Experimental study on machinability in sub-millimeter range of the Aluminum Alloy using Face Turning Method

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Abstract. One of the most factors that affect the quality of machining results is the machinability of materials. Machinability can affect the accuracy of dimension of the machining product, especially in producing small products. This study has purpose to obtain the circularity value and surface morphology of specimen as indicator of machinability of alloys Al 6020 by using face turning method in the range sub-millimeter. The effects of spindle speed and feed on circularity and surface morphology are the subject of the study. Three variations of spindle speed (440 rpm, 740 rpm and 1500 rpm) and six variations of feed (0.05 mm/rev, 0.1 mm/rev, 0.2 mm/rev, 0.3 mm/rev, 0.5 mm/rev and 1 mm/rev) were used. The circularity was calculated by image processing software and surface morphological was observed using SEM and optical microscope. Results show that the better circularity was found on smallest and largest feed for each spindle speed. The surface morphology shows some burr defect and also scatter.

Keywords. spindle speed, feed, circularity, surface morphology face turning

1. Introduction
The manufacture of engineering products with sub-millimeter sizes has earned many portions in recent years. The development of research in sub-millimeter area also led to small products improvement. The main goal of research for small product is stability and dimensional accuracy. The machining process also cannot be separated from the manufacture of products in this range. The word micro machining refers to the manufacture of the product by machining process which has dimension in range 1-999 micron [1-3]. However by reducing the size of the product in each manufacturing process is always accompanied by many problems. Some researchers have emphasized the change in material behavior during manufacturing of small product. Some of parameters have an effect on the fabrication of small metal products including size of the product, microstructure of raw materials, tools and also manufacturing conditions [4].

Several researchers have studied that in the range of sub-millimeter product, the raw materials shouldn’t be considered as homogeneous materials. However, the raw materials should be stated as heterogeneous materials [4-5]. This is due to size effect phenomena, where the grain size of the material is close to the size of the product. Consequently the shape and final size of the product could be inaccurate.

In machining process, machinability has been known as a parameter that indicates the material ability to be manufactured. The machinability of material tends to decreases in the area of micromachining.
Produce component in very small size is highly dependent on microstructure conditions of raw materials such as grain size, grain boundary, crystallographic orientation, composition and also inclusion [6-7].

Face turning is one of turning operation that aims to make a smooth surface on cylindrical cross-section of machined products. Face turning is generally performed after major machining operations. The cutting process in the face turning is applied on two cylindrical ends of the workpiece. As the final cutting process, the facing process generally uses high rotation and small feeding depth and as a result is a smooth and fine cross-sectional surface. Several approaches to the machining process have been developed to examine the machinability for small products [2,3,9,10]. This research tried to use face-turning as a method to describe the machinability of Al 6020 in the range of submillimeter especially in circularity value and surface morphology.

2. Experimental method

2.1 Material

The aluminum alloy was selected as testing material and the composition of the material shows in table1. The experimental set up was shown in figure1.

![Experimental Setup of Face Turning method.](image)

Table 1. The composition of raw material.

| Element | Mg  | Si   | Fe   | Pb  | Zn  | Cr  | Ni  | Cu  | Al  |
|---------|-----|------|------|-----|-----|-----|-----|-----|-----|
| %       | 1.91| 0.564| 0.248| -   | -   | -   | -   | 0.173| Bal |

2.2 Face turning experiment set-up

The experiments were carried out on conventional lathe (Emco Maier+Co). The tool used was HSS type. The process parameters of face-turning was shows in table 2. Specimen produced by face turning then observed using optical microscopes and SEM.

![Experimental Setup of Face Turning method.](image)

Table 2. Process Parameters

| Spindle speed (rpm) | Feed (mm/rev) |
|---------------------|---------------|
| 440                 | 1             |
| 740                 | 0.5           |
| 1500                | 0.3           |
|                     | 0.2           |
|                     | 0.1           |
|                     | 0.05          |
Circularity measurement is accomplished by the photo of cross section of the workpieces and then processed using image-J as processing software. The measurement of circularity as a machinability parameter is based on the outer circumference obtained from the cross section of the specimen after the face turning process.

3 Result and discussion

Figure 2 shows the example of the specimen after face turning. In this study, the final diameter was setup to 0.5 mm for each feed and each rotational speed of the spindle. After the face turning process, the specimen then observed under an optical microscope. The photo of the circular cross section was taken for circularity measurement.

![Figure 2: Specimen produced by face turning process with different feeds shows in red circle.](image)

Figure 3 shows the circularity value with different feeds in the experiment for each spindle speed. It is shown that at 400 rpm of spindle speed, the average circularity has a higher value at 1 mm/rev of feed but then decreases with decreases of feed (see figure 3a). However, at 770 rpm of spindle speed (see figure 3b), the average value of circularity has the higher value at 0.1 mm/rev of feed and for 1500 rpm of spindle speed (see figure 3c) the higher value of circularity is at 0.05 mm/rev.

From figure 3 also shows that by increasing the spindle speed, the circularity tends to have a higher inconsistency value, it can be seen from the scattering data of circularity, especially at 1500 rpm. This indicates that the geometry of the final circular cross section is influenced by the feed and spindle speed.

The value of circularity can be obtained from the equation

\[
\text{Circularity} = 4\pi \frac{\text{Area}}{\text{Perimeter}^2}
\]

From the equation, it is stated that the perfect circle occurs when the value of circularity equals to one. The lower circularity indicated that a lot of chips are still attaching on the circular cross section and reduce the quality of the cross section. This chip is also called uncut chip [8] which produces burr defects in the cutting process due to un-separated chips from the workpiece. According to Wu, that burr may be caused by the orientation of the crystallographic orientation and it has a great influence on the micro cutting force [4]. The geometry of contact area between the tool and workpiece will influence the geometry of chips and usually also produce segmented chips [5]. The geometry of contact area also affects the cutting force which is can create burr defect if the cutting force not successfully separate the chips.
Figure 3. Influence of feed on the circularity value at different spindle speed: a. 440 rpm; b. 740 rpm; c. 1500 rpm

At 1500 rpm as seen in Figure 3c, show a low circular value in the range 0.1 to 0.5 mm of feed. In this range not only produces low circular values but also shows deviation. Some researchers have proven the effect of size that causes inconsistent data and produce low quality of cutting especially in
micro cutting. One of the causes of this size effect is the crystallographic orientation and size ratio between the microstructure and the cutting size [4]. For the small of feed the cutting process will produces a very thin chips which is the size of the chips could be close to the size of microstructure of the workpiece and the size effect can be affect the cutting process.

Figure 4 shows the average circularity value as a function of different spindle speed conditions. It is clear that the circularity value is higher at 440 rpm and 740 rpm compared to 1500 rpm. The effect of high rotation speed provides low circularity value at feeds 0.2 mm/rev, 0.3 mm/rev and 0.5 mm/rev, this is due to uncut chips. It seems that the circularity tends to has better value at lower spindle speed. It has been known that the cutting force tend to has lower value at high spindle speed. However small feed also will produce a small size of chip and reduce the defect of cutting.

![Figure 4. Average value of circularity in different spindle speed.](image)

This can be also attributed to the high rpm value involves high friction and heat. The presence of heat due to friction plays an important role in changing the behavior of shear deformation that occurs at the time of cutting. The heat of the workpiece due to high rotational speed causes the material to has lower deformation resistance. So that the material flow out more easily and create a permanent deformation and left on the surface of the specimen. The result is a defect in the form of burr formation. The presence of the burr defect causes the tolerance and geometry cannot be achieved [8].
Figure 6. Result of face turning on surface morphology at different diameter of specimen for 1500 rpm with constant feed (0.5 mm/rev).

Figure 6 shows surface morphology with different diameter at 1500 rpm and 0.5 mm of feed. It shows that for small diameter, the diameter along specimen is tends to increases at the bottom of the specimen and show taper forms. This probably because of the tools geometry used in this study with high radius of nose. The face turning method used in this experiment shows the different result of circularity value and surface morphology. Its indicate that face turning method probably can be use to predict machinability in the range of micromachining.

Figure 7. SEM of surface morphology at different spindle speed; a). 440 rpm b) 740 rpm, c) 1500 rpm

Figure 7 shows surface morphology at different spindle speed obtained from SEM, it shows that burr defect was take place for almost area at outer diameter. The burr defect is different in size and also in coverage area at outer diameter. However at 440 rpm, the width size of burr defect is lower than other spindle speed. As mention before that spindle speed affect the temperature of cutting due to friction between tool and workpiece. The mechanism of cutting is depend on shear deformation behavior that influence of chips formation. Uncompleted chips formation is a result of instability condition in cutting process and could be effect of increasing temperature due to high spindle speed

4. Conclusion
The following result can be conclude from this study: The high of circularity value was obtained from highest and smallest feed for each of spindle speed. However the highest circularity was obtained from 440 rpm of spindle speed,
1. At 1500 rpm of the spindle speed shows poor of circularity especially at 0.2 mm/rev, 0.3 mm/rev, and 0.5 mm/rev of feed. At this cutting parameter, shows large of burr defect at the surface of specimen.

2. The face turning method used in this experiment shows the different result of circularity value and surface morphology due to different condition of cutting process.

3. The face turning method probably can be used to study the machinability in the range of micromachining.

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