# DETERMIMNING THE FRACTURE TOUGHNESS OF $B_4C$-NANO$TiB_2$ COMPOSITE BY USING VIF METHOD AT DIFFERENT LOADS

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**Abstract** - In this paper, Boron Carbide ($B_4C$) nanocomposite samples with a volume of 8% of $TiB_2$ were prepared and the values of density, hardness and elasticity modulus were determined and then the fracture toughness ($K_{IC}$) values were calculated by using various $K_{IC}$ formulas with Vickers Indentation Fracture (VIF) test method using loads of 100 and 150 N and their results were compared to each other. The results show that the new equation utilizing cracks leads to high accuracy and efficiency compared to other relations.

**Keywords** - Fracture toughness; Nanocomposite; VIF method.

## I. INTRODUCTION

There are different techniques for measuring the $K_{IC}$ values of materials; which can be divided into two groups. One group includes conventional fracture mechanics and determines $K_{IC}$ values by using notches and induced pre-cracks. This group of techniques, which has been employed for many years for determining the $K_{IC}$ values of different parameters, uses methods such as Single Edge Notch Beam (SENB), Single Edge Pre-cracked Beam (SEPB) and Chevron Notched Beam (CNB). Some of these methods have been used for obtaining the $K_{IC}$ values of biomaterials as well [1,2]. The second group, which is known as indentation fracture (IF) methods, is based on the use of a sharp indenter such as Vickers/Knoop indenter. In general, depending on the type of material and the needed degree of accuracy, each abovementioned methods is used differently [1,3]. However, according to the existing reports, IF techniques are more commonly employed in research works for determining the fracture toughness of ceramic materials, biomaterials, hard biological tissues, etc. [4-9].

The IF method for brittle materials can be classified into various groups such as Vickers Indentation Fracture (VIF), Cube Corner Indentation Fracture (CCIF), Vickers Crack Opening Displacement (VCOD), and interface indentation fracture (IIF) test [9]. Requiring less equipment and raw material, and easier and faster preparation of test specimens are some of the advantages of the IF method [4, 8, 10]. In the VIF technique, the $K_{IC}$ value of specimens is often determined by directly measuring the length of cracks created by the Vickers diamond tip around the indented zone of a sample, using the relevant governing equations [9]. A variety of equations exists in this method; some research works have reported the high accuracy of this technique for some ceramics [11] and some other works have reported the existence of large errors, even up to 48% [6].

In general, two models of Palmqvist and median/half penny cracks are considered in the VIF approach [12]. In the Palmqvist crack model, the length of the formed cracks is assumed to extend only from the tip end of the indented zone [13]; while in the median/half penny crack model, the crack length is assumed to extend radially from the center of the indented zone [14]. Also, the Palmqvist model and the median crack model mostly occur at low and high loads, respectively. A simple way to make a distinction between these two models is that in the Palmqvist crack model, after polishing the surface of a tested specimen, the formed crack is usually seen separated from the diamond-shaped surface trace left by the Vickers indenter; However in the median crack model, the crack is completely attached to the surface trace left by the indenter [15, 16]. Another way of recognizing these two models is that if $c/a < 2.5$, the model will be assumed as the Palmqvist crack model and if $c/a \geq 2.5$, the model will be considered as the median crack model [17, 18]. Figure 1 shows these two models and their differences.

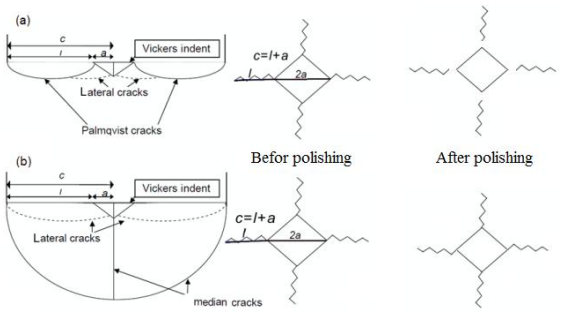


**Fig. 1: Crack traces left in the sample by the Vickers indenter; (a) Palmqvist crack model, (b) median/half penny crack model**

In this research, the $K_{IC}$ values of nanocomposites $B_4C$-8 vol. % Nano$TiB_2$ is determined by VIF test experimentally and the results are compared with the output values of these equations. Also, the loading process in VIF method plays an important role in determining the fracture toughness.

## II. EXPERIMENTAL PROCEDURE

In this study, a volume of 8% of $TiB_2$ nanocomposite powder was used which is prepared by sol-gel method in combination with $B_4C$. This nanocomposite powder contains 2 volume percent of carbon, as an additive. Method of preparation of the samples is based on the research activities carried out by Moradkhani et al [19]. In this method, after weighing the raw materials by a digital scale, raw materials were mixed by planetary mill in isopropanol for 2 h in 150 rpm. After milling, grout was vaporized by means of heating in an oven at 110 ºC for 24 h. After sifting the powder and obtaining the uniform particle size, it was formed in cylindrical parts with the diameter of 0.5 cm and height of 1 cm by hydraulic press with the pressure of 80 MPa. Then, the cylindrical specimens were sintered at 2300 °C by hot-press method in argon atmosphere for 1 h. After polishing the specimens, VIF method was used to determine the $K_{IC}$ and mechanical properties of specimens.

The density and porosity of the specimens were measured using the Archimedes method. The elastic modulus of the specimens was determined according to ASTM C769. Hardness determination of the specimens was carried out with Vickers method according to ASTM C1327. Using Eqs. 1 and 3, $K_{IC}$ of samples can be calculated as follows [11, 14, 20].

$$K_{IC} = 0.00366\left(\frac{E}{Hv}\right)^{1/2} t_{Ave}^{3/2} \frac{P}{A^{3/2}} \quad (1)$$

$$K_{IC} = 0.016\left(\frac{E}{Hv}\right)^{1/2} \frac{P}{C^{3/2}} \quad (2)$$

$$K_{IC} = 0.0089\left(\frac{E}{Hv}\right)^{2/5}\left(\frac{P}{a.C^{1/2}}\right) \quad (3)$$

Where E is sample's Young's modulus, Hv is sample's Vickers hardness, P is value of the applied load for indenting the Vickers impression, $t_{ave}$ is average thickness of micro cracks formed around the indented section, A is surface area of the effect of whole micro cracks formed around the indented section of the sample, C is the value of the crack length of median/radial and a is half of diameter of the indented section on the sample created due to application of the Vickers diamond. The average resulting from seven measurements per equation was reported as the sample's fracture toughness.

## III. RESULTS AND DISCUSSION

Figure 2 represents the values obtained by different equations of Vickers indentation tests on the samples with a load of 100 N and 150 N. As Figure 2 shows, the change in the $K_{IC}$ is not tangible for each equation. Figures 3 and 4 illustrate the effect of Vickers test on some specimens in loads of 100 and 150 N, respectively. Eq. 10 is the most recent of these equations, and by comparing the results obtained by this and other equations, it is found that Eq. 10 yields fairly accurate results. The accuracy of this equation in determining the $K_{IC}$ values of some other brittle materials verifies findings of this research [21,22].

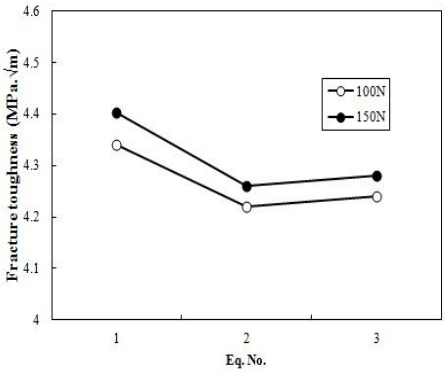


**Figure 2: Values of fracture toughness of $B_4C$-Nano$TiB_2$**

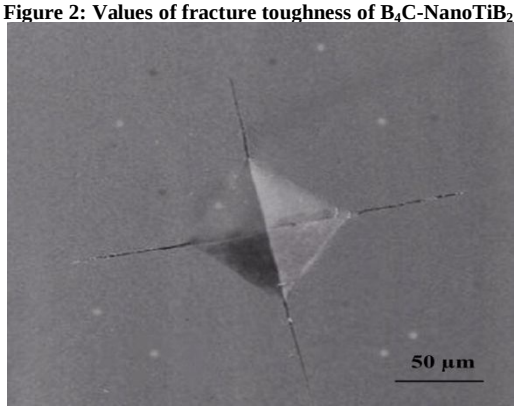


**Figure 3: Effect of Vickers test on the sample at the load of 100N**

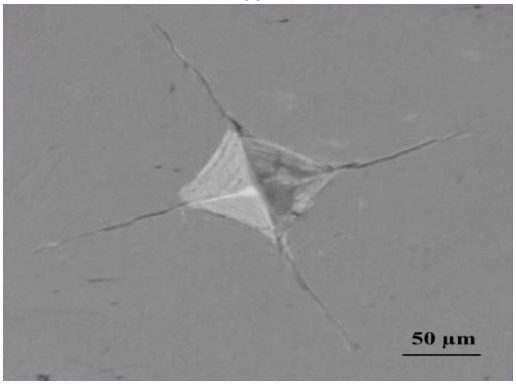


**Figure 4: Effect of Vickers test on the sample at the load of 150N**

## CONCLUSIONS

This research investigates the influence of crack growth in the various loads of $B_4C$-8 vol. % Nano$TiB_2$ nanocomposites. The following results can be noted:

- The $K_{IC}$ value obtained 4.2 - 4.4 MPa.√m and results obtained by the recent equation (Eq. 1) enjoy acceptable accuracy compared to results of other relations.

- Results of $K_{IC}$ are independent in loads of 100 and 150N in VIF method. In fact, comparing the fracture toughness results obtained from the VIF method, it is figured out that values obtained by VIF method, by taking proper loadings into consideration, causes the difference between results of various VIF equations for each sample to be less than 5%.

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