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Physical Properties Study on Ti-C/Nano-Ceramics Composite

Abstract- The effect of introducing Al₂O₃ and CuO nano particles on the physical properties of sintered Ti-C based materials has been studied. Titanium and carbon elemental powders have been mixed with nanoparticles of Al₂O₃ and CuO to produce composites of Ti-C/ceramics at 1100 °C. The XRD results show that for different amount of mixed nanoparticles, TiC, TiO₂, and some rest of the reacted powders are the most dominant stable phases. In terms of physical properties, the results show that the raised Al₂O₃ percentage leads to gradually increase in apparent density of the sintered mixture as compared with the purely prepared TiC. Moreover, porosity and water absorption decrease with increasing Al₂O₃ percentage. On the other side, adding CuO to the sintered mixture causes in decreasing the apparent density. Furthermore, it was observed that CuO creates much porosity and increase water absorption of the sintered mixture.

Keywords- Ti-C/nano-ceramics composite, nano additives, physical properties.

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1. Introduction

Titanium carbide and its composite materials have a wide range of different applications [1].

It is in good condition to be a candidate for many realizations like high hardness; thermal and chemical stability, wear, and high melting temperature [1 - 2].

Furthermore, the transition metal carbides and nitrides are suggested to be used for many potential applications as they combined some physicochemical features of ceramics beside the electronic characteristic of metals [3]. It is also reported that titanium carbide is an attractive material for the inert matrix fuel of GFR fuels [4]. Other applications such as gas-cooled fast nuclear reactor matrix materials, coatings, aerospace engineering, and interconnected material in solid oxide fuel cell are reported for such material [5].

The main mentioned problems facing the TiC production are the high melting point and low diffusion coefficient. Therefore, its sintering must be conducted under high temperatures and normally high pressure [1-5]. Moreover, the consolidation of sintered powders is a requisite for TiC as it is appeared to be one of its limitations [6]. It is well known that the fully dense products of TiC are very much difficult to be produced due to its strong covalent bond [7]. The limitation of having density ceramics is also reported for many other material systems [8-9].

According to high interface energy of nano particles, more attention has been given to the field of nanocomposites after 1991 [10]. In this work, it is firstly focused on producing Ti-C/nano ceramics using Al₂O₃ and CuO as nano additives. Hence, the effect of such nano particles on the physical properties presented by the apparent density and water absorption has been investigated along this direction.

2. Experimental

Materials used to fabricate the initial TiC ceramics were elemental powders of Ti (purity of >99%, 10 μm average dimensions) and graphite (purity of >99%, ~ 1μm average dimensions). The additives of nano Al₂O₃ (purity >99% with ~ 68.7 nanometers average size) and nano CuO (>99%, with 76 nanometers ~ average size) were added to form mixtures of about 2%, 4%, and 6% weight percentage of each addition, sequentially. For each addition, the powder mixture was mechanically mixed up for 1 hour with 60 rpm. The mixture was then uniaxially compacted for 15 min where the compression speed of the hydraulic press is 1 mm/s. Three different loads of 5, 10, and 15 ton were used for each different addition during compacting. After all, compacted mixtures sintered with the in Ar. atmosphere at 1100 °C [11]. The holding time of each sample was 1 hr., then the chamber was cooled down

slowly. Furnace controller was programmed to achieve the temperature of 500 °C with the rate of 40 ° per min. and then to 1100 °C with the rate of 20 ° per min. as shown in Figure 1.



Figure 1: The prepared samples

The XRD measurement was achieved using Shimadzu (XRD 6000) employing Cu K α with the wavelength of 1.54 Å, the measuring settings was 60 Kv and 80 mA. Apparent density, apparent porosity and water absorption have been measured using Archimedes method according to ASTM C373 by using the following steps [12]:

1) The dry weight of each sample is measured just after sintering (W_d).

2) The sample is then boiled in deionized water for 5 hour and cooled to room temperature for 24 hour and weighed the sample (immersed weight (W_n)) and weighed the sample in deionized water (saturated weight (W_s)).

These properties are calculated from the following rules:-

$$\text{(Apparent density)} \rho_a = \frac{W_d}{W_d - W_n} \times \bar{D} \quad (1)$$

$$\text{(Apparent porosity)} P_a = \frac{W_s - W_d}{W_s - W_n} \times 100 \quad (2)$$

$$\text{(Water Absorption)} W_a = \frac{W_s - W_d}{W_d} \times 100 \quad (3)$$

ρ_a : Apparent density in g/cm³.

W_d : the weight of the dry specimen in g.

W_n : the weight of the immersed test specimen in g.

\bar{D} : Density of water in (g/cm³) and equals to about 1 g/cm³.

P_a : is apparent porosity percent.

W_s : the weight the saturated test specimen in g.

W_a : Water Absorption

3. Results and discussion

Figure (2) shows the XRD result for the initial pure sintered mixture of Titanium and Graphite. It is obvious that at 1100 °C, almost pure TiC phase with a cubic crystal structure is appeared to be the most dominant peaks [13]. The required temperature presented here is comparatively lower than what mentioned for the condition of

pressureless sintering or other process like spark plasma sintering [5 - 14]. At this point, it is reasonable to say that titanium carbide phase is the most stable phase especially in the absence of other additives, while with additives, TiO₂ phase is the most stable as shown in figure (3a) and (b). In other words, the ceramic additives are expected to be more stable until the temperature reaches the final sintering level and then start interacting with the phase formed during the holding period.

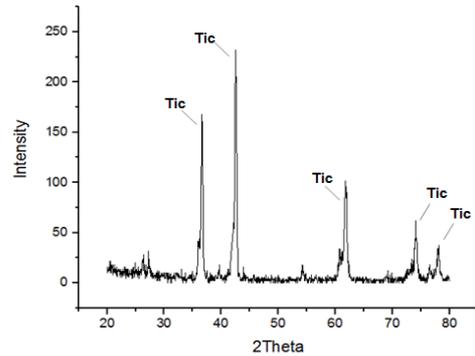


Figure 2: the XRD result of Ti-C mixture sintered at 1100 °C

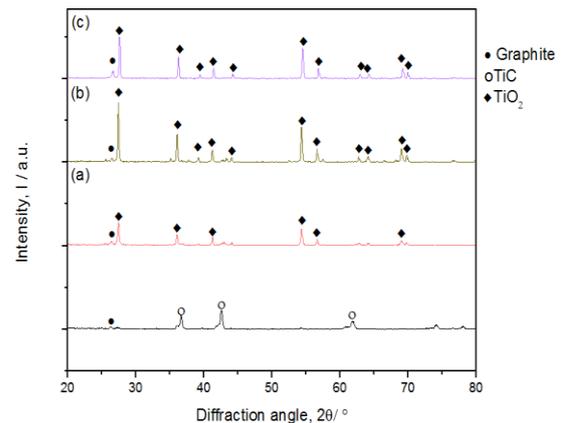


Figure 3a: Shows the comparison between Ti-C without additives and a- with 2%Al₂O₃, b- 4%Al₂O₃ and c- 6%Al₂O₃.

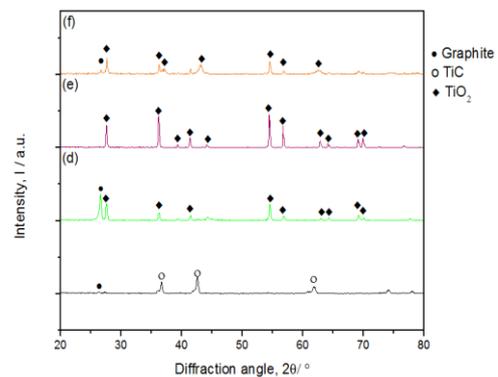


Figure 3b: Shows the comparison between Ti-C without additives and a- with 2%CuO, b- 4%CuO and c- 6%CuO.

The relationship between apparent density and different weight percentages of nano additives (Al_2O_3 and CuO) to titanium carbide have been shown in Figure 4. It is obvious that the apparent density increases with increasing nano Al_2O_3 weight percentages up to 2% as compared with TiC without any additions. Then, with further increasing Al_2O_3 up to 6% weight percentage the apparent density tends to be further increased. On the other hand, the additions of the CuO result in a decrease for value, which is evident in Figure 4. What is mentioned above may be logically consistent with what appear in Figure 5 form where it is evident that the increase in the Al_2O_3 ratio decreases the value of apparent porosity of the sintered product. It is also corresponds to what showed the behavior of the mix with the addition of copper oxide, where the porosity increases gradually with increasing the CuO percentage as shown in Figure 5.

The relative sizes of the TiC and nano Al_2O_3 can be expected to lead to more compact packing since the inter grain pores would be occupied, so the density of the composite decreases at high nano additive of CuO .

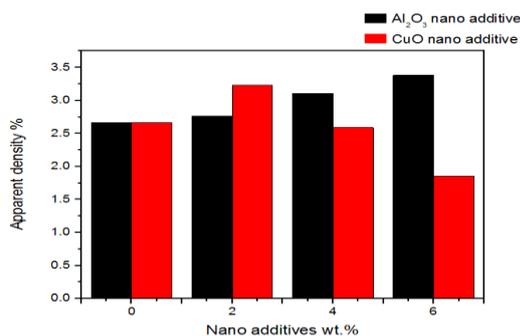


Figure 4: shows the variation of the apparent density in percentage with different wt. % of nano additives

The apparent porosity and water absorption in Figure 6 decrease with the increase of nano Al_2O_3 weight percent because the increasing of apparent density that Attributed to that Al atom have the same size with titanium so it can ingress the lattice. In Figures 7 and 8 the porosity of samples was shown. At (6wt. % nano additives) fills vacancies between titanium carbide particles and graphite and density increase and as a result the water absorption and apparent porosity decrease. This behavior retain to additive increase from formation of TiC and coalescence of TiC particles and decrease in porosity. Then caused by much more compact packing. Moreover, increasing the CuO percentage caused in decreasing the physical properties of the sintered mixture as compared with the prepared TiC sample. The best weight

percentage at (2%wt) for CuO . The results showed here might be in good agreement with what generally studied before [15-16].

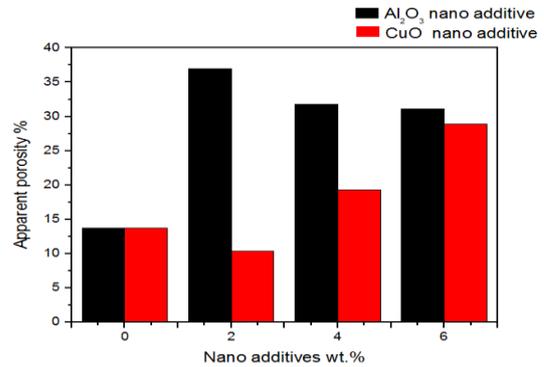


Figure 5: shows the variation of the apparent porosity in percentage with different wt. % of nano additives

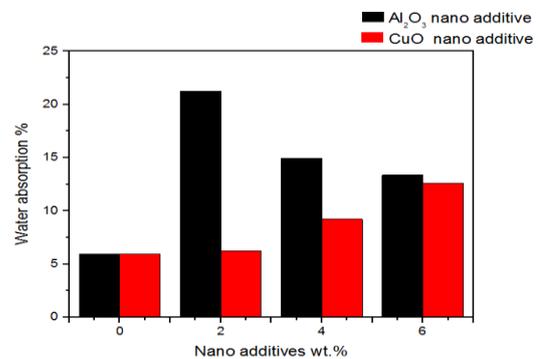


Figure 6: shows the variation of the water absorption in percentage with different wt. % of nano additives

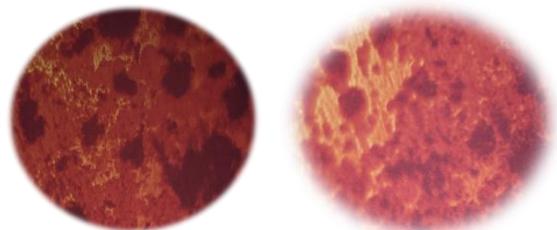


Figure 7: The optical Microscopy of Ti-C/ CuO

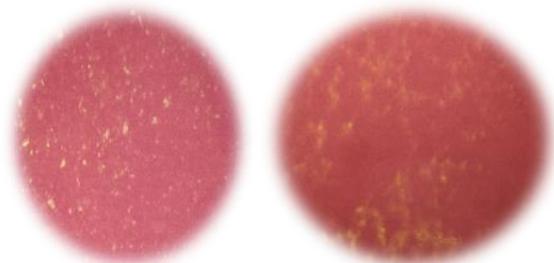


Figure 8: The optical Microscopy of Ti-C/ Al_2O_3

4. Conclusions

From the data represented in this paper, the following facts can be concluded:

- 1- Titanium carbide was successfully produced from elemental powders of Ti and Graphite at sintering temperature of 1100 °C.
- 2- Nano size additives of Al₂O₃ and CuO were added to form the composite of TiC/nano-ceramics.
- 3- The additive of nano Al₂O₃ improves the density and reduces the porosity and then this minimize the water absorption.
- 4- CuO nano-additives gradually impacts to reduce the physical properties of the ceramic nanocomposite.

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