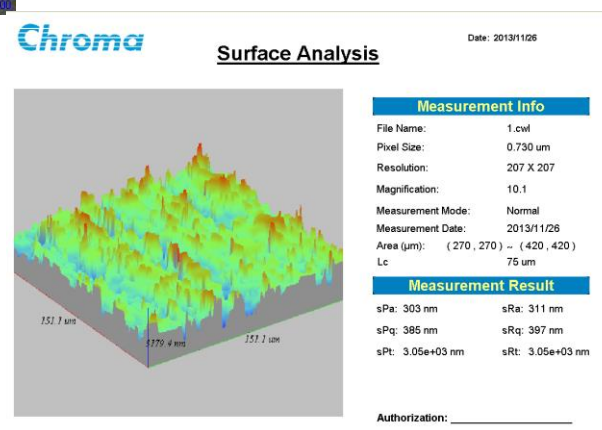

Figure 6(a) Ground surface of MIM AISI 316L workpiece of 1st experiment under L9

Table 3 S/N ratio of each factor levels and experimental verification in Ra under L9 (3^4)

factor	Level 1	Level 2	Level 3	Max-Min
A	9.696	11.741	**17.052**	7.356
B	12.947	12.630	**13.633**	0.685
C	11.937	12.536	**14.016**	2.079
D	**14.053**	12.328	11.153	1.724
Opt. levels: **A3,B3, C3,D1**	Predicted optimal S/N ratio: **20.324** Predicted optimal Ra: **0.097μm**	Experimental verification S/N ratio: **21.938 and 23.098** Ra: **0.08 and 0.07μm**		

The goal in the grinding process is to minimize the surface roughness value of the MIM workpiece by determining the optimal level of each factor. Since log is a monotone decreasing function, it implies that one should maximize the S/N ratio as Table2. Consequently, we can determine the optimal level for each factor as being the level that has the highest value. According to Figure 5, the combination of the optimal level for each factor is A3B3C3D1, in other words, A3 is #2000 grit, B3 is polished during 7 seconds, C3 is press-on force about 20 N. and D1 is 1200 rpm in rotational speed. As a result, the optimal parameters for grinding were as Table 2.

Two verification experiments were carried out to observe the repeatability of using the optimal combination of grinding parameters (Table 3). The surface roughness of 75 nanometers (nm) in *Ra* on average can be obtained based on the confirmation test results. It could then be confirmed that the combination of the level for each factor was the set of optimal parameters for the grinding of MIM

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AISI 316L workpiece. The predicted S/N ratio= 20.324 is very close to the experimental = 21.938 and 23.098 (Table 3) under the optimal grinding conditions. Accordingly, there is no interaction among the selected factors.

An observation of two surface roughness profiles (Figure 6a) shows a decrease in the magnitude of the marks and a great improvement in the Abbott Firestone curve which represents the material ratio of the profile as a function of level (Figure 6b). The integrities of the surface of MIM AISI 316L workpiece in grinding under L9 orthogonal matrix are shown in Figure 2. The results indicate that the Rt of the polished surfaces are 3.05 and 3.25μm by the abrasive belt of #800 grit. The average grit diameter is about 18.75μm. Increasing the normal press-on force may enhance the surface roughness in grinding which makes the hypothesis truly.

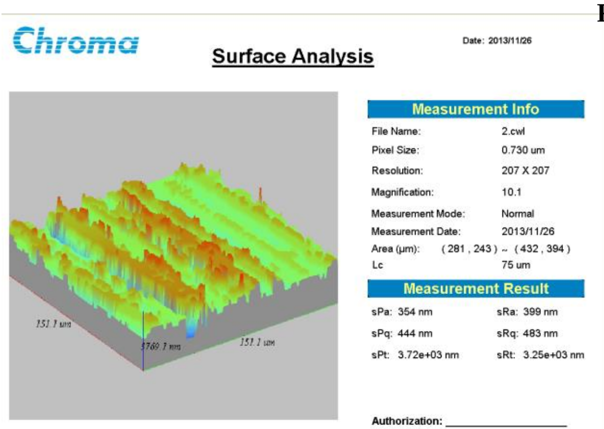

Figure 6(b) Ground surface of MIM AISI 316L workpiece of 2nd experiment under L9

4. CONCLUSIONS

Based on the Taguchi's *L9* matrix test results, the optimal grinding parameters for the test workpieces of MIM AISI 316L were derived and verified well in this study. The surface roughness *R*a of the verification workpieces can be improved from about 0.07 to 0.08 μm on average using the optimal grinding parameters based on the result of two verification tests. The higher press-on force even increased surface roughness. Besides, the surface roughness is time-dependent, showing the greatest improvement already after 7 s of grinding with each of the grinding components except for the amalgam. Grinding the surface with a grinding machine resulted in a significantly higher surface roughness in MIM 316L. By the Taguchi experimental design of three levels and four factors in $(3)^8$, results show that the morphologies of workpieces indicate the voids of the MIM parts are covered thanks to the mechanism of plowing gives the plastic flow while the individual abrasive acting on the workpiece exceeds to the yielding strength. Etching of the workpiece may reveal the voids under the polished surface. Experimental results further indicate that the lowest surface roughness in grinding by abrasive belts is Ra 97 nm and show this grinding process is perfect to derive the semi-bright surface for the MIM stainless steel.

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