THE PERFORMANCES OF COATED CUTTING TOOLS IN MILLING DAC52 ON SURFACE INTEGRITY

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ABSTRACT: Machining of hardened steel in die and mould making has been intensively used in recent years. Various coated carbide tools have been developed to improve the performance, quality and efficiency in machining hardened steel. Now, hardened steel products tend to have poor quality surface finish and cause major loss for the company. The purpose of this research is to investigate the performance of surface roughness of coated cutting tool on steel DAC52 under dry conditions. Machining process was carried out by using CNC milling machine under side milling operation by using three types of coated cutting tools. The measurement of images' microstructure, white layer and microcrack was done under Optical Microscope. The values of surface roughness were tested using Mitutoyo surface roughness tester while microhardness values were tested by using Vickers microhardness tester. The highest value of surface roughness was found when gold coated cutting tool was milled with DAC52, which is 0.40 μm, while the blue coated cutting tool produced higher length of microcrack which is 50 μm. In conclusion, the blue coated cutting tool is the best tool to be selected as a tool to be machined, because the tool produces less defect such as microcrack or white layer.

KEYWORDS: *Cutting Tools; Machining; Surface Integrity*

1.0 INTRODUCTION

The advantage of machining operation is its ability to produce high precision of component without wasting production time. There are limitations for machining operation such as unsuitable for removing large amount of material from component, which causes waste operation. Machining is characterized by its versatility and capability of achieving the highest accuracy and surface quality in the most economical way.

Recently, hardened steel is treated to HRC52 to be commonly used in the die and mould industry, and heat and pressure encountered when machining hardened steel can cause plastic deformation in cutting inserts and rapid insert failure. However, the hardened steel can be machined economically with the development of coated cutting tool. Surface integrity is a measure of the quality of a machined surface, and it will be interpreted as an element that can describe the actual structure of both surfaces and subsurface. In this study, the surface integrity is decided to be identified such as surface roughness, microhardness, white layer, microstructure and microcracks. Surface roughness is widely used to predict the quality of products, and technical requirements for mechanical properties of products. To achieve great desired product performances, the quality control on surface quality is important to be considered in the manufacturing process, such as milling and turning, and another machining process. The roughness average, Ra values are used by most researchers to get the value of surface roughness. Surface roughness is defined as closely spaced, irregular deviations on a scale smaller than waviness. It is expressed in terms of its height, its width and its distance on the surface along which it is measured. Recently, many optical measuring methods have been applied to overcome limitation method in measuring the surface roughness of work parts. An adaptive neuro-fuzzy inference system (ANFIS) and machine vision system are used to predict surface roughness in turning, which is the best example as a measurement system to overcome limitation method. SS201 and AISI 1045 materials were used with sharp and ramp corners flexure hinges on design [1].

In most high speed machining such as milling, the white layer is treated as a damage of the machined surface. It is a featureless layer that is mostly formed on the surface of machining, and appears white when it is observed under an optical microscope. A white layer consists of contained fresh martensite along the underneath surface due to rapid heating and cooling after being machined. Reduction in the temperature of machined surface may be due to faster chip removal and insufficient contact time. This is the deficiency that is mostly formed under machined surface, and it is likely to occur on dry high speed machining operation such as milling and turning. There is a possibility for identification of white layer on a machined surface by measuring some of the roughness parameters without previous metallographic preparation of samples. The performance of UVAM in cutting force reduction found the superior benefits of UVAM comes from the alternating cycle's between tool and workpiece [2].

Microhardness is a broadly used term referring to the testing of hardness involving materials by using small applied loads. The microhardness as a physical parameter of SI characteristics depends on numerous factors, technological parameters, stereometry and micro geometry of a cutting edge. Then FEA is used to evaluate the static and dynamic performance of the FTS [3]. It is a parameter which significantly determines the intensity of heat generated in the machining zone. There is a variety of hardness testing method applied to most application such as Vickers, Knoop, Brinell and Rockwell method. Using analytical and experimental results, updated finite element analysis (FEA) models are used to predict the effect of dynamic modifications in the structure of the machine that is to be used for vibration- assisted machining[4].

A microcrack is a type of material damage consisting of cracks small enough to require magnification to observe this internal damage which can be classified into macro and microscopic levels. Tool wear was reduced and surface roughness improvement by applying the 2D UVAM compared to the CM when choosing the optimum amplitude and appropriate frequency [5]. Microscopic scale damage such as microcracking occurs as a result of impact and internal stresses [6]. It is an indication of material failure that can ultimately lead to complete failure. The formation of microcrack will decrease the material strength, stiffness and stability, possibly leading to undesirable properties such as failure to protect the underlying materials from environmental contact and corrosion [7]. This type of defects is difficult to be detected due to limitations in the resolution of these techniques, and hence will not be repaired. Quantitative information on the initiation period, growth and coalescence of cracks, statistical distributions of crack length and crack depth, density of cracks, distribution pattern and characteristics of the major crack, is obtained [8]. A close examination of the end tip reveals that the surface is covered with small pores and tiny cracks [9].

The structure of engineering materials is related to the arrangement of its internal components. Many metal alloys exist in more than one crystal structure depending on the temperature and composition, but, in most cases, transitions are between four crystal structures which are Face-Cantered Cubic (FCC), Body-Cantered Cubic (BCC), Hexagonal

Closed-Packed (HCP) and Tetragonal [10]. Large groups of atomic arrangements are considered as components of the microstructure, which determine most of the properties of the material. Microstructure consideration in the machining process covers the phase of transformation, dynamic recrystallization, grain morphology and dislocation density [11-12]. Microstructure is a very small scale structure of a material, defined as the structure of a prepared surface of material as revealed by a microscope above 25× magnification. All of the physical properties such as strength, toughness, ductility, hardness and temperature behaviour are strongly influencing microstructure. The purpose of this research is to study the performances of types of cutting tools by analysing the characteristics of surface integrity present on the workpiece after being machined.

2.0 METHODOLOGY

Research methodology is all about the description on types of equipment, tools, and procedure to be used. Several methods and procedures are conducted for this study which consist of the parameter of the study, design of experiment, instrumentation, research procedure, and data analysis. Tools are expensive items, and therefore an economical approach for machining is required considering the time and energy spent on machining. Therefore, all the cutting conditions and machines used must be standardised by following the specifications and capability of machine in order to avoid any damages. Tables 1 and 2 show the machining parameter and types of coated cutting tools used.

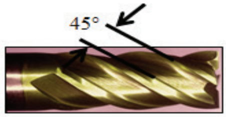
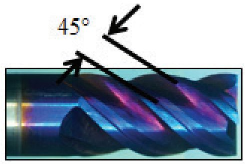
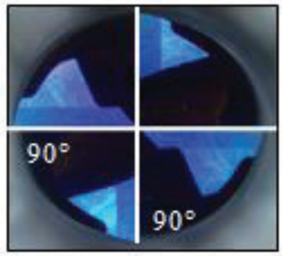
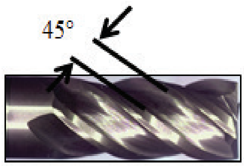
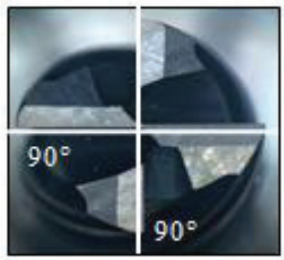
Table 1: Machining parameter

Parameter	Characteristics
Spindle Speed, (CS)	10,000 rpm
Feed Rate, (f)	2000 mm/min
Axial Depth of Cut, (A_p)	0.5 mm
Radial Depth of Cut, (A_e)	1.5 mm
Diameter of Cutting Tool	6mm

2.1 Surface Roughness Tester

The cutting parameters of this study were being considered since the start of milling operation. The two main parameter values were kept as variable parameters that are the cutting speed and feed rate. At the same time, the depth of cut and axial of cut were kept constant. Three points from machined surface were selected to test the surface roughness. Figure 1 shows the workpiece setup on the tester.

Table 2: Helix angle and flute angle of cutting tool

Types of Coated Cutting Tools	Helix angle (°)	Flute angle (°)
 TiSiN (Gold)		
 AlTiSiN (Blue)		
 AlTiN (Grey)		

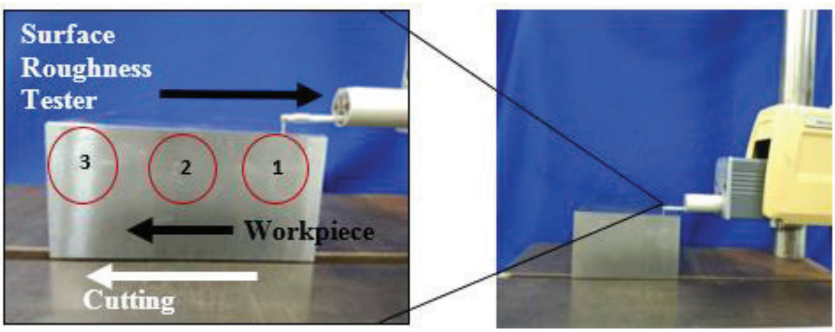


Figure 1: Image of workpiece is setup on surface roughness tester

2.2 Microhardness Tester

The microhardness tests were performed by using the microhardness tester as shown in Figure 2 to determine the hardness of the material. The consideration of material hardness can be obtained from the surface of material of machined surface, and the measurements were taken under subsurface with the distance between indent point 60 μm. The screen of tester showed two types of value of hardness which are hardness in HRC (Rockwell Hardness) and HMV (Microhardness Vickers).

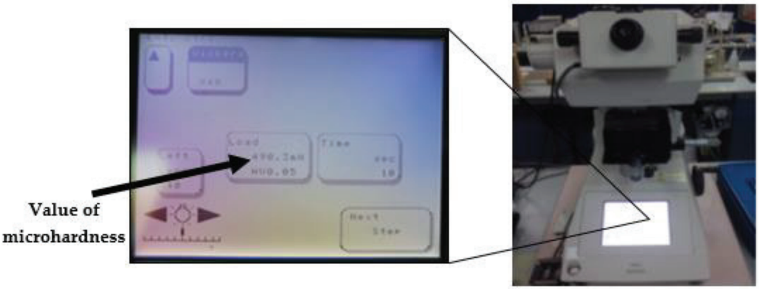


Figure 2: Value of microhardness on the screen

2.3 Optical Microscope

The instrument was used to observe the presence of microcrack defect, microstructure and formation of white layer of Heat Effected Zone (HEZ) into the specimen. Three points were taken for each machined surface for image capturing of the surface integrity. There was a limitation for an optical microscope shown in Figure 3 to capture the image because the magnification of lens is up to 1000x only.

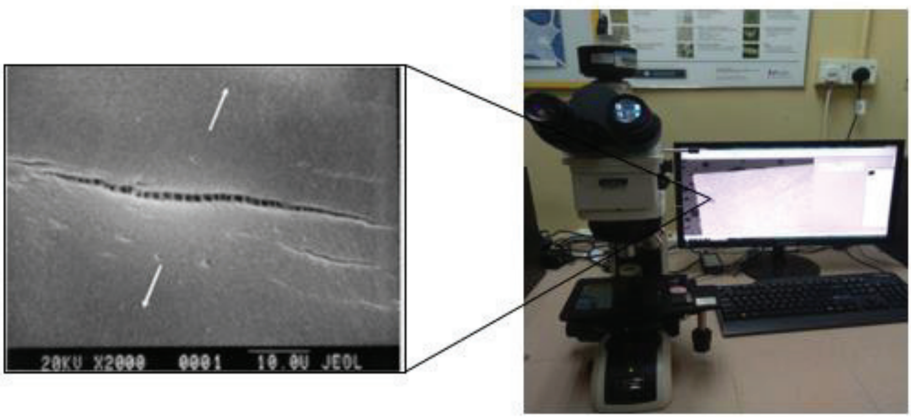


Figure 3: Image setup between lens and specimen

3.0 RESULTS AND DISCUSSION

3.1 Optical Microscope

The surface roughness of the workpiece was measured at 3 different locations along the machined surface by using surface roughness tester.

The more the data was taken, the more accurate the averages of the results. The surface roughness value revealed the performances of coated cutting tool. Figure 4 shows graph value of surface roughness for 3 types of coated tools.

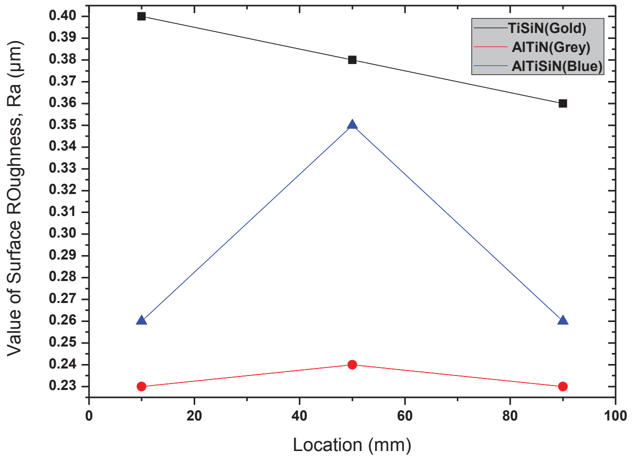


Figure 4: Graph value of surface roughness for 3 types of coated tools

The result distribution of surface roughness when milling DAC52 with 3 types of coated cutting tools in dry condition. The values of surface hardness at all the cutting tools were almost the same each other. For example, for the surface roughness of TiSiN (gold) cutting tool, the data shows that point 1 got the highest value compared to point 2 and point 3 with the decreasing order ranging from 0.40 µm to 0.36 µm.

Figure 4 also depict that the TiSiN (gold) coating had a higher value of surface roughness, Ra, followed by AlTiN (grey) coating and lastly AlTiSiN (blue) coating. The level of goodness of surface roughness value depends on how the application is used. If the application is used to get better friction such as brake pad. Higher value of surface roughness was needed in order to increase the efficiency. Thus, for the application that needed low surface roughness, coating AlTiSiN (blue) was the best choice.

3.2 Microcrack

The machined surface was examined by using Optical Microscope (OM) at higher magnification up to 1000X to determine the discrepancy in the surface due to the changes of cutting tool.

Generally, the machined surface suffered a lot of defect such as microcrack and crash. The example of crack propagation occurred on machined surface as shown in Figure 5.

Figure 5: Image of microcrack occur along machined surface

Table 3 shows the values of microcrack along the machined surface at three different locations. The values were interpreted in the graph shown in Figure 6. The data taken showed that the machined surface using blue coat produced the biggest crack of up to 50 µm, and it occurred at the end of the machining process. The second biggest crack happened at the early stage machined surface of blue coated cutting tool. The second biggest crack happened at the early stage of machined surface of blue coated cutting tool which carried the value of about 35 µm. This showed that the blue coated experienced bad machining operation with the workpiece. This already denied the fact of blue coated to produce less defects because of uncertainty while milling the workpiece and causing some errors [13].

Table 3: Values of microcrack along the machined surface at three different locations

Location (mm) \ Length of microcrack (mm)	Gold	Blue	Grey
10	10	35	0
50	25	25	10
90	13	50	15

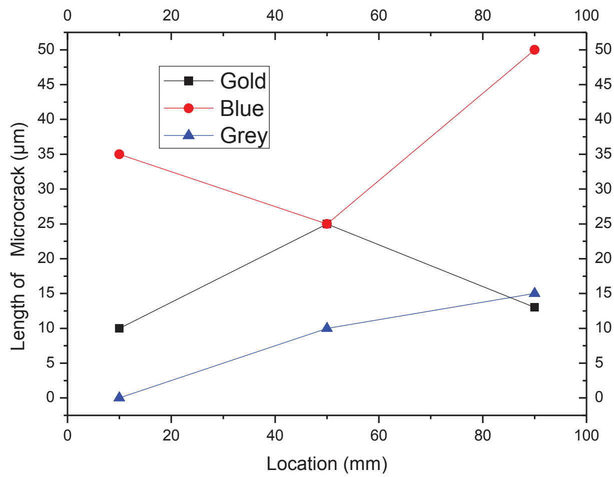


Figure 6: Graph of length of microcrack defects again location

For gold coated, the highest length of microcracks occur at the middle of machined surface which is 25 µm. The machined surface for gold coated cutting tool experienced less microcrack defect as the crack formed was just in a grain size. The same pattern of microcrack defects was found for both operations under gold and grey coated cutting tool. The direction of microcrack formed followed the cutting and feed direction during the cutting process. The small pore crack presented on the surfaces might not interrupt the microstructure of DAC52, which has strong mechanical properties. Microcracks are normally formed in machining brittle materials or low speed machining process. DAC52 is not a brittle material, yet it has a low possibility of getting a giant crack on machined surface.

3.3 Microstructure

Microstructure of the machined surface of DAC52 specimen was studied and analysed by comparing three machining processes. The image of image can be revealed if the lens was capable to penetrate the surface of workpiece. The nital solution (Nitric Acid + Ethanol) was needed in this phase to remove shiny surface, so that the image scanning was able to penetrate the surface to get the microstructure. The distance between grain sizes was determined as they revealed the performances of all three coated cutting tools. Even though the properties of DAC52 hardened steel were good in machinability and had high strength, there was a tendency for the microstructure to be deformed.

Figure 7 shows the scanning image of microstructure, which shows grain size of structure of workpiece, while Figure 8 shows the graph of grain size of microstructures of DAC52 after being machined. For the machined surface by gold coated, the grain size varies from 10 µm to 21 µm, but the average values can be considered from 10 µm to 12 µm. Bigger grain size was found on the blue coated, ranging from 18 µm to 21 µm, while for the grey coated, it brought the values from 7 µm to 12 µm. There was a limitation of performance of Optical Microscope, as it can go up to 1000x of magnification only. The measurement scales were taken to 30 µm for each point of specimen. So, it can be concluded that the less disturbed layer underneath the machine surface was due to low cutting temperature promoted to good microstructure pattern. The blue coated was the best selection of cutting tool, as it produced larger distance between grains.

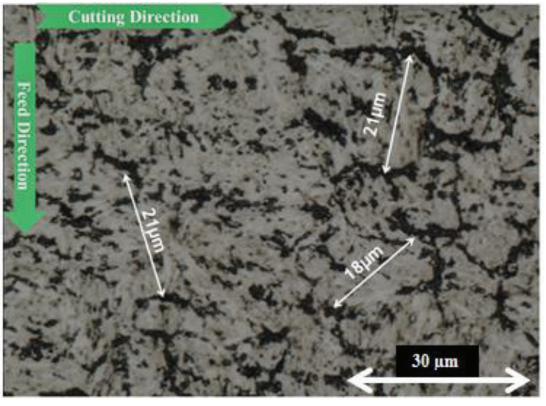


Figure 7: Image of grain size of microstructure

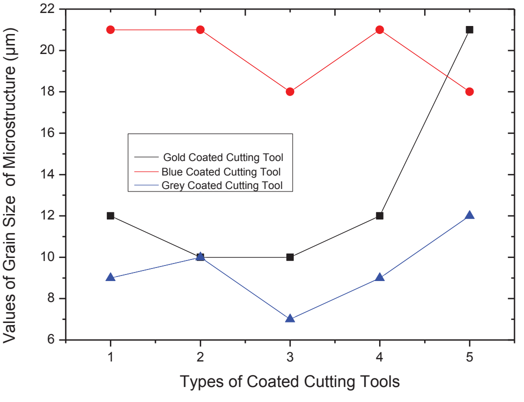


Figure 8: Graph of grain size of microstructure

3.4 White Layer of Heat Effected Zone (HEZ)

White layer is typically a featureless layer formed underneath the machined surface. The formation of white layer was promoted by moderate high-speed milling process produced by HEZ between cutting tool and machined surface. Figure 9 shows a white layer present underneath the machined surface.

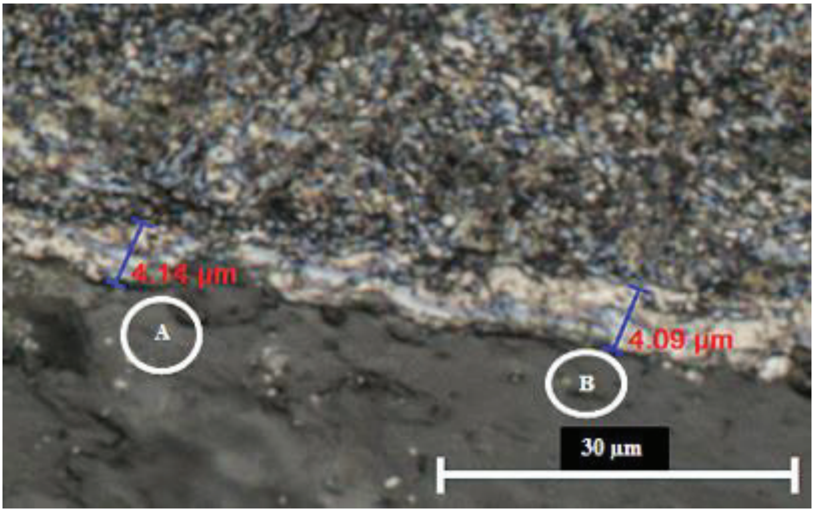


Figure 9: Image of white layer of HEZ

From the observation from graph presented in Figure 10, the thick white layer underneath the surface ranged from 4.14 µm to 2.01 µm. But thicker white layer under the surface was gold coated cutting tool that brought the range to 4.14 µm. The results from all three specimens really showed the cutting temperature contributed a huge factor on formation of this featureless layer. The gold coated carried high temperature compared to others when machined with DAC52, while the blue coated produced lower cutting temperature. The blue coated cutting tool was considered the best cutting tool among them as it produced less defects.

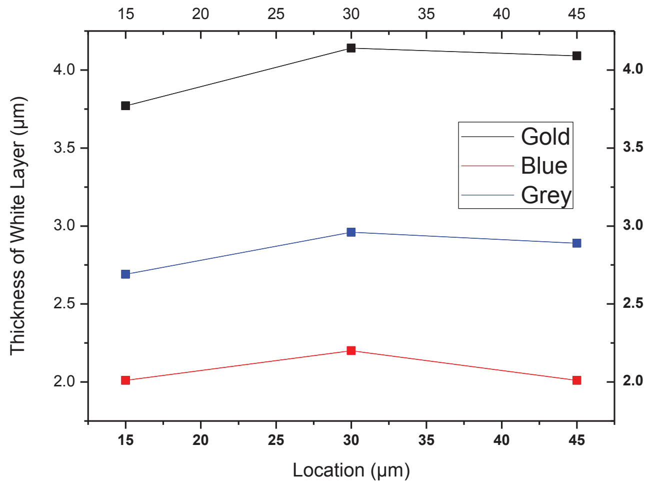


Figure 10: Graph of white layer of HEZ

3.5 Microhardness

Microhardness is a broadly used term referring to the testing of hardness involving materials by using small applied loads. The load given to the surface was 9.807 N with the duration of 10 seconds. The shape of indent point formed after being indented was shown in Figure 11 which brought values from 55 µm to 59 µm.

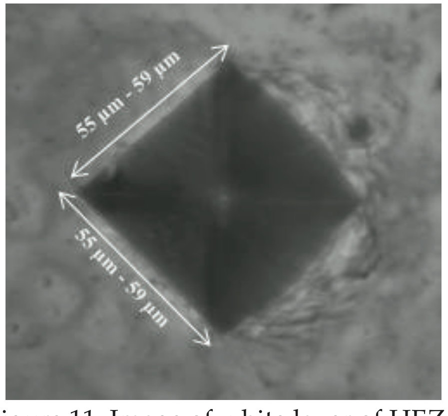


Figure 11: Image of white layer of HEZ

Figure 12 shows the hardness of material increased as the location of indent point was far away from the machined surface. The data showed the highest value of indent point occurred at the distance of 600 µm from machined surface from grey coated cutting tool operation, while the lowest microhardness was found at location 60 µm from the machined surface. The highest value of microhardness found was 53.9 HRC, while lower microhardness was found when machined surface was operated with blue coated cutting tool which carried the value of 51.2 HRC. The tests also found that the average microhardness carried by gold coated was 53.24 HRC, while for blue coated, the average value was 52.27 HRC. Lastly, the average value for grey coated cutting tool was 53.05 HRC.

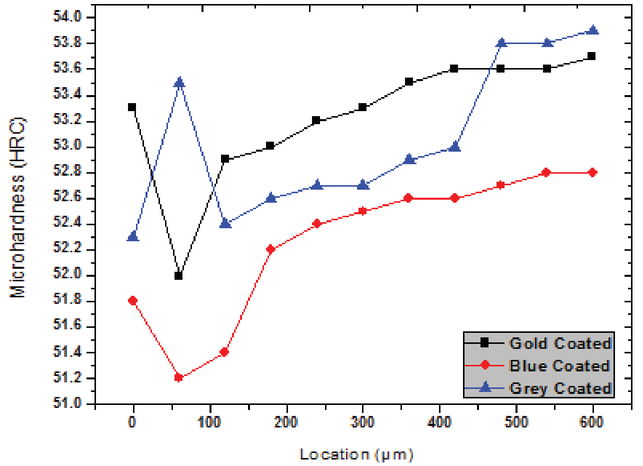


Figure 12: Graph distribution of microhardness (HRC) vs. location (µm)

The increment in the hardness value can be associated with thermal contact occurring on the machined surface. The nearest point with machined surface experienced thermal due to the high cutting speed that generated high temperature while machined. The irregularities of microhardness value were found because of machine error, while the test was carried out. The inconsistency of machine to put the right load to the specimen gave error on data analysis.

4.0 CONCLUSION

From the research done, the performances of coated cutting tool are revealed by the properties of surface integrity after machining operation is carried out. From the findings, it can be concluded that the surface roughness values are lower when experiencing low cutting temperature. The goodness of surface roughness totally depends on the application of product, while the formation of white layer underneath the machined surface is due to the thermal contact and high-speed machining. The lowest value of surface roughness is found when blue coated cutting tool is milled with DAC52, which is 0.24 µm. Lastly, from the finding of the research, the blue coated cutting tool is the best tool to be selected as a tool to be machined because the tool produces less defect such as microcrack and white layer. Several suggestions also suggested for future such as the detailed image of formation of microcracks and microstructure can be produced using Scanning Electron Microscope (SEM) and the performance of surface integrity of hardness steel can be studied with other coated cutting tools.

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