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Effect of Compressed Air and Cutting Speed on Surface Roughness of 6061 Aluminium Alloy

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ABSTRACT

Globally, the manufacturing industry is moving towards sustainable manufacturing in order to preserve natural resources and human well-being. Compressed air is not only recognised as an ideal option to replace cutting fluid in order to flush away chips for surface quality reasons but also to reduce the environmental burden due to disposal of used cutting fluid, as well as to minimise the consumption of natural resources in cutting fluid production. However, chip clearing in order to prevent a tool from recutting the chips is a great challenge in dry milling. Considering this issue, compressed air is necessary to prevent a tool from recutting the chips. In this experimental work, slot milling experiment based on 3^2 factorial experimental design was conducted in order to identify the effect of compressed air and cutting speed on the surface roughness of 6061 aluminium alloy. Three levels of compressed air and cutting speed were used, whereas the depth of cut and feed rate were held constant. The results demonstrated that the higher amount of compressed air and cutting speed will lead to high surface quality and vice versa. Nevertheless, the surface roughness generated at different cutting speed does not depend on the amount of compressed air.

Keywords: *Compressed air, cutting speed, surface roughness, 6061 aluminium alloy, slot milling*

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Introduction

6061 aluminium alloy has been widely used in various sectors, especially in the automotive sector where light weight, high thermal conductivity, and better corrosion resistance with good strength are required [1]-[3]. This gives an explanation why 6061 aluminium alloy can be found in automotive parts, such as panels, wheels, and the structure of the vehicle [1, 2]. Furthermore, it has most of the good qualities of aluminium alloys and it can be machined by most of the commonly used machining processes, as well as milling processes.

Nowadays, the production of automotive parts remains high as vehicle demand increases around the world. Consequently, this matter leads to the rise of applying higher number of milling processes and indirectly increases the use of cutting fluids. In fact, cutting fluids have a significant influence on the environmental burden due to the disposal of used cutting fluids and the consumption of natural resources in cutting fluid production [4]-[6]. Referring to this issue, the ecological aspect should be considered in order to preserve natural resources and human well-being while performing manufacturing activities. Subsequently, a plethora of options have been implemented to reduce the environmental impact of cutting fluid usage, such as cryogenic, nanofluids, near dry or minimal quantity lubricant (MQL), solid lubrication, gaseous cooling, sustainable cutting fluids, and dry that have been stressed in many published papers [5, 7]-[15].

As claimed by Benedicto, Carou, and Rubio [15], dry machining removes cutting fluids and it is an ideal option by considering that the method is not only free from atmosphere and water contamination but also reduced cost. Nevertheless, dry machining is still unable to obliterate any doubt over their suitability to be an ideal option in replacing cutting fluids due to the chip evacuation issue. Undoubtedly, cutting fluids are the catalyst in the high surface quality of the machined material. This can be seen through their role to evacuate the chips from the cutting zone to prevent a tool from recutting the chips. For these reasons, most of the machine tools are equipped with built-in air nozzles to blow compressed air on the machined surface when dry machining is applied. However, it seems that compressed air in machining has received less attention since very few scientific papers have stated the influence of compressed air on surface roughness in dry machining. Meanwhile, surface roughness research has revealed that the increase in the feed rate results in the decrease of surface quality [16]-[19]. In contrast, an incremental increase in cutting speed leads to an incremental increase in surface quality [16, 17, 19], whereas the depth of cut has the least significant effect on surface quality [18, 20]. It can be defined that the highest cutting speed and the lowest feed rate produced better surface roughness. Hence, the objective of the study is to present an understanding towards the effect of varying compressed air and cutting speed simultaneously on the surface roughness of 6061 aluminium alloy in dry slot milling. Besides, recutting the chips that cause low surface quality is a common obstacle in slot milling.

Experimental Set Up

As presented in Table 1, 3^2 factorial experimental design was used to identify the effect of varying compressed air and cutting speed on the surface roughness of 6061 aluminium alloy. In addition, compressed air was supplied through the built-in air nozzles from the machine tool itself, and the amount of depth of cut and feed rate were held constant at the lowest value in order to avoid the interruption on the main factors.

Table 1: Variable parameters used in the experiment

Compressed air (PSI)	: 80, 100, 120
Cutting speed (m/min)	: 90, 106, 122
Depth of cut (mm)	: 2
Feed rate (mm/min)	: 300

The experimental set-up in this study was conducted on 90 mm × 90 mm × 35 mm 6061 aluminium alloy with the original hardness of 104 HV using an Okuma MX-45VA vertical CNC machining centre as shown in Figure 1, whereas Table 2 shows the chemical compositions of 6061 aluminium alloy.

Figure 1: Okuma MX-45VA vertical CNC machining centre

Table 2: Chemical composition of 6061 aluminium alloy (wt%)

Al	Si	Mg	Mn	Fe	Cu	Ti	Ni	Cr	Zn
97.40	1.00	0.57	0.53	0.29	0.03	0.02	0.02	0.01	0.01

The slot milling was performed using AMF 2100T tungsten carbide (AlTiN coated) with the end mill diameter of 10 mm with two flutes from TaeguTec in dry condition. The surface roughness of 6061 aluminium alloy was measured using Mahr Perthometer S2 with 5.60 mm (DIN/ISO) traversing length and plotted as the roughness average (Ra) in µm.

Results and Discussion

Figure 2 shows the milled 6061 aluminium alloy block and Figure 3 depicts the surface plot, which is a three-dimensional graph representing the effect of varying compressed air and cutting speed simultaneously on the Ra of 6061 aluminium alloy. The surface plot shows that the highest values of Ra for dry slot milling of 6061 aluminium alloy are located at the upper back corner of the plot, which corresponds to the low values of both compressed air and cutting speed. Meanwhile, the lowest values of Ra are observed at the lower middle corner of the plot, which corresponds to the high values of both factors.

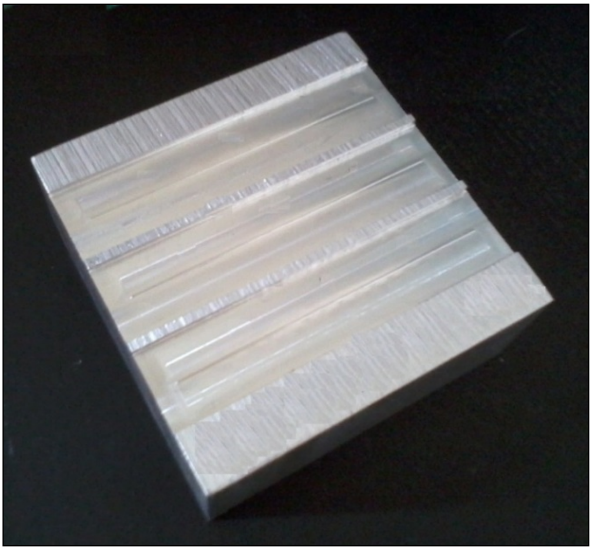

Figure 2: Milled 6061 aluminium alloy block

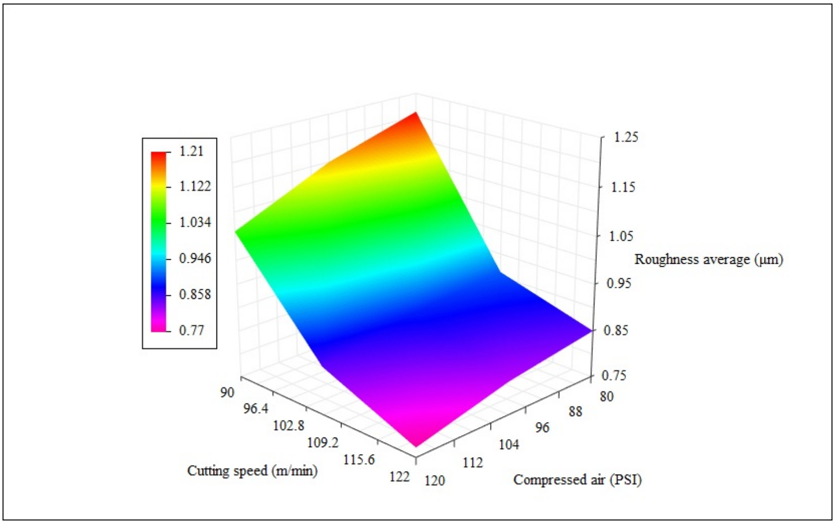

Figure 3: Surface plot of the relationship between cutting speed, compressed air, and roughness average

By referring to the main effect plot for Ra in Figure 4, the slope of the lines reveals that the steeper the slope, the smaller the mean of Ra. In short, both compressed air and cutting speed seemed to have a significant effect on Ra as each line falls steeply between 80 and 120 psi of compressed air and 90 and 122 m/min of cutting speed. It means that the value of Ra decreases with increasing compressed air and cutting speed, and vice versa. On the other hand, the main effect plot indicates that applying the compressed air of 120 psi has a minor effect, whereas using the cutting speed of 122 m/min has a greater effect. Therefore, it would be necessary to determine whether the interaction effect is statistically significant or not towards Ra.

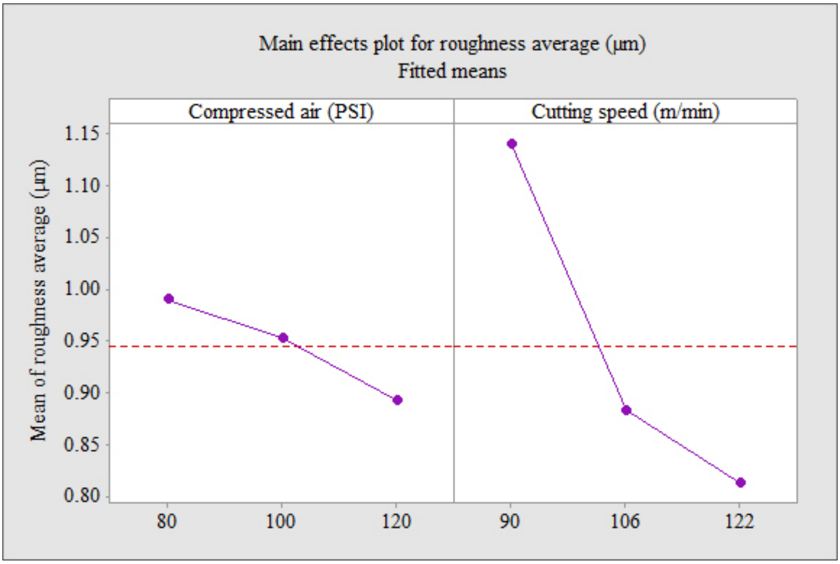

Figure 4: Main effects plot for roughness average

As presented in Figure 5, the lines are parallel, thus there is no interaction. In general, the diamond shape appeared as the lower data mean, followed by the square shape and the circle shape, hence there is likely a main effect of compressed air such that 120 psi leads to lower Ra values than 100 and 80 psi. This phenomenon is supported based on the findings in [21-24], which studied high pressure in both water and coolant during the machining process. It is believed that the increase of compressed air leads to an incremental reduction in the tool-chip contact area due to the fragmentation of the chip and subsequently improves the chip breakability and efficiency of the tool rotation, as well as decreases the tool-chip friction interface. Moreover, the Ra values at cutting speed of 122 m/min are lower than the roughness values at cutting speed of 106 and 90 m/min, suggesting that there is a main effect for cutting speed as the cutting speed behaviour is similar as previously reported in [16,17,19]. Finally, as there is no interaction effect present, it means that the interpretation of the main effects is complete and it can be said that the relationship between Ra and cutting speed does not rely on the amount of compressed air.

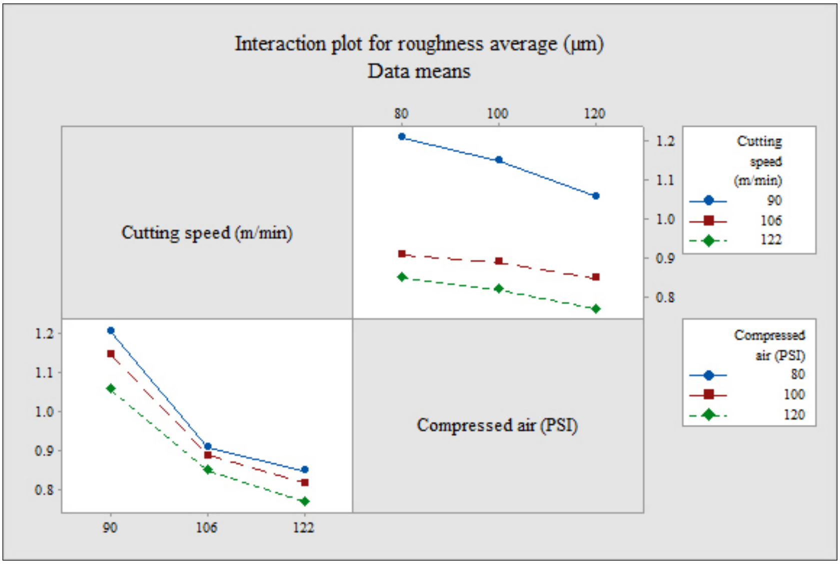

Figure 5: Interaction plot for roughness average

In summary, higher amount of compressed air and cutting speed will lead to excellent surface quality. The minimal surface roughness corresponds to excellent surface quality, which occurred at compressed air of 120 PSI and cutting speed of 122 m/min. However, the surface roughness generated at different cutting speed does not depend on the amount of compressed air.

Conclusion

Due to the increasing concern towards the consumption of natural resources and human well-being while performing manufacturing activities, the idea to replace cutting fluid in order to flush away chips for surface quality reasons and to reduce the disposal of used cutting fluid as well as to minimise the consumption of natural resources in cutting fluid production has increased phenomenally in the past three decades. Chip evacuation for preventing a tool from recutting the chips is a great challenge in dry slot milling. Therefore, compressed air is necessary to prevent a tool from recutting the chips, and dry slot milling experiment based on 3^2 factorial experimental design was carried out to screen factors affecting the surface roughness of 6061 aluminium alloy. The results revealed that higher amount of compressed air and cutting speed will lead to high surface quality, and vice versa. The minimal surface roughness corresponds to high surface quality, which occurred at compressed air of 120 psi and cutting speed of 122 m/min. However, cutting speed appeared as the dominant factor affecting surface roughness compared to compressed air. Furthermore, there is no interaction effect of both factors as the main effects are independent of one another. It can be said that the surface roughness generated at different cutting speed does not depend on the amount of compressed air. Despite no interaction effects between both factors, a further study should be carried out to evaluate the effect on tool life in dry milling of 6061 aluminium alloy, since chip evacuation issue is not only affecting surface quality but also the tool life.

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