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Tungsten Carbide Matrix Nanocomposite

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Abstract**:** ***Tungsten carbide is one of the ceramic materials characterized by high hardness. It has many uses in manufacturing, including cutting tools, die inserts and other parts that need materials with high mechanical wear resistance. In this study, tungsten carbide was reinforced with alumina and different ratios of graphene to improve its mechanical properties. The BSE mode used the electronic imaging device (SEM) to study the powders and manufactured sample's microstructure. The densification, hardness, and toughness of fabricated specimens were evaluated. The results proved that the density of samples was decreased by adding alumina and graphene due to their low density. The samples' toughness was improved due to the addition of nickel, where no cracks were established from the hardness test. The hardness was increased by adding 2.5 wt % Al_2O_3 and different percentages of graphene up to 0.9 wt %.***

Keywords: Tungsten Carbide; Graphene; Density; Hardenss; Toughness

I. INTRODUCTION

The cutting tool is an essential variable in metal cutting operations. It is exposed to harsh conditions in the cutting area that require manufacturing it from materials with unique properties. Steel, ceramics, cemented carbides, and super-hard materials are the most common materials used for manufacturing cutting tools. They should be distinguished by high productivity, high wear-resistance, and good tribological properties. Designing new nano-composites by the powder metallurgy technique is a promising way to enhance the performance of these materials. In cemented carbide composite, hard ceramic materials are bonded together by the cobalt metallic binder. It is widely used in fabricating powder press dies and metal cutting tools. The metal phase percentage is generally between 3-30% of the total weight of the compound. The SiC, TiC, and TaC are added to increase the tool's deformation resistance and crater. Also, they restrict the grain size, promotes the formation of metal carbides, and improves thermal stability and oxidation resistance. In cemented carbides, the mechanical properties are influenced by different parameters such as initial powder, particle size, purity, alloy composition, sintering time, sintering temperature, structure homogeneity, and compressive stress. The growth inhibitors VC and Cr_2C_3 also have a significant effect on the microstructure of the WC [1-7]. Graphene has unique properties, and adding a small amount to copper raised its softening temperature and increased its strength and thermal conductivity [9-10]. Generally, improving the wetting between metals and ceramics enhances the adhesion and interfacial bonding between them and, consequently, the composites' properties. Researchers have used the electroless coating method for ceramic powders coating to facilitate the adhesion between the different composite constituents [8, 11]. The effect of adding GNs on copper nanocomposite's mechanical and electrical properties was studied [12]. The results show that Cu/GNs composites exhibited excellent wear resistance. The graphene addition enhanced the mechanical properties of the composite up to 0.5 wt% GNS. An increase of 49.1% in yield strength compared with pure Cu was established [13-14]. This investigation tries to improve the properties of the WC cemented carbide cutting tool by reinforcing it with a graphene nano-layer.

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II. PROCEDURE

A. Materials

The WC, graphene, and alumina powders with the grain size of 3-5 µm, 2-10 nm, and 0.5-1 µm respectively were used to form 5 composites with different weight percentages GNs. The electroless nickel process deposited the Nano-nickel metal on the WC- TiC- Co grains.

B. Electroless Ni Of Wc /Al2o3 / Gns

The cemented carbide, graphene, and alumina powders were coated by Ni in three steps: cleaning, metallization, and Ni precipitation. The nickel was deposited with 10 wt%. The powders were cleaned by stirring in 10% sodium hydroxide solution and acetone, respectively, for 1 hr, then dried at 100 °C for 2 hr. The WC, graphene, and alumina surfaces were coated with silver to facilitate the precipitation of Ni. By adding Formaldehyde, the reaction was established. For electroless nickel precipitation, the nickel chloride was dissolved in 50 ml ethylene glycol; then, hydrazine hydrate was added to the above solution. The NaOH (IM) solution was added with stirring. After the reaction was completed, the nickel nanoparticles were washed several times, then dried at 100 °C for 2 h.

C. Powder Forming And Characterization

The powder samples were cold pressed at 600 MPa and sintered at 1450 °C for 1 h in a vacuum furnace.
1000, 1200, and 2500 SiC papers were used to polish the sample surfaces to investigate the microstructure by SEM. The density of the fabricated specimens was evaluated by Archimedes' method according to ASTM C 373-72, 1984.
The distribution of the diffrent constituents, particles shape, and size S were investigated by Quanta FEG 250 scanning electron microscope.

The Optical microscope device was used to study the cracks that propagate during the hardness measurements and consequently the Fracture toughness KIC according to the Palmqvist method [11-12]. The KIC was calculated from the following relationship:

K_{IC}=6.5 (HV 50/ΣL) $^{1/2}$ MN/mm $^{3/2}$

Where the KIC represents the fracture toughness (MPa), HV represents the value of the Vickers hardness, and (L) represents the crack length.

III. RESULT AND DISCUSSION

A. Raw Material Characterization

Figure 1 exhibits the particle shape and size of the cemented carbide and graphene nano-sheets. It is evident from image (a) that WC grains are sub-rounded with different particle sizes ranging from 3 to 5 µm. It is clear from image (b) that graphene has a nano-layer shape. Photo (c) shows that the Ni particles are spherical and linked together, forming a dendritic shape. The formation of dendritic and aggregation are due to strong interaction among the magnetic dipoles of nickel nanoparticles. Image c also shows the WC particles, Al_2O_3 particles, and graphene nano-sheet coated with nano Ni particles with good adhesion.

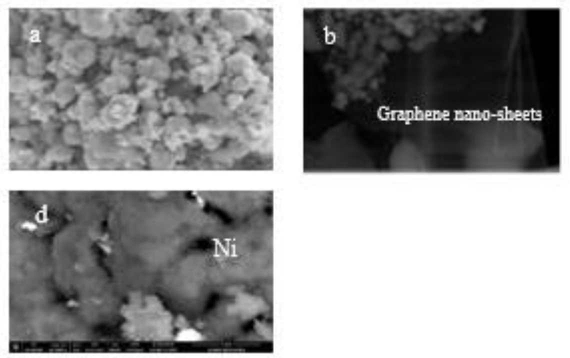

Fig. 1 SEM images of (a) WC, (b) GNs layers coated with silver, (c)Ni and (d, and e) WC/2.5Al_2O_3 /0.9 wt.% GNs coated with Ni

B. Density measurement

Figure 2 demonstrates the density of the fabricated samples at 2.5%Al_2O_3, 10%Ni, and different weight percentages of the graphene. The density of the pieces is reduced by adding Al_2O_3 and graphene nanosheets. This reduction is due to the lower density of the Al_2O_3 (3.987 g/cm^3) and graphene (2.2 g/cm^3), which is less than of cemented carbide (13.26 g/cm^3) and Ni (8.908 g/cm^3).

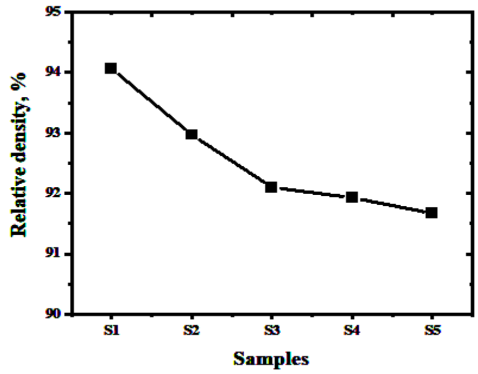

Fig.2 Relative density of the (S1 (WC / Ni), S2 (WC-Ni/Al_2O_3), S3 (WC-Ni-Al_2O_3/0.3GNS), S4 (WC-Ni-Al_2O_3/0.6GNS), and S5 (WC-Ni-Al_2O_3/0.9GNS)) composites.

C. Microstructure of sintered sample:

Figure 3 represents the microstructure of manufactured nanocomposites. The figure shows four regions, which are white-gray (WC), dark gray (Ni), and black spots (GNs). The cemented carbide particles are homogeneously distributed and diffused with the added nickel element. In the second sample, some pores are observed. The dark spots that represent the graphene layers are homogeneously distributed, and this can be attributed to the stirring for a suitable time 30 min during the electroless coating process.

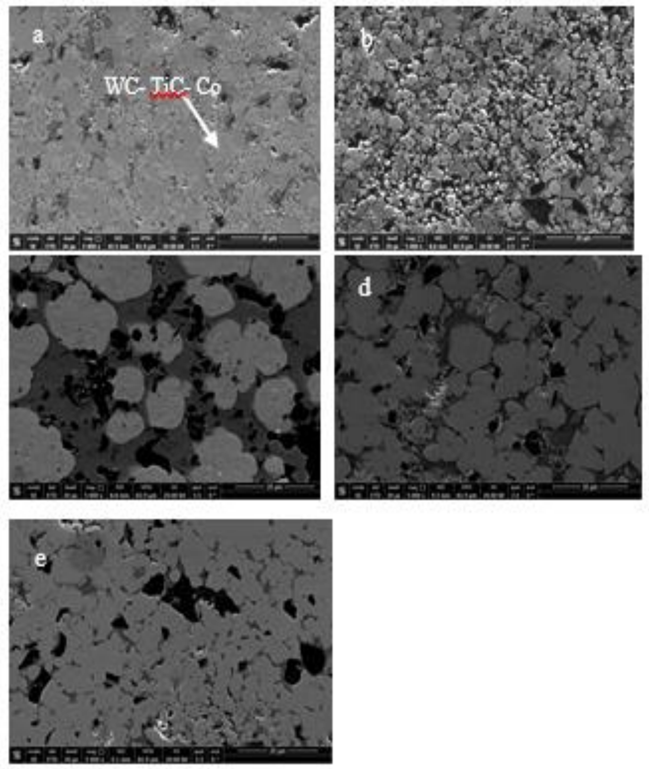

Fig. 3 FESEM images of samples sintered at 1450 °C for 1 h. composites (a) WC- TiC- Co/ Ni (b) WC- TiC- Co/ Ni/Al_2O_3 (c) WC- TiC- Co/ Ni/Al_2O_3/0.3GNS (d) WC- TiC- Co/ Ni/Al_2O_3/0.6GNS (e) WC- TiC- Co/ Ni/Al_2O_3/0.9GNS

D. Hardness Measurement

The influence of graphene content on the WC-Ni/Al_2O_3 hardness is shown in **Figure 4.** The figure shows that the hardness was increased by increasing the weight percentage of graphene due to the higher strength and hardness of graphene.

The hardness increased from 565 to 1190 HV at 0.9 GNs. The impact of GNs addition on the hardness and microstructure of aluminum composites was studied [15]. The results demonstrated that the hardness of composite increased from 38 to 57 HV compared with pure aluminum. Also, R.Pérez-Bustamante et al. [16] evaluated the hardness of GNs/Al composites fabricated by mechanical alloying. The results showed that adding the graphene-platelet to aluminum enhances the mechanical properties of the Al composites.

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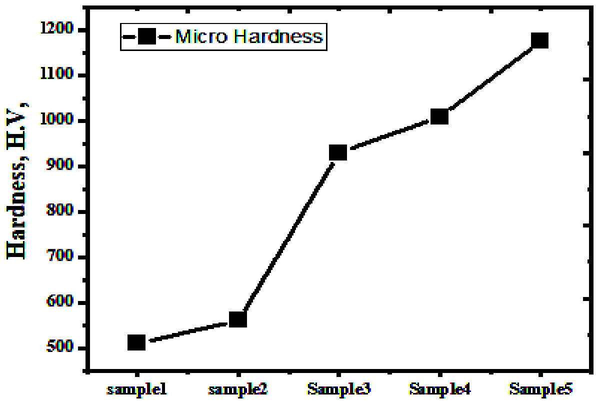

Fig.4 Hardness (WC-Ni-Al_2O_3 /GNs) nanocomposites.

E. Fracture Toughness Measurement

Figure 5 illustrates the Vickers indentation of the fabricated samples, WC/Ni, WC-Ni/Al_2O_3, WC-Ni-Al_2O_3/0.3GNs, WC-Ni-Al_2O_3/0.6GNs, and WC-Ni-Al_2O_3/0.9GNs, respectively, at a 50 kg load. No cracks were established due to the penetration of the indenter into the samples, which indicates that this material has high toughness. The toughness may be improved due to the presence of ductile nickel in the composite [17-18]. It can be seen that the impact dimensions decrease with the increase in the percentage of graphene with no cracks forming.

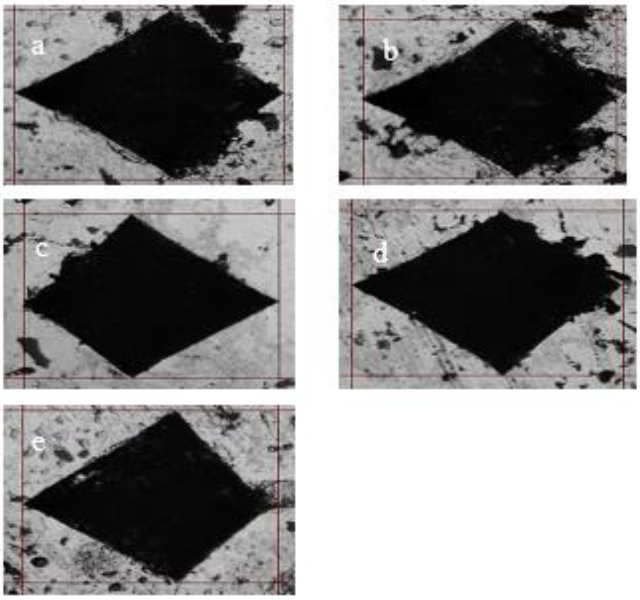

Fig. 5 Optical Micrograph of the Vickers hardness indentation (a) WC/ Ni (b) WC-Ni/Al_2O_3 (c) WC-Ni-Al_2O_3/0.3GNs (d) WC-Ni-Al_2O_3/0.6GNs (e) WC-Ni-Al_2O_3/0.9GNs

IV. CONCLUSION

It is clear from the following results and discussion:

1. The 600 MPa and 1450 °C for an hour using a vacuum furnace were the best conditions for sample fabrication.
2. The microstructure showed a good distribution of graphene within the WC-Ni/Al_2O_3 matrix.
3. The realtive density was decreased by increasing the proportion of graphene.
4. The hardness was improved by increasing the graphene due to its unique properties.
5. Toughness was enhanced due to the presence of nickel with the WC matrix, as no cracks propagated.

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Eng. Mohamed, has a Bachelor in industrial Education, Production Technology, Helwan University. He is familiar with different work culture and able to manage himself easily with the changing work order. He modify himself to perform efficiently even in condition of severe work pressure. Even during those working tenure, He worked as a team member and on demand worked with individual responsibility also. He is familiar to work at different places.

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