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# Dimensional Analysis and Surface Characterisation of Ground Alumina Sintered Guide Pin

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## ABSTRACT

*Alumina ($Al_2O_3$) has been considered as satisfactory material used for ceramic guide pin in mechanical engineering applications owing to its excellent properties particularly high strength, good wear and corrosion resistance and extremely low thermal conductivity. However, there is still a major concern with regard to the manufacturing process of the ceramic guide pin, especially in controlling dimensional consistency after the sintering process, leading to part rejection. In this work, the manufacturing of alumina guide pin using powder processing is presented. The focus of this paper is to evaluate dimensional changes and surface analysis of the ground sintered guide pin using an upgraded grinding system. Alumina ceramic guide pin samples were fabricated by a Cold Isostatic Pressure (CIP) technique with four different ranges of diameters known as M6, M8, M10 and M12. All samples underwent sintering process at 1600°C, followed by secondary process by a micro-grinder to remove excessive diameter after sintering. Dimensional measurement was taken using a Vernier calliper, before and after the grinding process for evaluation. The surface roughness of the guide pin was then analysed by a surface roughness analyser followed by morphological analysis by scanning electron microscopy (SEM). From the result obtained, it clearly showed that, the proposed method of post-*

*processing using of micro-grinding has worked successfully in reducing numbers of part rejection by the company owing to the inconsistency of dimensional changes after the sintering process. Diameter reduction of about 20 – 50 µm was done for all guide pin models corresponded to the improved surface roughness of Ra, Ry and Rz by 1.3 to 2.0 µm, 8.5 to 11.0 µm and 5.0 to 7.0 µm, respectively. From the SEM analysis, better surface morphology was observed corresponded to surface roughness improvement.*

***Keyword***: *powder processing, cold isostatic press (CIP), sintering, sintered guide pin, micro-grinding*

## INTRODUCTION

Guide pin is one of the components used in applications that require consistency in the repetitive motion of moving parts within a mechanism. Alumina was introduced as a ceramic material for guide pin a long time ago due to its characteristics of hardness, good corrosion resistance, low thermal conductivity, and brittle [1]. Even though ceramic components can be shaped using different approaches such as slurry method, powder compaction and ceramic injection moulding, the selection of the manufacturing route strongly depends on the required strength, dimensional complexity, total volume production and cost of operation. One of the popular processing routes is the compaction of ceramic powder followed by sintering at extremely high temperatures, generally greater than 1500$^o$C. This method is known as the simplest process as very minimal, or no additional binder is required. In advanced ceramic powder compaction technology, whereas dimensional tolerance plays a vital role, pressure during compaction is the most important factor, since it influences the physical and mechanical properties of the compacted and sintered components [2]. Increasing the compaction pressure resulted in better densification of ceramic powder, leading to improved mechanical properties [2], as well as wear properties [3]. The sintering temperature of many ceramic components is generally conducted at a temperature range between 1500 and 1700$^o$C by referring to 70% to 80% of the materials melting point [4]. In some cases, cold-isostatic-press is also employed prior to the sintering process in order to improve the densification and surface roughness of the compacted powder [5]. One of the critical issues in the manufacturing of ceramic components is dimensional consistency, particularly after sintering to achieve the desired tolerance. The sintered parts generally shrink around 14% to 18% compared to the green stage [4]. This would be more difficult if the part's geometry is complex and consist of steep angle which may deteriorate the final part quality.

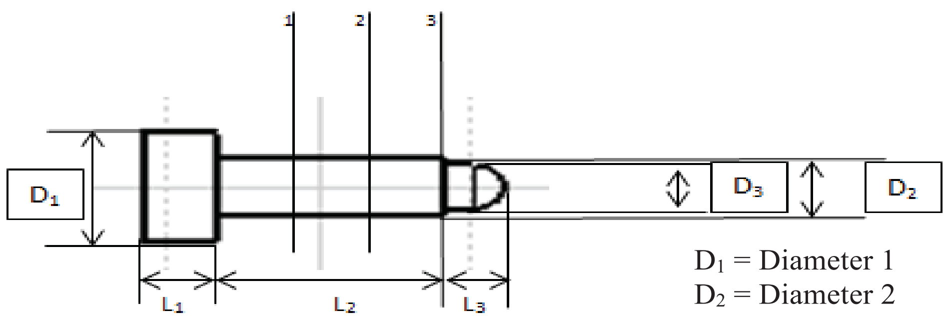
The main objective of the proposed work is to reduce the component rejection experienced by a ceramic manufacturing company, known as RS Advanced Technology (RSAT) Sdn. Bhd. Figure 1 shows some of the ceramic guide pin components manufactured by RSAT using the powder processing techniques. One of the critical issues faced by the company is to maintain the final dimension of the guide pin in accordance with the customer requirement. Sintered alumina guide pin should have dimensions within the acceptable tolerance after sintering at above 1600$^{o}$C. It was reported that annual parts rejection due to this issue was approximately 5%. Prior to the proposed post-processing by micro-grinding, the company had used a manual lathe machine to remove the excessive diameter, however, due to some difficulties particularly in parts' alignment and owing to the brittle nature of ceramic materials, failure had always occurred. To address this issue, a micro-grinding mechanism was successfully developed, funded by the Public Private Research Grant (PPRN). To study the effectiveness of the proposed mechanism, in the present work, the guide pin with different models were manufactured following the standard procedure by the company, comprising cold isostatic press (CIP), green machining and sintering processes. All samples were investigated for dimensional analysis according to the required dimensional tolerance as specified by the RSAT. Samples that did not meet the requirement underwent post-processing by micro-grinding for further investigation. Besides dimensional analysis, the surface quality of the guide pin was also carried out to justify the effectiveness of micro-grinding mechanism developed.


**Figure 1: Alumina Sintered Guide Pin Manufactured by RSAT Sdn. Bhd (Source: RS Advanced Technology SDN BHD)**

## METHODS AND MATERIALS

The samples used in this study were classified as rejected guide pin; components with excessive diameter after the sintering process. These components were fabricated by a powder processing technique with four different ranges of diameters known as M6, M8, M10 and M12. The dimension of the guide pin is shown schematically in Figure 2. The critical diameter is at D2 section, known as body guide pin which is required to align and pass through the supported hollow parts. Two grade of alumina powders with different composition tagged as P96 and P99 were used in the present work. The powder was initially compacted into an alumina cylinder by Cold Isostatic Press (CIP) at a pressure of 117.2 MPa. The alumina cylinder or blank was then machined manually into a specified guide pin using a lathe machine. The green guide pins were then sintered at a temperature of 1620°C for ten hours. Dimensional analysis was done for all samples, before and after sintering for comparison. Guide pins that were not in accordance with the specified dimensional tolerance underwent micro-grinding. The guide pin was positioned in straight condition to ensure the surface of the guide pin body to be ground uniformly as described in detail in [6].

Following the micro-grinding process, the surface roughness of the components was systematically analysed by a Mitutoyo Surface Roughness Profilometer with three parameters which are Arithmetical mean roughness (Ra), Maximum peak (Ry) and Ten-point mean roughness (Rz). Ra is a section of standard length, sampled from the mean line on the roughness chart. The mean line is laid on a cartesian coordinate system wherein the mean line runs in the direction of the x-axis and magnification is the y-axis. The value obtained with the formula on the right is expressed in micrometer. Ry is a section of standard length sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y-axis direction. Rz is a section of standard length sampled from the mean line on the roughness chart [7]. The distance between the peaks and valley of the sampled line is measured in the y-direction. Then, the average peak is obtained among the five tallest peaks as is the average valley between the five lowest valleys. For surface morphology, the surface of the ground samples was examined by a Scanning Electron Microscope (SEM), and the dimensional measurement was performed using a Vernier calliper.




$D_1$ = Diameter 1
$D_2$ = Diameter 2
$D_3$ = Diameter 3
$L_1$ = Length 1
$L_2$ = Length 2
$L_3$ = Length 3

**Figure 2: Dimensional Variation of Ceramic Guide Pin Manufactured by RSAT**

## RESULTS AND DISCUSSIONS

### Diameter of the Sintered Guide Pin

It is important to ensure that the diameter of the guide pin manufactured is within the acceptable range before they are delivered to the respective companies. Thus, a high tolerance reading is significantly required. Figure 3 shows the results of the average dimensional changes, before and after micro-grinding for five samples for each model of the guide pin. Besides, the graph also shows the acceptable range of diameter for every model. A total of three diameter readings of D2 as shown in Figure 2 were taken from the body of the guide pin and the average values were plotted in Figure 3. From the results obtained, it clearly shows that the excessive diameter of all the sintered components to the maximum allowable range was about 0.01 to 0.05 mm (10 – 50 µm). After the grinding process, approximately 20 to 50 µm of the excessive diameter was removed to attain the required dimension. It is shown that the new approach of micro-grinding process in the present work has improved the surface quality of the guide pin and resolved significantly the issues of previous technique by manual lathe machining such as surface chipping and over-machining. In addition, the number of rejected guide pin components has reduced markedly and improved the productivity of the company.

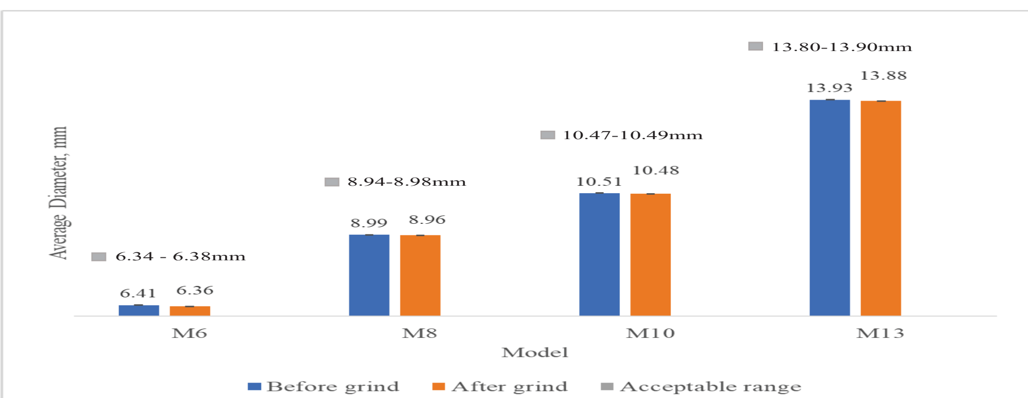



**Figure 3: Average Diameter of the Guide Pin, Before and After Micro-Grinding Process for (a) Model M6 (b) Model M8 (c) Model M10 (d) Model M13**

## Surface Roughness of Sintered Guide Pin

Surface roughness is one of the essential properties for assessing the workpiece quality of components being manufactured, depends upon its functional requirement. In the present work, the surface roughness of the sintered guide pin was done before and after the micro-grinding process for comparison. Owing to the nature of the guide pin to align a tool and die properly with the workpiece such as during stamping and spot welding, maintaining good quality is significantly important. Part with a better surface finish will reduce friction between two surfaces in contact, thus improving their service life. Figure 4 shows three significant parameters in surface roughness analysis for the four models of guide pin used. There is arithmetical mean roughness (Ra), maximum peak (Ry) and ten-point mean roughness (Rz).

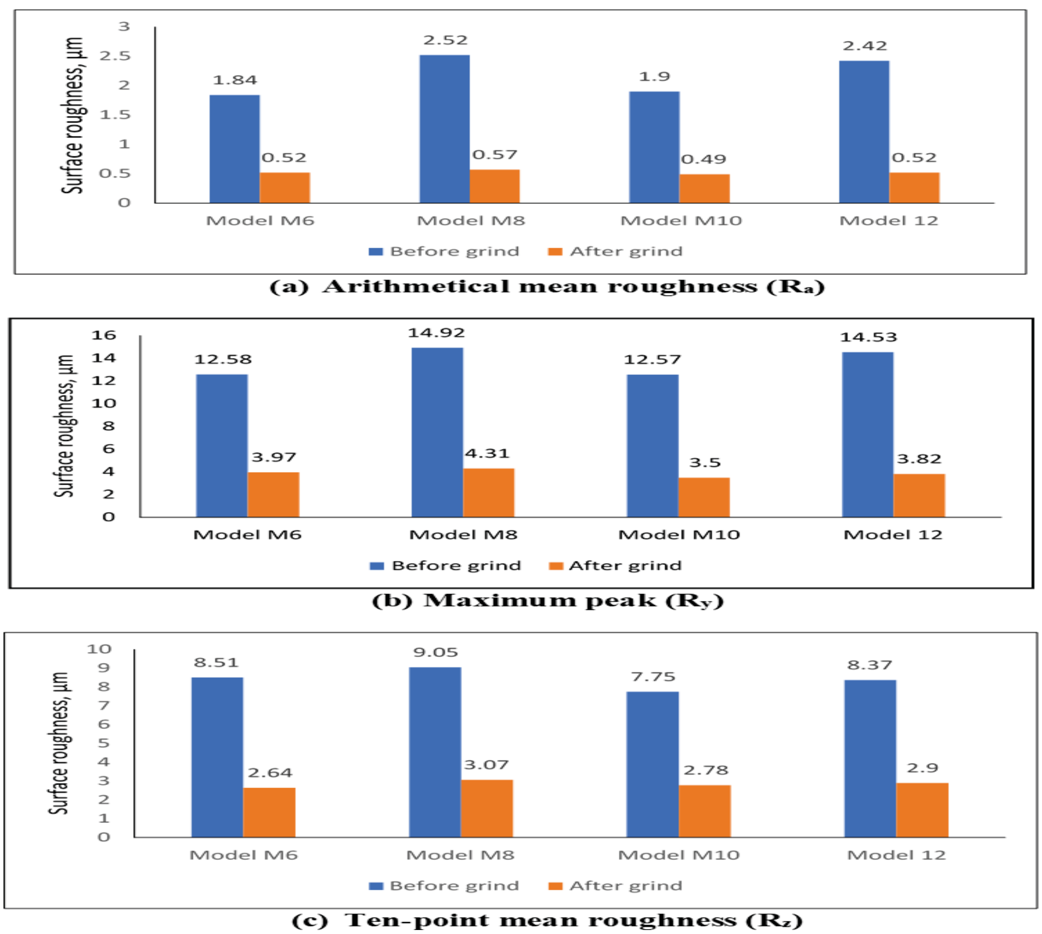



**Figure 4: Surface Roughness Parameters (a) Ra (b) Ry (c) Rz**

The value of Ra indicates the average of the absolute value along the sampling length. For all models of guide pin tested, the Ra values show a reduction in a range of 1.3 to 2.0 μm after micro-grinding process. Applying the grinding technique does not only fill the dimensional acceptance range, yet reduced the surface roughness value [8]. For the Ry, which was measured from a distance between the peaks and valleys of the sampled line in the y-direction, all models of guide pin show the maximum values between 12 to 15 μm before grinding. Model M8 guide pin exhibited the highest Ry value of nearly 15 μm before micro-grinding, which corresponded to the highest Ra. After micro-grinding, a reduction of about 10.6 μm was obtained, resulting in a final Ry value of 4.31 μm. In average, the reduction of Ry value for all models of guide pin was in a range of 8.5 to 11 μm. This aspect is crucial as a greater Ry indicates larger peak-valley distance, thus greater tendency of surface failure such as chipping can easily occur. Finally, the Rz which is defined as the average peak, obtained among the five tallest peaks and the average valley between the 5 lowest valleys. The average value of Rz before grinding was between 7.75 and 9.05 μm and after grinding, a total of between 5 and 7 μm was removed, resulting in final Rz values in the range of 2.64 to 3.07 μm. Similar to Ra and Ry, model M8 guide pin showed the highest value compared to other models. From the surface roughness point of view, it clearly shows that the level of surface roughness for each sample has improved significantly after the micro-grinding process, and no surface defects were observed during grinding. The same pattern of data collected from all models can also be observed, proving that the concept of grinding of sintered guide pin has promoted better surface finish in terms of surface roughness and surface crack that might happen in sintered guide pin can be minimised remarkably. Lisa et al., (2017) has stated that by decreasing surface roughness, the attractive Van der Walls force was increased because of the larger contact area caused by the peaks [9].

Figure 5 shows the image of the guide pins for model M8, (a) before and (b) after micro-grinding process, clearly smoother and shiny surface can be observed for guide pin (b), resulting from the improved surface roughness as discussed previously.

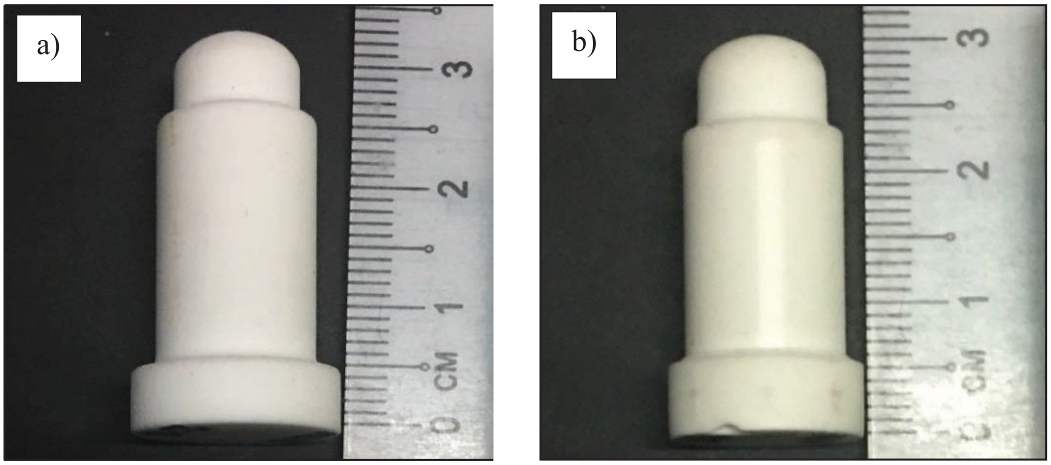
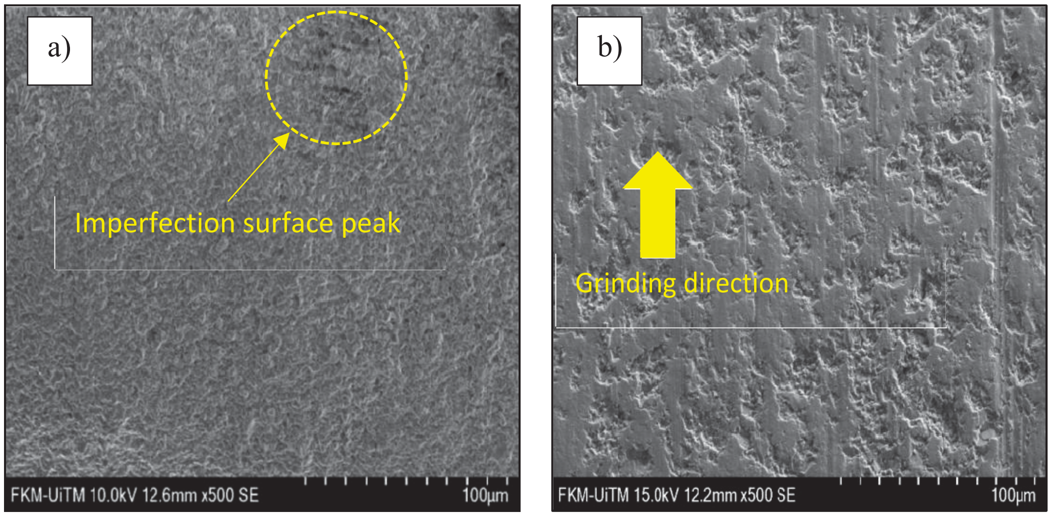



**Figure 5: Image of Model M8 Guide Pin a) Before Polishing b) After Polishing**

### Scanning Electron Microscope (SEM)

To get a clear picture of the morphology of the particular surface samples sintered guide pin, the Scanning Electron Microscopy (SEM) analysis was performed to evaluate the surface, before and after grinding process. Figure 6 shows the surface morphology for the model M8 guide pin sample (a) before and (b) after micro-grinding process at a magnification of 500x. Figure 6 (a) clearly shows the bonding of the alumina particle as a result of the sintering process. No porosities were observed, indicating the guide pin exhibited uniform powder packing during the CIP process. It was also observed that some imperfection as shown with a circle in the figure which could be originated from the inconsistent green machining process. This imperfection led to a greater surface roughness value as discussed in the previous section. Figure 6 (b) shows the morphology after the grinding process, clearly indicate the flow of the grinding direction. As a result of micro-grinding, it was believed that some of the maximum peaks of surface roughness had been polished off, resulting more refined surface finish [10].




**A 500x magnified SEM image** **A 500x magnified SEM image**

**Figure 6: SEM Image a) Before Grinding b) After Grinding**

## CONCLUSION

It can be concluded that the proposed surface grinding mechanism has improved the surface quality of the sintered guide pin. The issues of rejected guide pin components resulted from excessive diameter after sintering and surface chipping from manual lathe machining have been resolved successfully. After micro-grinding process, approximately 20 to 50 µm of the excessive diameter was removed with ease to attain the required dimension corresponded to an improved surface roughness of Ra, Ry and Rz by 1.3 to 2.0 µm, 8.5 to 11.0 µm and 5.0 to 7.0 µm, respectively. The improved surface finish with a smooth and shiny appearance was observed attributed to promising morphological observation by scanning electron microscopy (SEM).

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