The Effects of Indentation Loading Force and Number of Indentations on the Micro Hardness Variation for Inconel 718

W Noor Fatihah, Mohd Shahir, Muhammad Akmal, Mohammad Shah All Hafiz, Saiful Bahri Mohamed

Abstract*: The accuracy of the hardness test depends on the effects of variations of the loading force and the number of indentations. The purpose of this study was to compare the micro hardness data of these factors. Aged Inconel 718 with a hardness of 450 HV was used as the specimen in this test. The investigation was carried out by observing the amount of dispersion in a set of hardness data at different loads and number of indentations. The applied loading force ranged from 0.05 to 0.3 Kgf, while the number of indentations was set from 10 to 30. From the result, it was found that increasing the applied load brought the hardness value close to the standard hardness of the material. However, an increase in the number of indentations failed to produce an accurate value.

***Keywords* : Aged Inconel 718; Effect loading force; Number of indentations; Micro hardness.**

I. INTRODUCTION

T The Vickers hardness test was established in 1921 as an alternative to the Brinell method for measuring the hardness of a material [1]. The basic principle of the micro hardness measurement involves measuring the length of the diagonal in a material that is deformed by a pyramid-shaped indenter during penetration under a specific load. The micro hardness of the material can be determined since different materials possess different plastic deformation values. The micro hardness check is an important process for identifying changes in the property during the cutting or heat treatment process. However, the hardness testing has many pitfalls. The number of indentations and the appropriate load for the indenter has to be reported. Typical micro hardness testing problem due to accuracy, repeatability and correlation that associated with operator, machine, sample preparation, calibration and testing environment [2]. Quinn et al. explained that the common problems in hardness testing consist of the crosshair technique, indentation cracking, impact, vibration, resolution of optical and indentation size effect [3]. The load varies according to the application; a low load of 0.01-0.05 Kgf is normally used to check thin layers, while small geometries and hardness progressions in specimens with a medium load of 1-3 Kgf. A high load of 30-100 Kgf are used for the Jominy test and surface hardness testing [4]. The drawback of a low load is uncertainty in the result due to errors in the measurement of the diagonal and elastic recovery [3,5]. Generally, more observations will give more accurate micro hardness results. A few observations will suffice to obtain a reasonable result without a waste of effort. During the measurement, there may be a large variation in the micro hardness depending on the type of cutting process and the cutting parameters. The hardness commonly fluctuates by 50% [6]. The hardness is highest close to the machined surface due to work hardening and is gradually reduced by the subsurface depth. During their study on the WEDM cutting process, Kasim et al. reported that the difference between the maximum and minimum hardness was 40-130 HV at different cutting parameters [7]. Another factor to be considered during the testing is the dwell time of the loading. A study by Chuenarrom et al., however, found that the variation in the indentation time did not have a significant effect on the results [8]. In this study, the effect of variations in the indentation load and number of indentations on the Vickers hardness number, HV for Inconel 718 were investigated.

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II. EXPERIMENTAL DETAILS

A. Material and equipment

The workpiece material used for this experiment was aged Inconel 718 grade AMS 5663 as presented in Figure 1. The American Iron and Steel Institute (ANSI) has defined relative ratings (machinability ratings) that materials which scores above 100 are easier to machine Each specimen was cut with a precision cutter into pieces with dimensions of 30 × 20 × 10 mm. The standard value of the hardness was 450 HV. The material was aged at a high temperature of 980 ˚C for 1 hour and then, quenched. After that, the material was heated for 8 hours at a temperature of 720 ˚C, before being quenched slowly to a temperature of 620 ˚C. For this experiment, the samples were ground and polished flat so as to obtain a mirror finish. This process flow follows, according to Kuo et al. **Fig. 2** shows the material after heat treatment and graph of process treatment [9]. A micro hardness tester, the Mitutoyo HM 200 series with 18 runs, was used throughout this experiment (see figure 3). Inconel 718 specimen was impressed with loads of 0.05 kgf, 0.1 kgf, 0.2 kgf and 0.3 kgf using a Vickers indenter. Dwell time is set of 10 sec. The minimum spacing between indent locations was 2.5 times. The diagonal indenter size of 3-5 mm to be used in this experiment. Location indenter of specimen is random. Then, each test will repeat at least three times with the same load and time. The average three readings were recorded in HV value of a specimen. Lastly, the value obtained will be analyzed by using mini tab software.

Fig. 1. Aged Inconel 718 AMS 5663 (155 x 106 x 50 mm)

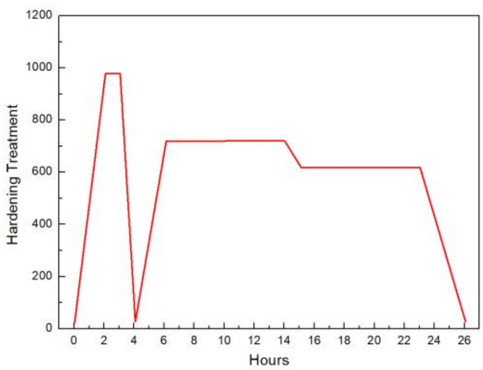

Fig. 2. Flow of aged hardening treatment of Inconel 718 [9]

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Effect of indentation load on microhardness certainly

Fig. 3 shows the size of the indentation at different loads. Higher loads increased the diagonal length. During the determination of the micro hardness, it was difficult to locate the exact tips of the crosshairs for the length measurement. Therefore, the size of the indentation had an effect on the reading and calculation. The measurement uncertainty increased when the size of the indentation mark decreased. The Vickers indentation at loads of 0.05, 0.1, 0.2 and 0.3 Kgf for 450 HV were approximately 14, 20, 28, 35 µm in size, respectively. With an image magnification of 50x, the position of the crosshairs snapped by one step on the indentation tip and created an error of 0.2 µm, where the reading changed with a maximum HV of 2.3, 4.6, 9.2 and 13.9. Therefore, it is vital that the diagonal length be measured precisely. Preferably, a higher load should be used so as to minimize the error at a large diagonal size. However, the application of too heavy a load may give rise to excessive cracking that may interfere with the reading. This was proven by the data that was gathered during the experiment.

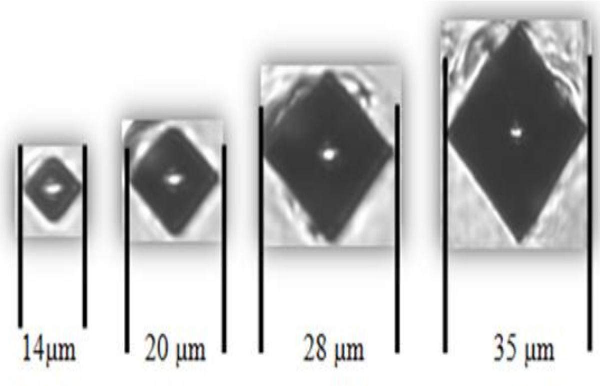

Fig. 3.Variation of diagonal indenter size with different loads (0.05, 0.1, 0.2 and 0.3 Kgf)

Measurement of HV hardness was done up to 35 µm below the surface, as most previous studies found that the hardness at that distance was stable with bulk hardness. For the Vickers hardness setting, the weighting scale depends on the measured material. For soft, adequate material with a small power value because the bends will give a large size, as well as for materials expected to have high hardness, the value of the applied force is greater so that the burge image is clearer and easier to calculate. The previous researchers used the ranges from 50 to 500 gf for idling time for 10-15 seconds for Inconel 718 alloys [9]. Practically, the large curved surface display is better than reading compared to a small display, this will reduce the error of the calculation of the width of the curve and make it more reliable [10]. Experiments of the effects of microstructure and temperature changes on hardness were performed, to identify the changes in hardness due to temperature mechanics and plastic appearance defects (**Fig. 4**).

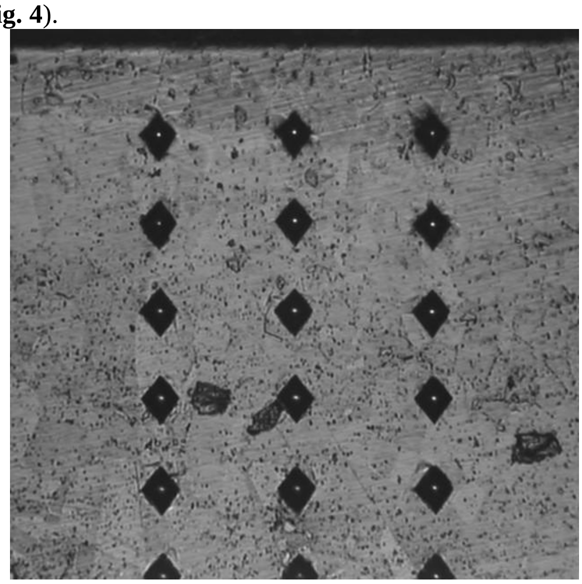

Fig. 4. Examples of measurements for micro hardness (HV)

The cross-validation from the plotted graph in **Fig. 5** showed that the indentation with a higher load gave a better result that was close to the standard hardness of 450 HV.

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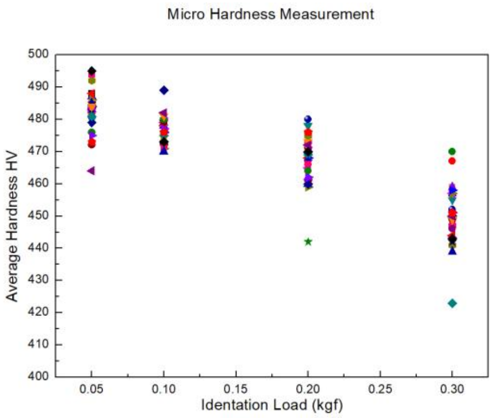
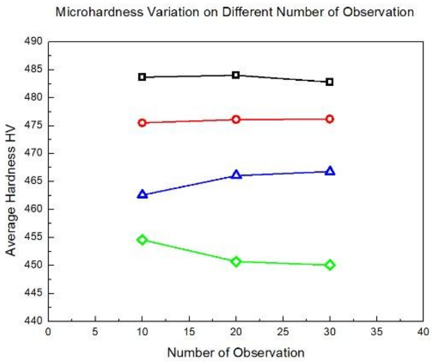


Fig. 5. Micro hardness range at different indentation loads

B. Effect of number of indentions on micro hardness certainty

It was necessary to take into account the number of observations during the experiment. **Fig. 6** shows the effect of the number of observations at different indenting loads and average hardness versus number of tests. The results showed that there was a minimum variation in the hardness readings at small loads (0.05 and 0.1 Kgf) compared to 0.2 and 0.3 Kgf. ANOVA was used to statistically identify the significant effect on the HV result.



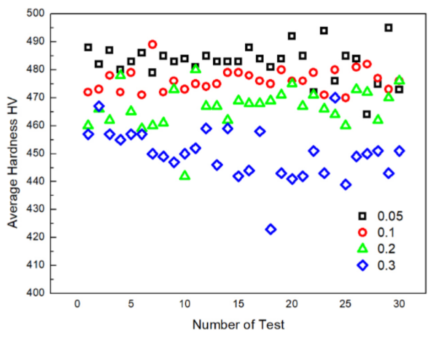


Fig. 6. Micro hardness results carried out for various measurements

Based on Table- I, the model was fit on 20 observations trials, and the first line of the table summarizes the model. The sum of squares (Partial SS) for the model is 2548.896 with 2 degrees of freedom (df). This line results in a mean square (MS) of 1274.448/2≈637.224. The corresponding F statistic is 193.6457 and has a significance level of 0.0001. Thus, the model appears to be significant at the 0.01% level. The model that was generated was found to be significant with a p-value of less than 5%. The indentation load with a p-value of less than 0.05 indicates that this factor was significant compared to the number of indentations. The minimum indent burden is more deviate as summed up in Table- II.

Table- I ANOVA table for micro hardness effect

ANOVA for Response Surface Linear Model						
Analysis of variance table [Partial sum of squares]						
Source	Sum of Squares	Dof	Mean Square	F-Value	P-Value	
Model	2548.896	2	1274.448	193.6457	< 0.0001	significant
Load	2547.759	1	2547.759	387.1185	< 0.0001	
No. of Indentations	1.137346	1	1.137346	0.172814	0.6844	
Residual	85.55741	13	6.58134			
Cor Total	2634.453	15				

The error of measurement in Vickers tester which is ± 0.1µm		
Loads of indents Unit	*Average of diagonal length on a different load Unit*	*Percentage of error gaps Unit*
0.05kgf	14 µm	0.8 %
0.1kgf	20 µm	0.5 %
0.2kgf	28 µm	0.4 %
0.3 kgf	35 µm	0.3 %

Table- II Percentage error gap with a different indented load

IV. CONCLUSION

In the present research, experimental investigations were performed to study the effect of the loading force and the number of observations on the accuracy of the hardness readings for Inconel 718. The major findings are summarized as follows:

In the indentation hardness, the most important thing is the accuracy of the readings. So, the repeatability of the reading was one important factor in this study. Then, in the indentation hardness, the number of observations was shown to have different effects on the hardness value. The results showed that with the lower repeatability of the number observations, the readings were significantly inaccurate, but when the repeatability was much higher, it did not have much of an effect on the readings. Based on that, a suitable number of observations required to obtain the best value of hardness was identified, namely 20 observation trials.

In this study, the results showed that when the load force applied on the same material was increased, there was a significant decrease in the Vickers hardness results. Moreover, it could be clearly seen, that an indenting load that was lower than 0.3 Kgf was inappropriate for measuring the hardness distribution. An applied load of 0.3 Kgf was used to obtain accurate results in terms of the hardness values. It can be concluded that the optimum parameters have been obtained for producing the desired response, namely that the best number of observations to use is 20 trial measurements and a suitable indentation load of 0.3 Kgf is required for Inconel 718. This was supported by the results that were obtained. From this study, it is understood that varying the conditions can have different effects on the hardness value. By understanding the effect of loading force and number of indentions load it may contribute a good basis understanding for new strategy of machining of Inconel 718 in order to improve for future study.

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