Ceramic tools insert assesment based on vickers indentation methodology

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Abstract. In the interrupted cutting process, the risk of tool chipping or fracture is higher than continues cutting. Therefore, the selection of suitable ceramic tools for interrupted cutting application become an important issue to assure that the cutting process is running effectively. At present, the performance of ceramics tools is assessed by conducting some cutting tests, which is required time and cost consuming. In this study, the performance of ceramic tools evaluated using hardness tester machine. The technique, in general, has a certain advantage compare with the more conventional methods; the experimental is straightforward involving minimal specimen preparation and the amount of material needed is small. Three types of ceramic tools AS10, CC650 and K090 have been used, each tool was polished then Vickers indentation test were performed with the load were 0.2, 0.5, 1, 2.5, 5 and 10 kgf. The results revealed that among the load used in the tests, the indentation loads of 5 kgf always produce well cracks as compared with others. Among the cutting tool used in the tests, AS10 has produced the shortest crack length and follow by CC 670, and K090. It is indicated that the shortest crack length of AS10 reflected that the tool has a highest dynamic load resistance among others insert.

1. Introduction

In practice, the machining process is optimized based on factors, such as tool failure, cutting temperature, cutting force or power, chatter, surface finish and dimension errors left on the workpiece. The performance of the cutting tool, or the machinability, is normally measured on the basis of the life of tool edge, surface texture, and chip volume ratio as a function of tool geometry. In relation to ceramic tools, especially in the application in interrupted cutting, failure of the ceramic tool is occurred due to chipping or fracture. In interrupted turning, the tool undergoes a cyclic load and when the tool enters the work material, the cutting edge suffers a shock load or the impact force.

Ceramic cutting tools are very popular in engineering industries because of their better performance in high cutting speeds. This tool can be operated at high material removal rates. In comparison with usual cutting tool materials such as high-speed steel and cemented carbides, the most important aspects of ceramics are their higher wear resistance, higher hot hardness and higher chemical stability. Desperate limitation s of these tools are the ceramic properties of low tensile strength and poor toughness [1].

Vickers Indentation method has widely used in the evaluation of hardness of the hard material, when this method applied to the brittle material the impression of indentation along with crack length produced is used to measure the fracture toughness. The main advantage of the indentation technique is its simplicity, usefulness, and the fact that the fracture initiating cracks approximate natural defects in the brittle material [2]. The results obtained are typically almost equal to the direct test method but minimal specimen preparation, and less amount of material [3, 4].

2. Fracture Toughness

The fracture toughness is an important property required to evaluate the mechanical performance of structural materials. One method used to measure fracture toughness is using Vicker's hardness indentation which yields critical intensity factor (K_{IC}) value of Mode I. This method is principally useful for low fracture toughness of brittle material since it is simple, rapid and permit small sample size. Furthermore, fracture toughness also represents the capability of brittle material to resist the growth of an existing micro crack or flaw. Principally, the indentation technique needs to measure the length of cracks formed around the indentation of the load in excess of the critical load, required to induce cracks surrounding the indentation. The fracture toughness (K_{IC}) of a material is presented by the energy per unit area that is required to produce new crack surfaces and thereby propagate a crack through the material. This value is also known as the critical stress intensity factor represents the effective local stress at the crack tip. It should be emphasized that the fracture toughness value measured using this method is usually not as accurate as those from other more conventional tests. This method relies heavily on the use of indentation models. On top of that, there are a variety of expressions available in the literature and the prospect of selecting the most suitable one for a particular test condition can be varied. Furthermore, most of the models are based on ideal crack patterns that may or may not be present in the tested due to the difference of work materials and indenter to be used. This will affect the result of the indentation test, causing inconsistency between fracture toughness values obtained by the indentation method and those obtained from the conventional techniques.

Normally, fracture toughness (K_{IC}) carried out either using double cantilever beam, a single edge notched beam or chevron-notch test, these methods need complex testing procedure, the samples require a relatively large size of specimens and time-consuming. However, indentation methods require a small amount of specimen in the size of the cracks formed surrounding the indentation impression and at loads in excess of the critical load required to initiate the cracks [4].

When an indenter penetrates a brittle, three different zones can be found in the material. Just below the wedge, where a hydrostatic core produced due to the high compressive stress induced beneath the indenter. Outside the hydrostatic core, the large strain develops due to the pushing action of the core. In this area, tensile cracks may be initiated starting from pre-existing flaws in the material.

Indentation crack may be categorized into two groups according to the geometrical shape of crack just below the indentations surface. First is in the shape of the halfpenny crack system (also called median or radial- median crack system) and the other is in the shape of the Palmqvist crack system [2, 4-6]. To recognize between them is to polish the surface layers of the cracks produced in the indentation zone. The median cracks system, the cracks remain connected to the corner of the diagonal while the Palmqvist crack system, the cracks become detached as shown in figure 1. Lateral cracks are generated in the form of fracture of materials on the surface due to microscopic chipping occurred around an indentation. This fracture is ultimately caused by the propagation of cracks just below the plastic deformation zone and penetrates to the surface specimen during the unloading sequence. Lateral crack has been studied very rarely, as they are usually considered as a secondary indentation crack system that does not impart the strength and seems difficult to model.

From *Mikio Fukuhara et al.* [7], the value of fracture toughness K_{IC} were determined from the hardness indentation tests using hardness-testing machine with a Vickers' diamond pyramid indenter. The K_{IC} value was used to show the performance of cutting tool in machining of Cast Iron with high speed and feed. The K_{IC} value was calculated by the following equation for the median crack:

$$K_{IC} = \frac{0.203 \cdot H \cdot a^{1/2}}{(c/a)^{3/2}} \ldots \ldots \ldots \tag{1}$$

Where H is the Vickers hardness indentation value, 2a is the length of diagonal impression and 2c is the total of indentation crack length. The crack is examined under a scanning electron microscope.
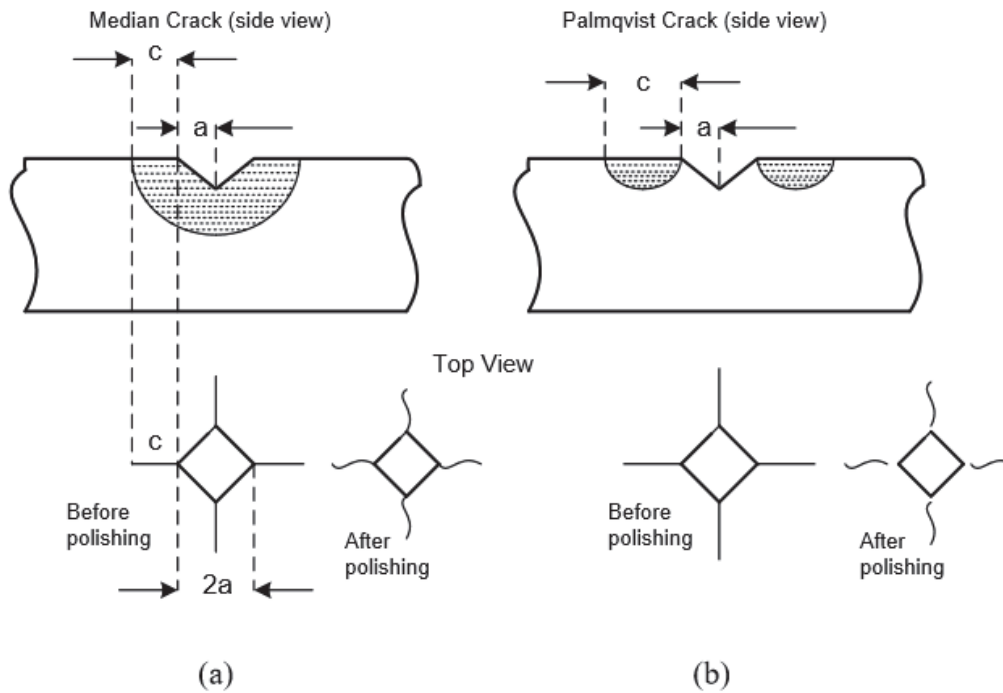
Figure. 1 (a) Median crack system around Vicker Indentor (b) Palmqvist Crack System around indentor

3. Experimental Procedure

In indentation tests, the square pyramidal diamond indenter has been used to evaluate the ceramic tool inserts. Four different loads were used during indentation tests; 0.2, 0.5, 1, 2.5, 5 and 10 Kgf. The cutting tool used were AS10 (S_3N_4) denoted by sample A, CC650 (70%Al_2O_3 +22.5% TiN+7.5%TiC) denoted by sample B, and K090 (70%Al_2O_3 +30% TiC) denoted by sample C as shown in figure 2. Each sample was polished with diamond paste started with 2.5, 1 and finished with 0.5 μm before being tested. The purpose of polishing the tool is to eliminate the residual stress zone on the surface [5]. All indentation were conducted with a constant indenter dwell time of 15s at room temperature. After indentation, the lengths of the cracks formed are immediately measured. The cracks length arising at the four corners of indentation impression were measured, and the total of four crack length of the indentation was divided by four. However, small size cracks around the indentation and cracks branched from the main corner cracks were ignored [4]. The value of fracture toughness K_{IC} was analyzed by using Eq.1.

Figure 2. Types of cutting tools used

4. Results and Discussion

In indentation, the cracks are initiated at the corner of the impression. Nevertheless, only well behave cracks are used for analysis. Based on visual observation during indentation tests, the crack is formed only after unloading. The median crack systems were formed on all types of the tool. The lateral cracks are formed around the surface of the indentation impression figure 2, 3 and 4 and in certain cases, microscopic chipping occurs as seen in figure 5. Microchipping also occurs after unloading. During penetration of the indenter into the body, plastic deformation or destructive of the material occurs beneath the surface. However, the indenter brings about high compressive stresses in the contact region at the same time, inhibiting the separation of atoms. However, as soon as the indenter leaves the penetration point, the situation changes. The plastically deformed thin surface layer maintains tensile stresses under the surface. Since no compressive stress acts in this region now, these tensile stresses may generate one or more cracks despite their small magnitude. Owing to the elastic rebounding of the relieved material, even minute fragments may split off the surface.

4.1. Selection of Suitable Indentation Load

The results show that, the magnitude of indentation load is influenced by the hardness impression and crack formation significantly. Figure 3 (a), (b), (c), (d), (e) and (f) show the results of Vickers indentation of AS10 (Si_2N_3) ceramic with different indentation loads. From the figure, it is seen that the crack length and the hardness impression of Si_2N_3-based ceramic increases with increasing indentation load. The indentation impression induced by indentation loads of 5 kgf is produced better crack length compare to other loads. At lower indentation loads, measurement uncertainly encounter since the small hardness load having difficulties in producing surface crack on each corner of indentation impression. At the higher loads, the breakage and cracking of cutting tool surface make the measurement tending impossible. There is also influence the indentation size, wherein the hardness of the material decreases with increasing indentation load.
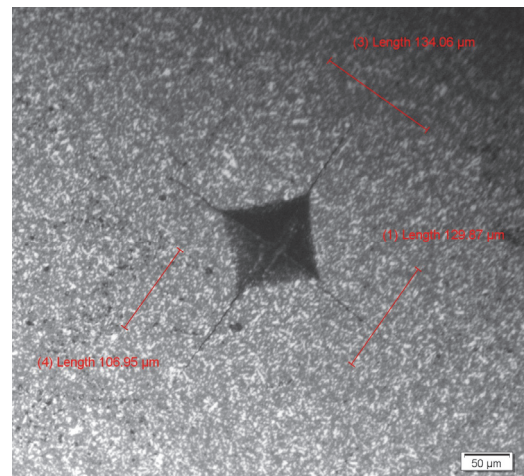
(a)

(b)

(c)

(d)

(e)

(f)
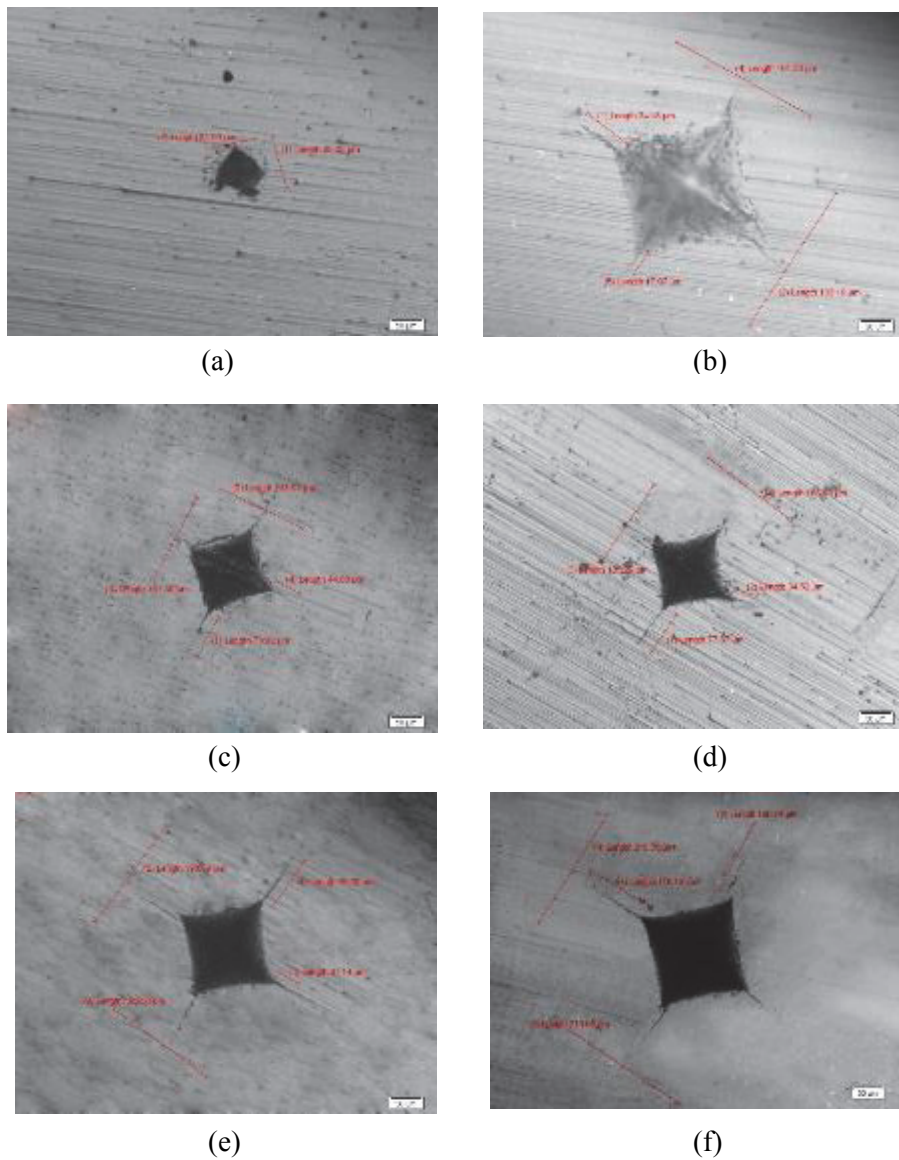
Figure 3. Identation Impression for different load of AAS10 (a) 0.2 kgf, (b) 0.5 kgf,
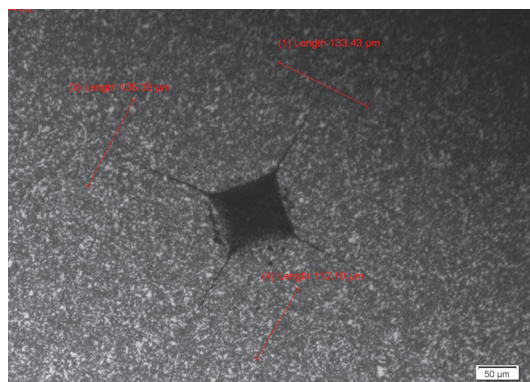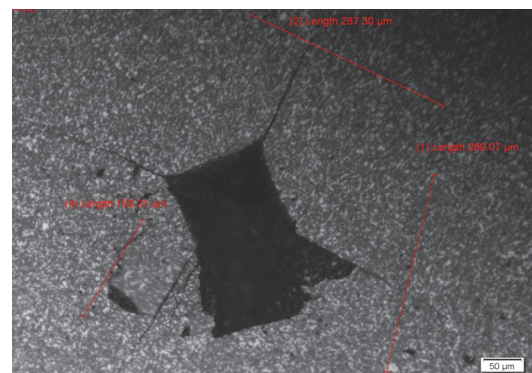(c) 1.0 kgf, (d) 2.55 kkgf, (e) 5.0 kgf dan (f) 10 kgf
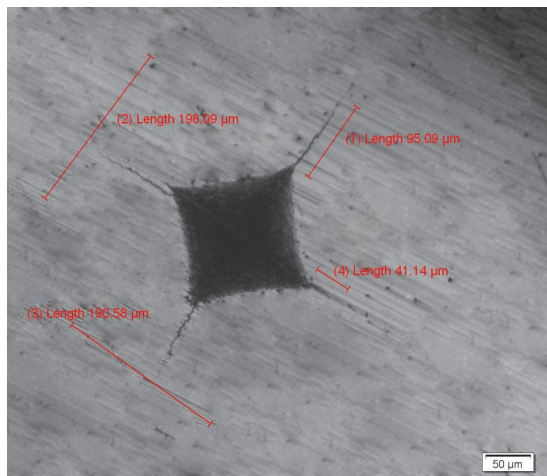
Figure 4. Indentation made at 5.0 kgf load on sample A showing four corner cracks

Figure 5. Indentation made at 5.0 kgf load on sample B showing four corner cracks

Figure 6. Indentation made at 5.0 kgf load on sample C showing four corner


**Figure 7.** Microchipping occurs after unloading on sample C made at 10 kgf.

In general, the indentation impression induced by indentation load of 5 kgf is always well developed as compared to other loads. Figure 4,5, and 6, also show the indentation impression of 5 kgf load for different cutting tool material, all the cutting tool develop well crack length. However, the indentation-induced by indentation load of 10 kgf chipping was found around the indentation impression.

4.2. Crack Length
The indentation study was concentrated on understanding a fracture mechanics interpretation of the crack length and load relation. The crack length increases as the load increases (figure 8). The crack length of sample A is shorter compared to the other samples. It is indicated that the cutting tool has higher fracture toughness but lower hardness. The higher of the crack length meaning that has lower the fracture toughness and the cutting tool has higher hardness and lower fracture toughness, the cutting tool with lower fracture toughness cannot be used for cutting process produced cyclic load such as interrupted cutting.
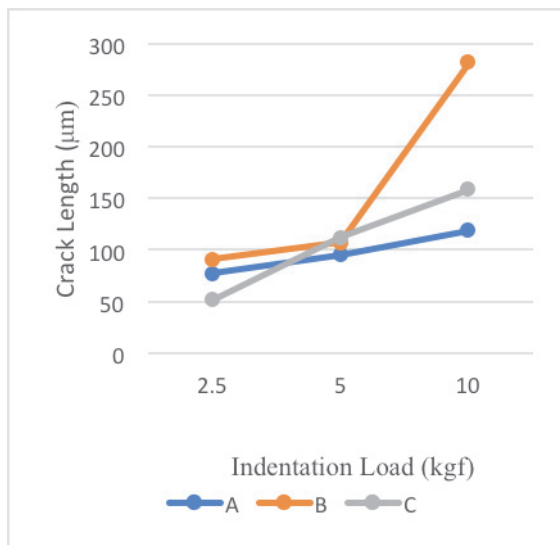
Figure 8. The relation between crack length and indentasion load
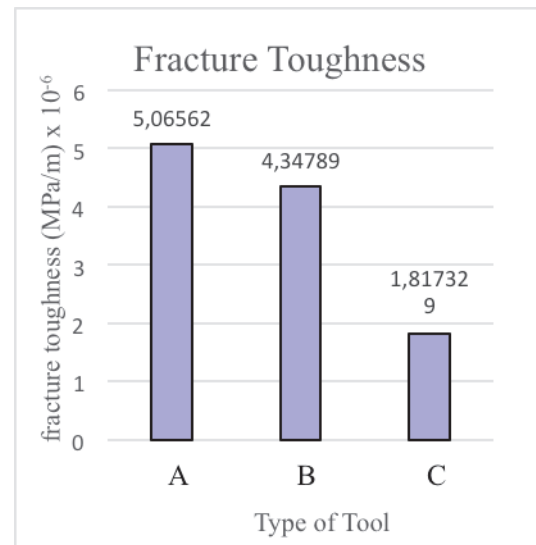
Figure 9. Fracture toughness of tool

4.3. Fracture Toughness (K_{IC})
To determine the K_{IC} of ceramic tool inserts the equation (1) developed by Nihara et al. (1984) was used. The indentation impression induced by indentation loads of 5 kgf is well developed as compared to other loads. Figure 9 shows that the tool AS10 has the highest fracture toughness and follow by CC 650 and K090. It is indicated that higher fracture toughness means the better performance of cutting tool and vise versa.

5. Conclusion
From the result, we can conclude that, Based on visual observation during indentation tests, it can be concluded that, the crack is formed only after unloading. The median crack systems were formed on all types of the tool. Lateral cracks on the surface are formed around the indentation and microscopic chipping usually occurs after unloading. The indentation impression induced by indentation loads of 5 kgf is produced better crack length compare to other loads. At lower indentation load, the problem altered relay on the load dependence of hardness tester and from measurement uncertainly owing to the small indentation impression size. At higher load, the cutting tool pronounces to chipping around indentation impression. The crack length of sample A is shorter compared to the other samples. It is indicated that the cutting tool has higher hardness and lower fracture toughness, the cutting tool with lower fracture toughness cannot be used for cutting process produced cyclic load such as interrupted cutting.

Acknowledgements

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