

# Analysis of defects on machined surfaces of aluminum alloy (Al 7075) using imaging and topographical techniques

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**Abstract.** Aluminum alloys 7075 (Al 7075) are widely used for various industrial components in which machining operations are often conducted during their manufacturing process. However, the machining operations could introduce defects on the machined surfaces of the components which will be carried over and may lead to either issues in the subsequent fabrication process or failure during the products' service life. This study investigates the machined surface's defects of Al 7075 underwent drilling operations using imaging and topographical techniques which include optical microscope, scanning electron microscope and 3D surface profiler. Surface roughness was analysed with respect to the surface defects to investigate the correlation between the roughness parameters and topographical features of the machined surfaces. The defects found on the machined surfaces of Al 7075 are microcrack, adhesion, feed mark and burr. Surface roughness was found to be highly influenced by topographical features particularly feed mark. Thus, in addition to measuring the roughness, inspection through imaging and 3D topographic techniques is important for analyzing the surface characteristic in order to determine the defects, hence deducing the detailed surface features and deformation caused by the drilling operations.

**Keywords:** Aluminum alloy / machining / topography / defect / roughness

## 1 Introduction

Surface defects are critical issue in manufacturing industry, particularly when it comes to automotive and aerospace components. A huge variety of metallic products are manufactured by various machining operations such as milling, turning and drilling. The machining operations often resulted in irregularities, deformation and geometrical deviation of the surfaces. Characteristic of metallic surfaces is typically defined by their roughness, waviness, lays and flaw on the surfaces. The quality of the machined surfaces is often determined by assessing their surface roughness, commonly in terms of  $R_a$  values to confirm the quality and maintaining the visual appearance of the products [1]. However, the  $R_a$  assessment does not often indicate the true characteristic of the surfaces, which then could lead to inconsistent product quality and performance. For instance, the crack or porosity on the surfaces could not be determined

through the  $R_a$  values. Therefore, determining the product quality based on the  $R_a$  values only might lead to a higher possibility of product failure in the future.

In manufacturing industry, imaging and topographical techniques are typically overlooked as an assessment for indexing the surfaces finish of the manufactured products. These techniques are normally applied in the medical field to analyze the true condition of a patient which cannot be assessed by unaided eyes. Whereas, in manufacturing industry, the application of imaging and topographical method is also seen as crucial in order to provide a better evaluation of the surface quality of the products, which have undergone machining process. The machined surface finish and defects should be determined throughout the fabrication process. Product inspection need to be conducted during the quality control process to ensure the products or parts produced meet the specified requirement set by the customers.

The surface defects are influenced by various factors during machining processes which include the cutting parameters and conditions [2–6]. Imaging techniques through the use of optical microscope has often been practiced for inspection purposes due to the ease of use and reliability. Various techniques emerge as the technology

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**Table 1.** Cutting parameters used to drill the Al 7075.

Cutting speed (m/min)	Feed rate (mm/rev)	Cutting environment
120	0.01	Dry
	0.01	Chilled air
	0.10	Dry
	0.10	Chilled air
160	0.01	Dry
	0.01	Chilled air
	0.10	Dry
	0.10	Chilled air

advance which includes topographical techniques such as 3-dimensional (3D) surface profiler. Similar to imaging techniques, the topographical technique allows the users to observe and analyze the surface with a more thorough analysis through 3D views using computer. Surface roughness and topographical features of the surfaces may also be generated through the application of topographical techniques. This research investigates the means to determine the quality and characterize the features and defects of the machined surfaces of aluminum alloy (Al 7075) using imaging and topography techniques involving microscopy and 3D profiling.

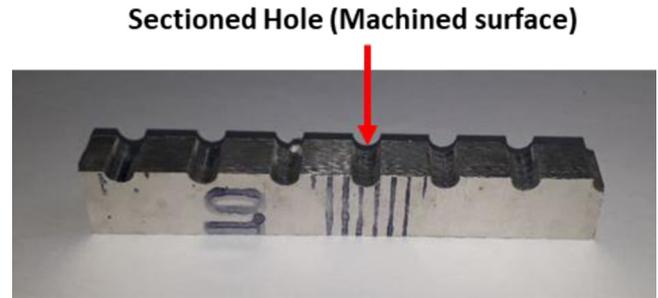
## 2 Experimental methodology

In this study, machined aluminum alloy Al 7075 which had undergone drilling processes using MAZAK-NEXUS 410A-II were examined. Table 1 shows the cutting parameters and conditions used to produce the holes through the Al 7075 samples (thickness of 13 mm). The samples were sectioned into halves as shown in Figure 1 to allow inspection on the hole's wall surface. Surface defects analysis and surface roughness measurement were conducted on the hole's wall surfaces. Surface roughness was measured by a non-contact method using 3D surface profiler (Alicona InfiniteFocusSL) as well as by stylus/direct contact method (with Accretech Surfcom Touch 500-12). The surface defects were inspected using imaging techniques which include optical microscope, Dino-Lite Edge AF4515ZTL and scanning electron microscope, Jeol JSM-5600 Schottky Field Emission. Topographical technique using Alicona InfiniteFocusSL was conducted to generate 3-dimensional (3D) topography of the surfaces. The model of the surfaces was generated using MeasureSuite software. The resolutions used for the instruments were set at 970 nm for vertical resolution and 8.40  $\mu\text{m}$  for lateral resolution.

## 3 Results and discussion

### 3.1 Comparison and analysis of defects on machined aluminium alloy using imaging and topographical techniques

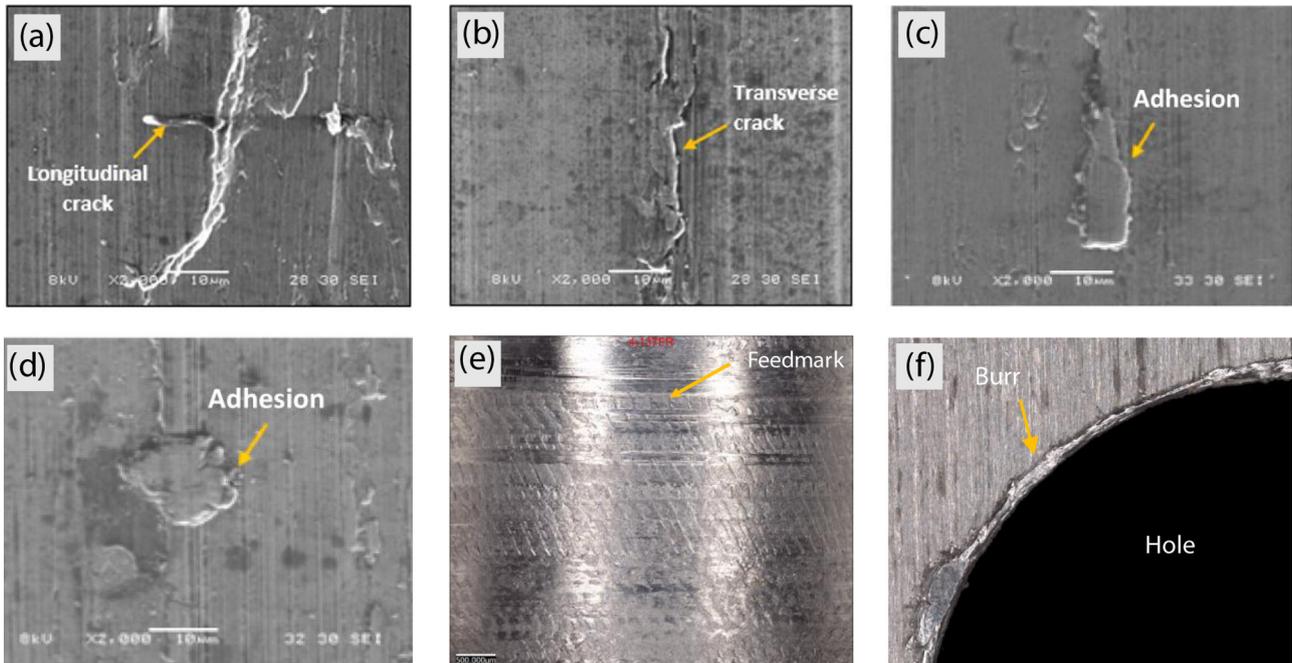
Several defects were discovered on the machined surfaces through the assessment conducted using imaging and

**Fig. 1.** Sectioned specimen of Al 7075.

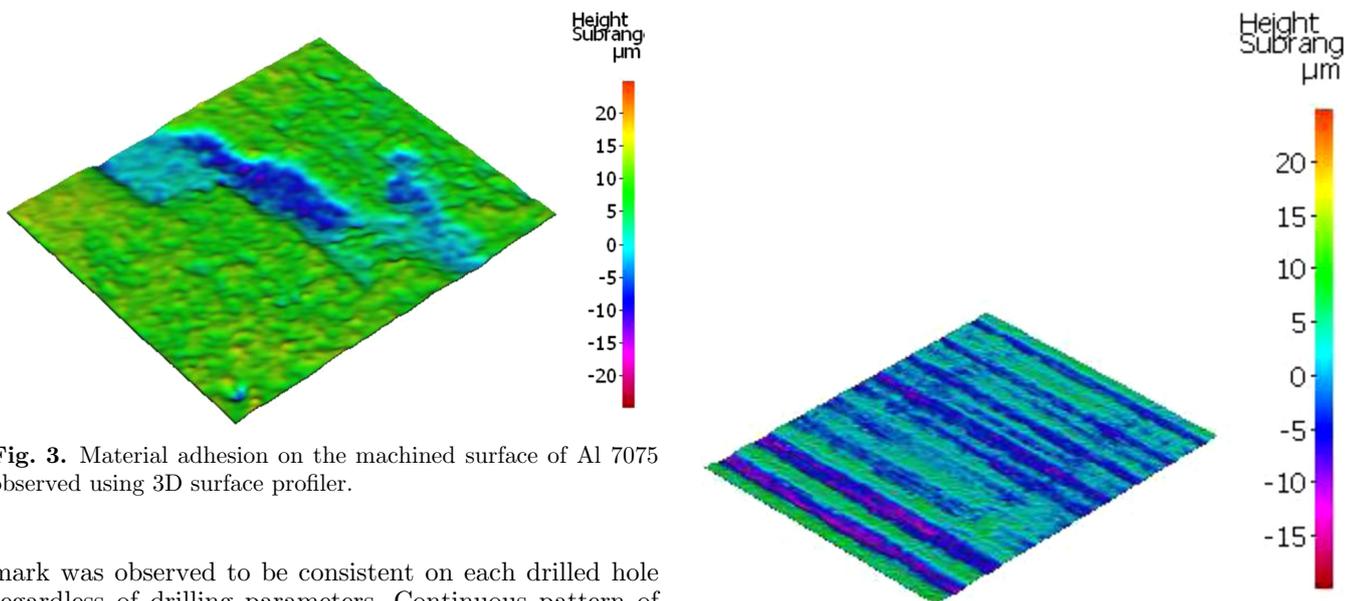
topographical techniques. The defects discovered on the machined surfaces of Al 7075 are (a) longitudinal crack, (b) transverse crack, (c, d) adhesion or overlapping, (e) feed mark, and (f) burr as shown in Figure 2. The longitudinal and transverse cracks observed on the machined surface using Scanning Electron Microscope (SEM) at the 2000 $\times$  magnification rate were found to have the length and width within 0.5–120  $\mu\text{m}$ . This microcrack was not observed during the examination using optical microscope which indicates the need of using a higher magnification microscopy for better evaluation of the surface features. Both types of microcracks (longitudinal and transverse) which were observed using the SEM occurred mostly on the surfaces produced by drilling at the lower cutting speed of 120 m/min regardless of feed rates and drilling environment. The crack on the machined surface is likely to occur as a result of stress concentration zones formed on the surfaces due to tool-chip friction during drilling process. In addition, microcracks were formed as residual stress reaches the fatigue strength of Al 7075.

Furthermore, material adhesion with various size and pattern on the machined surfaces of Al 7075 were also observed using SEM as shown in Figures 2c, 2d and surface profiler as shown in Figure 3. On average, the height of material adhesion on the surfaces were found to be approximately between 10  $\mu\text{m}$  and 15  $\mu\text{m}$ . Adhesion on the machined surfaces is the result of chip formation and material softening during drilling process and they are likely to occur when drilling was conducted in dry condition and at higher cutting speeds due to higher heat generation. The examination of material adhesion was harder using optical microscope due to limited height profile. Generating the surface topography using 3D surface profiler provided detailed height profile which can be seen in Figure 3. The depth and height profile of the adhesion are shown through a colour difference which facilitates the detection and provide comprehensive insight of the defects compared to optical microscopy and SEM.

Feed mark is another type of defects that were observed on the machined surfaces of Al 7075, as shown in Figure 2e. Feed mark is considered as common defects due to machining process. Feed mark can be distinguished on the machined surface as the cutting path profile that was resulted due to material removal process. The severity of the defects can be controlled by adjusting the feed rate of the machining process from which a higher feed rate resulted to deeper feed mark [7,8]. The occurrence of feed



**Fig. 2.** Types of defects observed on the drilled holes and machined surface of Al 7075 (a) longitudinal crack, (b) transverse crack, (c, d) adhesion, (e) feedmark, (f) burr.



**Fig. 3.** Material adhesion on the machined surface of Al 7075 observed using 3D surface profiler.

mark was observed to be consistent on each drilled hole regardless of drilling parameters. Continuous pattern of cutting tool path can be observed on the surfaces through imaging techniques by optical microscope as shown in Figure 2e. The feed mark was commonly observed to occur parallel to the cutting feeds during drilling process. However, analysis through optical microscope does not provide information on the height and depth profiles of the feed mark on the surfaces. Therefore, the use of 3D profiler is needed to provide detailed information on the height profile. Figure 4 shows the topographical features of the feed mark observed on the surfaces, which were analyzed using the 3D surface profiler. The height and depth profile of the feed mark was observed to vary up to  $15\ \mu\text{m}$  which are highlighted by the color difference.

**Fig. 4.** Feed mark on the machined surface of Al 7075 observed using 3D surface profiler.

Burr existence which was observed at the hole exit using optical microscope are shown in Figure 1f. The burr occurs due to plastic flow of material during drilling process [9]. However, the images generated through imaging method utilizing the optical microscope does not provide information on the height of the burrs. The topography of burrs generated through topographical techniques utilizing 3D surface profiler are shown in Figures 5 and 6.

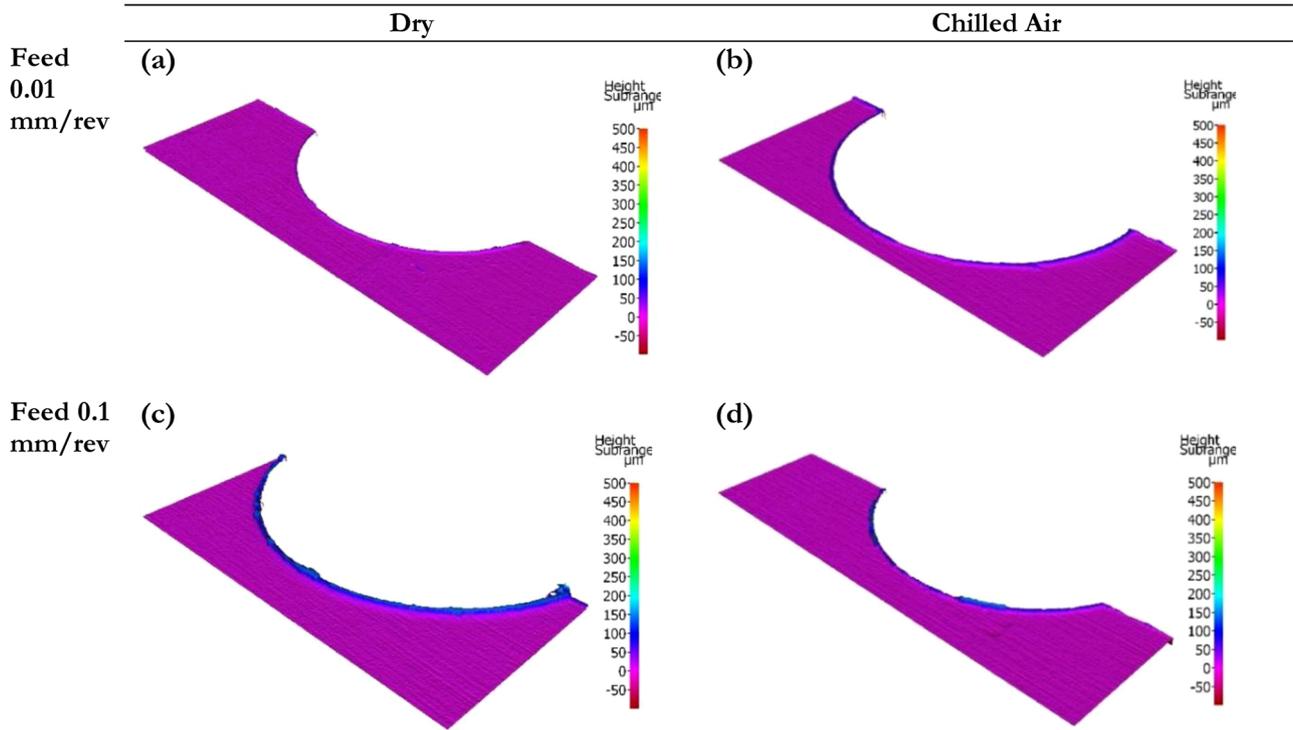


Fig. 5. Burr produced by drilling at lower cutting speed of 120 m/min, observed using 3D profiler.

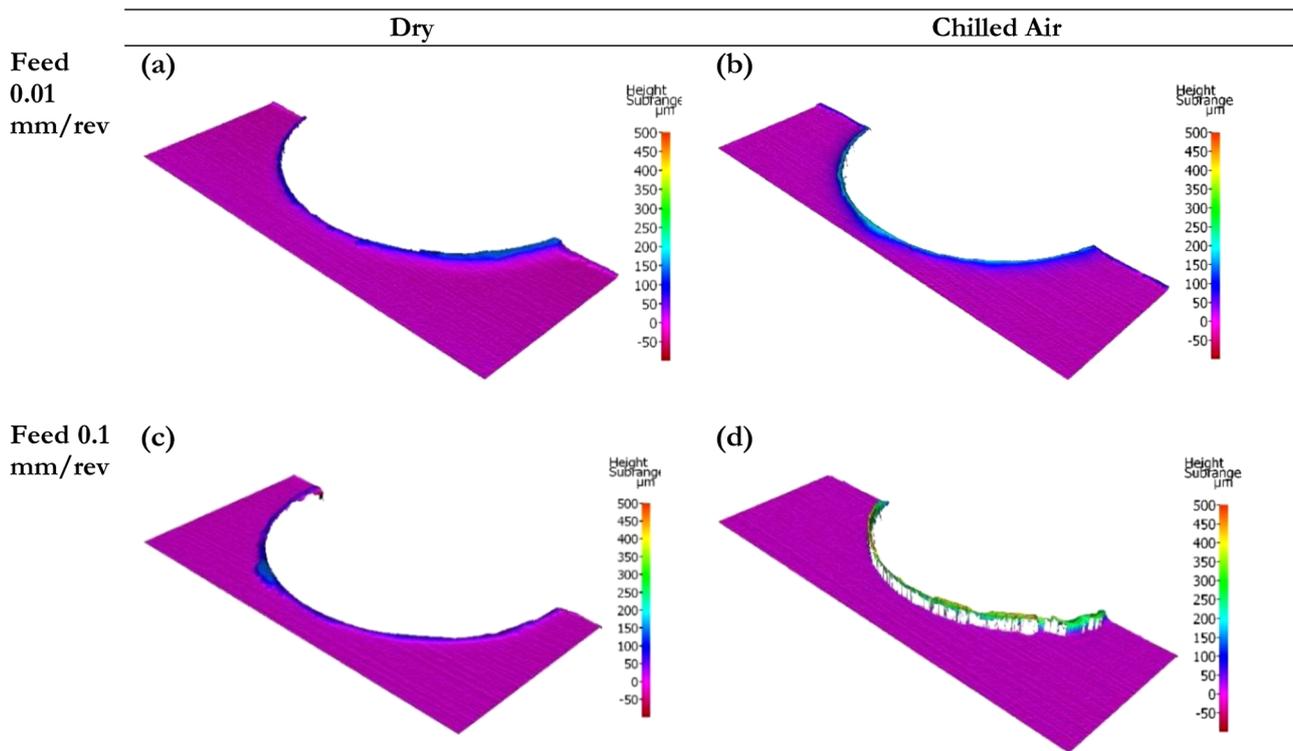


Fig. 6. Burr produced by drilling at higher cutting speed of 160 m/min, observed using 3D profiler.

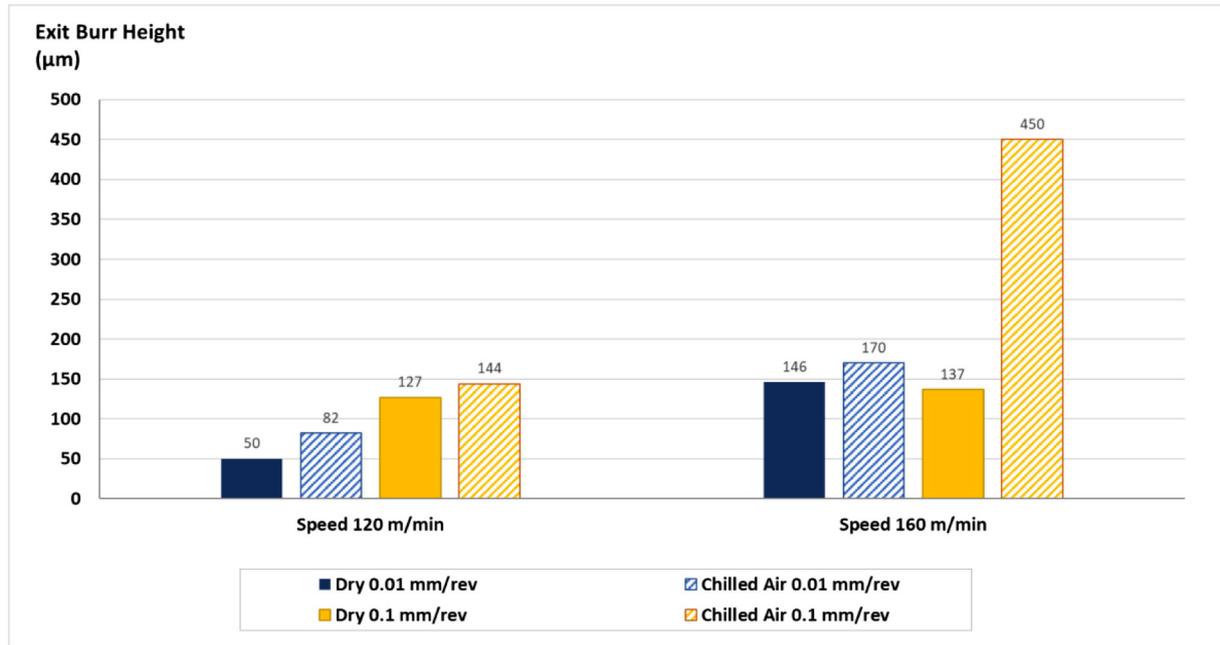


Fig. 7. Comparison of burr height measured using 3D profiler.

Through the topographic generated, the height profile of burr was generated and the comparison burr height produced by drilling at various cutting parameters is shown in Figure 7. The results indicate that cutting speed, feed rate and condition affect the burr formation in which higher cutting speed and higher feed rate resulted in the higher burr formation. The burr height difference up to 67.9% was observed between the holes produced by the cutting speed of 120 and 160 m/min. In addition, the height of burr was also observed to increase when the drilling processes was done in chilled air environment compared to dry environment. The higher burr observed on the Al 7075 samples drilled in chilled air is likely due to the reduction in cutting performance due to higher tool wear caused by material hardening [9].

The findings are consistent with previous research [5,7], which also discovered feed mark, burrs and adhesion through topographical techniques which involve 3D profiler however microcrack was not observed. The use of higher resolution of microscopy resulted in a surface model with a higher accuracy. Through topographical techniques, topography of the surfaces generated provides additional information for the user to evaluate the height variation of the surfaces. The findings are similar to previous research [5,7,10], which also reported that topographical techniques are important to assess the surface texture and surface height profile. Thus, both imaging and topographical techniques are suitable, necessary and complement each other in assessing the quality and texture of the machined surfaces.

### 3.2 Analysis of surface roughness and topographic features

Surface roughness is a typical criterion which has been used to determine the quality of the machined surfaces.

Machined surfaces often contain irregularities and deviations from the desired form as a result of machining operations, cutting parameters and cutting conditions used. These deviations are normally assessed as surface roughness in terms of  $R_a$  values. The  $R_a$  value which represents the amplitude (hills and valley) average parameter of the surfaces. This is achievable by comparing the deviation between the numbers of height of the actual surface from the mean line [11]. Figure 8 shows the comparison of  $R_a$  values of the machined surfaces of Al 7075 obtained via non-contact method using 3D surface profiler and via direct contact method using a stylus. Although there was a difference in the  $R_a$  values obtained between both methods, it is evident that the same trend with respect to the cutting parameters can be concluded regardless of the  $R_a$  measurement methods. Generally, the  $R_a$  values were observed to reduce when the feed rate increases from 0.01 mm/rev to 0.1 mm/rev. In addition, the  $R_a$  values were observed to be lower when the drilling processes were conducted in dry environment compared to chilled air environment. However, no significant difference in  $R_a$  was found with respect to the change in cutting speed. The lower  $R_a$ , hence improved surface finish produced by drilling at higher feed rate and in dry environment is likely due to lower tool wear resulted by shorter drilling time compared to the lower feed rate [12].

Interestingly, as can be seen in Figure 8, the  $R_a$  values obtained through non-contact method (3D surface profiler) are significantly higher than the  $R_a$  value obtained through direct contact method (stylus). On average, the difference in percentage between the roughness parameter obtained by both methods was found to be 21.6%. The difference between the values obtained is reflected by the resolution used in 3D surface profiler. The different resolution used during the measurement resulted into different result of roughness measurement. Higher resolution used during the

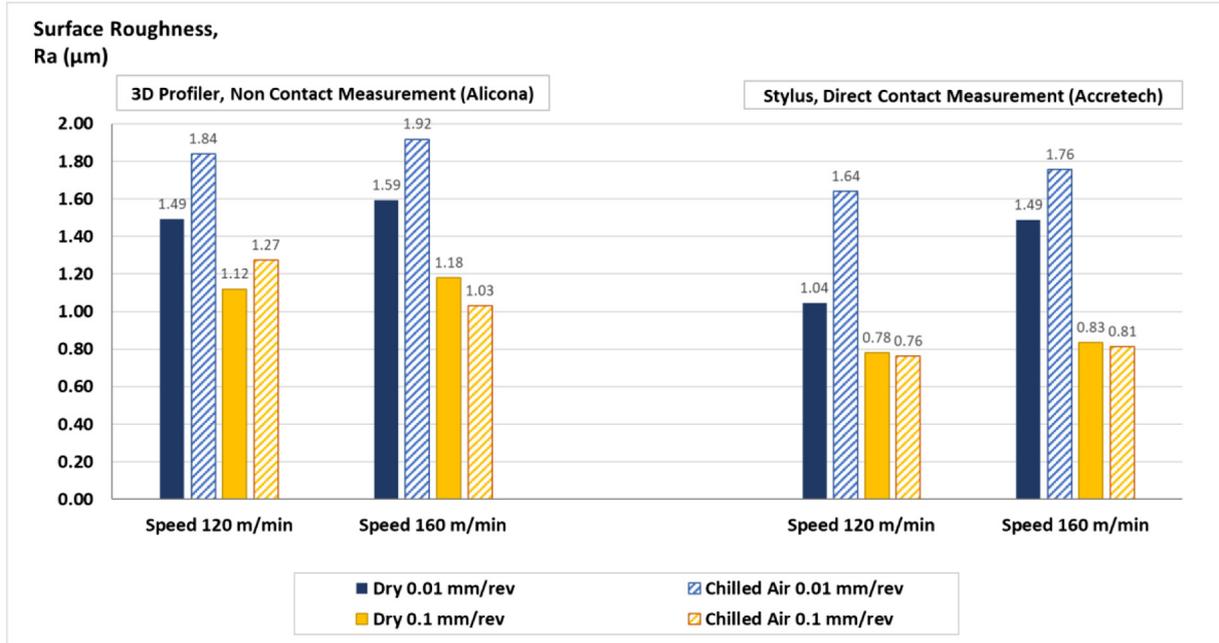


Fig. 8. Comparison of  $R_a$  values obtained using non-contact and direct contact measurement.

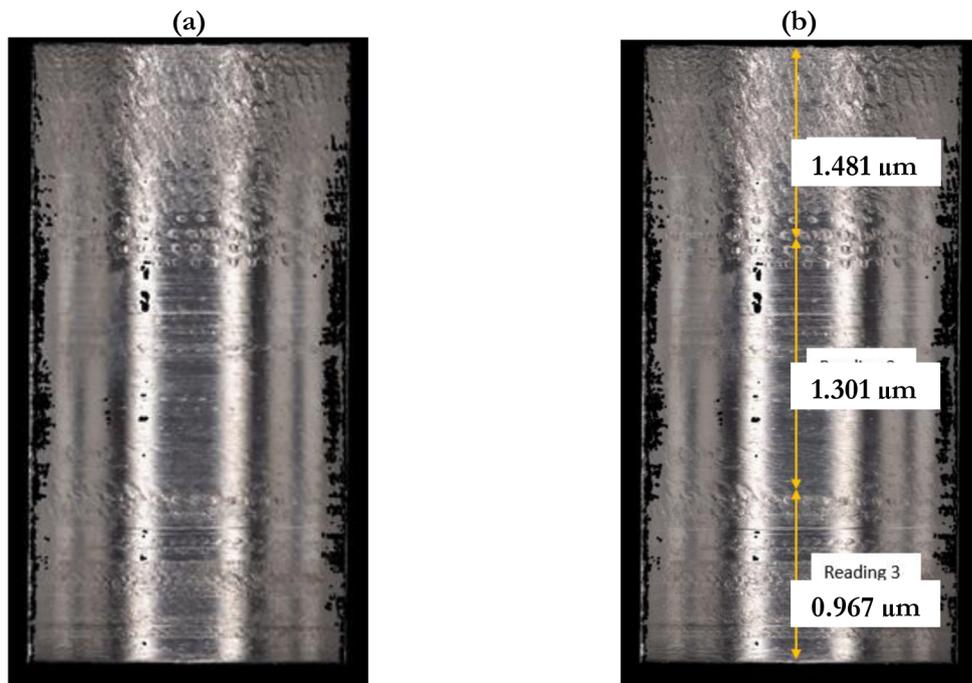


Fig. 9. Image of surface topography obtained through 3D surface profiler.

measurement resulted into more accurate reading compared to lower resolutions. Also, the 3D surface profiler permits measurement at various and more thorough location on the machined surfaces compared to the  $R_a$  measurement using stylus. For instance, Figure 9 shows the overall machined surface of Al 7075 obtained through 3D surface profiler. The result obtained shows the true condition of the surface which the topographic features

or feed mark observed are not consistent along the surface. Thus, correlation between surface roughness values and topographic features were made by measuring 3 different readings of  $R_a$  along the surfaces, as shown in Figure 9b. It is apparent that the  $R_a$  values measured for each location are significantly different. This was resulted due to inconsistent topographical features along the machined surfaces.

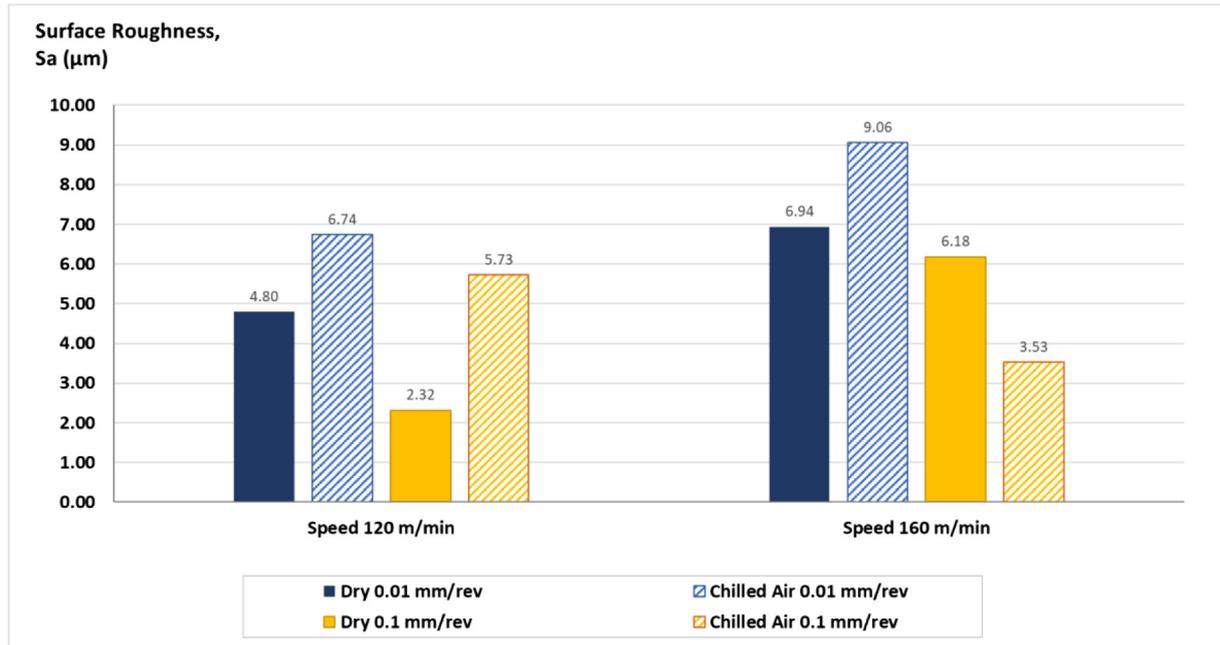


Fig. 10.  $S_a$  values of the machined surfaces obtained using 3D surface profiler.

Previous association between the topographical features and surface roughness which reduction of surface roughness was also reported when surface quality is improved, and less topographical features resulted on the surfaces [9]. In summary, the topographical features along the surfaces influence the surface roughness. However, measuring the surface roughness by  $R_a$  only is not sufficient to determine the quality of the machined surfaces. Surface topography or texture with respect to area which is  $S_a$  values (area roughness parameter) is needed to provide a thorough analysis of the machined surfaces. The  $S_a$  value is evaluated by calculating the arithmetical mean of the absolute on the surface area [13]. Figure 10 shows the comparison of  $S_a$  values of the machined surfaces produced by drilling at various parameters as in Table 1. The  $S_a$  values provide more thorough measurement and as can be seen in Figure 10, the  $S_a$  values are generally higher than the  $R_a$  values, Figure 8. Nevertheless, the same trend of roughness can be observed by both  $R_a$  and  $S_a$  values.

## 4 Conclusions

This study has shown that both imaging and topographical techniques were effective and needed to be used for analysing the defects on the machined surfaces. The observed defects were cracks, feed mark, adhesion and burr. Imaging techniques which involve the use of optical microscope and scanning electron microscope were observed to show the types of defects which includes microcracks, adhesion and feedmark. Whereas, topographical techniques using 3D surface profiler are more effective to analyse the defects on the surface such as adhesion, feed mark and burr due to their ability of

generating the surface model in 3-Dimension (3D) and provide the height profile as well as the roughness parameters in terms of  $R_a$  and  $S_a$  of the machined surfaces. Investigation on the correlation between surface roughness and topographic features shows that different topographic features especially feed mark directly affect the surface roughness values obtained. Measurement of surface roughness obtained via non-contact method (3D surface profiler) generally produces 21.6% higher  $R_a$  values compared to direct contact method (stylus) due to more thorough visualization of the surface topography. Nevertheless, similar trend of  $R_a$  values with respect to the cutting parameters can be deduced by both methods. In addition, aerial surface roughness in terms of  $S_a$  values generated by 3D profiler is useful to provide improved indication of the surface texture and quality.

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