Studying the Effect of Aluminum Oxides Composition and Particle Size on the Mechanical Properties of Metal-TiC Composite for Different Heat Treatment Process

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Abstract:- The composites design goals to have combined properties of each of the materials component. Different materials composition between metals, ceramics, and polymers can change the composite properties. In this research, metal matrix composite was selected to be aluminum as matrix phase while the reinforced materials were selected to be Nano particles Titanium carbide and different volume percentage of aluminum oxides (whiskers). All specimens were fabricated one time by annealing and another time by hardening heat treatment process. It was found that the heat treatment process, Alumina particle sizes, and Alumina weight percentage have sever and significant effect on the measured mechanical properties; ultimate tensile, compressive strength and hardness of the metal composite while it have minor effect on the material ductility represented in the measured elongation percentage.

***Keywords**:- Metallic composite, metal matrix, Titanium carbide, Aluminum oxide particle size, Reinforced material, heat treatment, annealing, hardening, mechanical properties.*

I. INTRODUCTION

A composite material contains two or more type of material; metals, ceramic, or polymer as shown in figure 1. The engineering composites goalsto have combination of properties of each of the component materials. The improved properties cannot be gained by one type of material. Different weight or volume fractions between the metals, ceramics, and polymers change the engineering composite material and its characteristics.

The primary phase is called matrix. Generally, matrix has high toughness and ductility. It contains the dispersed phase (reinforced material) and keep it in place. The dispersed phase is put inside the matrix in a different pattern and ways. The reinforced material is used to increase the strength and hardness compared to matrix.

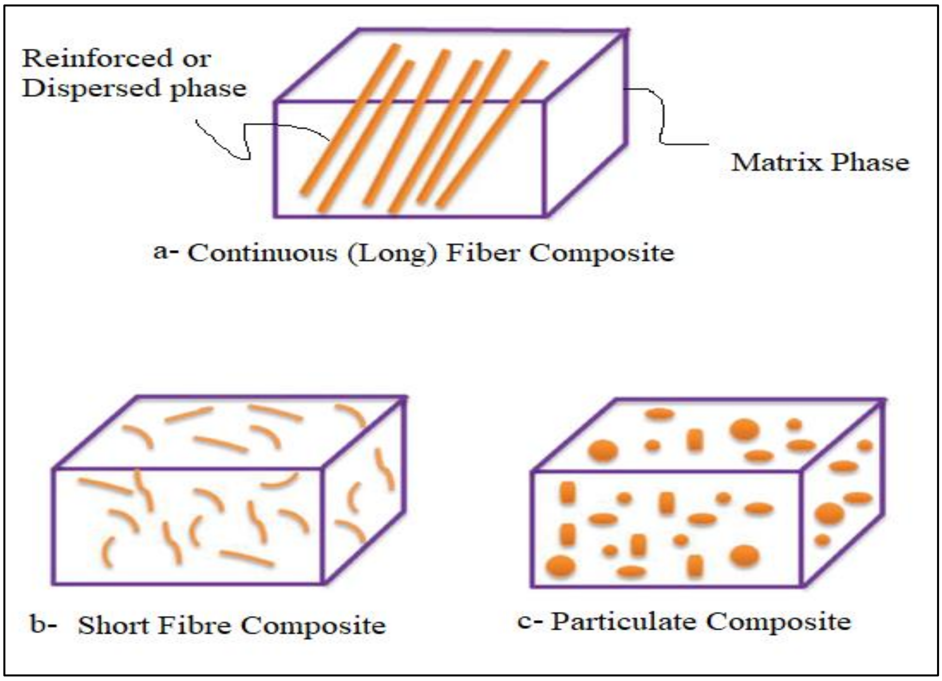

Fig. 1: Composite material containment and types

Metal Matrix Composites is the most common type of composites. It contains metallic matrix such as aluminum (AL), copper (Cu),or cobalt (Co) that has high ductility and high toughness. While the other (dispersed) phase contains ceramic materials such as oxides, nitrides, or carbides that have high strength and hardness. The composite may be formed in different reinforcement shapes as per shown in figure 1. It may be in particles, short fibers, or long continuous fibers.

In this research, the metal matrix was selected to be aluminum while the reinforced materials was selected to be as the following:

- Titanium carbide (in Nano particle form)
- Different weight percentage of aluminum oxides (whiskers).

Generally, the existence of Titanium carbide (TiC) in the matrix is important because of its good mechanical properties. It has high hardness, melting temperature, ultimate tensile strength, and impact strength. That’s why, it is commonly used in cutting tools fabrication and several industrial applications.On the other hand, adding the aluminum oxides whiskers to the dispersed phase were proposed and tested to enhance the mechanical properties that would be measured during the heat treatment process. The Alumina whiskers diameter were measuredand ranged from 10 to 100 µm.

Heat treatment is a process that heat and coolthe metal with a certain gradient to modify the crystalline structure of the metals composites. Depending on the treatment process, the physical and mechanical properties change. There are main three types of heat treatment process. The first one is annealing. Annealing is the process of heating metal to a temperature below the melting temperature, stabilize at this temperature in order to allow the grains to rearrange itself. Consequently, the microstructure increases its ductility and reducesthe residual stresses.The metal is then cooled back to ambient temperature with slow cooling rate to produce high ductilecrystalline structure.

The second heat treatment process is hardening. It is used to improve the hardness. This is through heating and rapid cooling. The material is heated in a hardening furnace to a temperature less than the melting point. The metal is then kept for one to two hour, followed by rapid cooling process. The quick cooling process establishes a harder, more stable crystalline structure but the structure would have several line dislocations in the material structure.

The third one is quenching. Heated materials are often cooled in oil or air. The metal composite is heated to a point below the melting point where the crystalline structure is fluid. It is held for a specific period of time, depending on the desired properties, and then quenched in oil to reduce the temperature of the material and establish the required internal structure. Selection the heat treatment process is depending on the required physical and mechanical properties.

II. MATERIALS PREPARATION AND METHODOLOGY

In order to investigate the effect of the ceramic compound (Aluminum Oxides) composition on the mechanical properties of TiC metal composite; 32metal composites samples wereprepared with different alumina particle sizes and weight percentage.16 sample was prepared one time by annealing and another time by hardening heat treatment process.The total numbers of samples were 32 samples.

The annealing process was performed by heating the elements in the heater at 500^{o} C and held for 7 hours until the elements were dissolved in the matrix solution. Then, it was cooled in the furnace temperature for 12 hours. All samples were observed that there were not line dislocation in the material microstructure as shown in figure 2. The samples ID and compositions are illustrated in table 1.

Fig. 2: Microstructure of composite by annealing process

Table 1: TiC Metal composite by annealing – Sampling ID

Sample ID	Reinforced Matrix			
	% wtTiC (Nano Particles)	% wt Al2O3 (whiskers)	Alumina Particle Size ± 5% (µm)	Heat Treatment Process
R10-0-10a	10	0	10	Annealing
R10-0-30a			30	Annealing
R10-0-60a			60	Annealing
R10-5-10a	10	5	10	Annealing
R10-5-30a			30	Annealing
R10-5-60a			60	Annealing
R10-10-10a	10	10	10	Annealing
R10-10-30a			30	Annealing
R10-10-60a			60	Annealing
R10-15-10a	10	15	10	Annealing
R10-15-30a			30	Annealing
R10-15-60a			60	Annealing
R10-20-10a	10	20	10	Annealing
R10-20-30a			30	Annealing
R10-20-60a			60	Annealing

On the other hand, the hardening process was performed by heating the elements in the heater at 500° C (below the melting point). Then, it was cooled suddenly in the water bath. All samples were observed and line dislocations and alumina whiskers were observed in the material microstructure as shown in figure 3. The samples ID and compositions are illustrated in table 2.

All these samples were tested to measure the mechanical properties; ultimate tensile strength, compressive strength, hardness, and %elongation in respect of changing the following parameters:

- Heat treatment process; annealing and hardening
- %wt percentage of Alumina whiskers
- Alumina particle sizes (Whiskers diameter)

Thus, comparisons were applied for all materials to investigate the effect of each previous parameter.

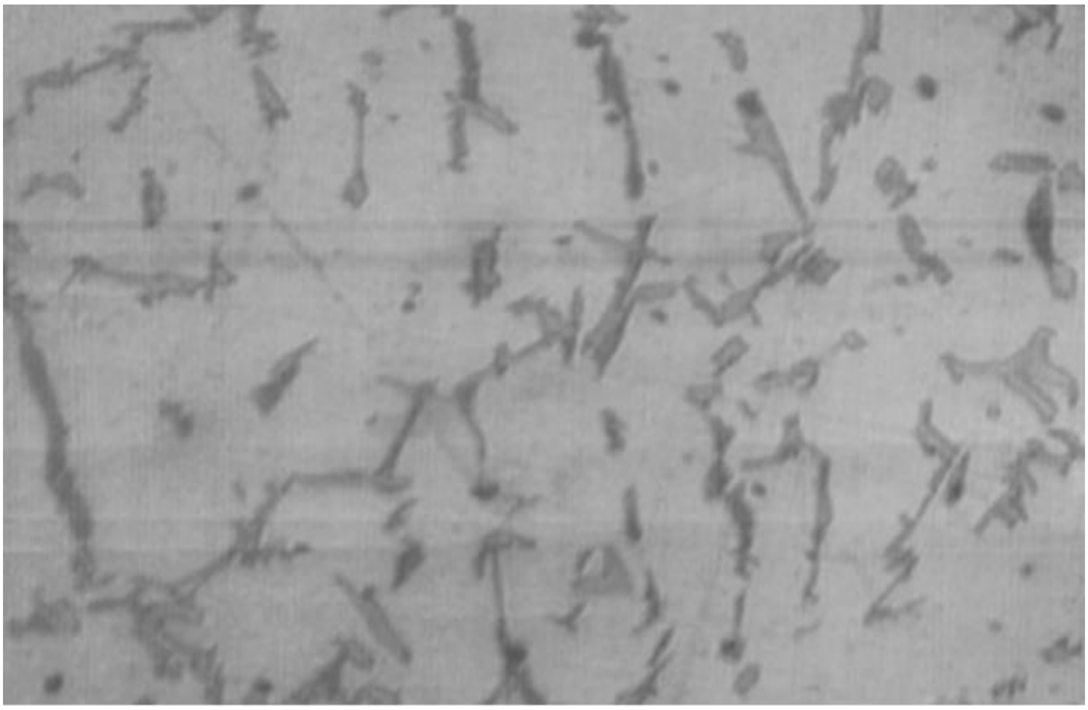

Fig. 3: Microstructure of composite by hardening process

Table 2: TiC Metal composite by Hardening – Sampling ID

Sample ID	Reinforced Matrix			
	% wtTiC (Nano Particles)	% wt Al2O3 (whiskers)	Alumina Particle Size ± 5% (µm)	Heat Treatment Process
R10-0-10h	10	0	10	Hardening
R10-0-30h			30	Hardening
R10-0-60h			60	Hardening
R10-5-10h	10	5	10	Hardening
R10-5-30h			30	Hardening
R10-5-60h			60	Hardening
R10-10-10h	10	10	10	Hardening
R10-10-30h			30	Hardening
R10-10-60h			60	Hardening
R10-15-10h	10	15	10	Hardening
R10-15-30h			30	Hardening
R10-15-60h			60	Hardening
R10-20-10h	10	20	10	Hardening
R10-20-30h			30	Hardening
R10-20-60h			60	Hardening

III. RESULTS AND DISCUSSION

A. Heat treatment process; annealing and hardening

Samples were prepared and tested using universal testing machine and hardness Brinell tester. As per figure 4, 5 and 6, the ultimate tensile, compressive strength, and hardness were increased during hardening heat treatment process compared with the annealing process. This is due to random crystalline structure and grains dislocation which lead to increase the surface rigidity.

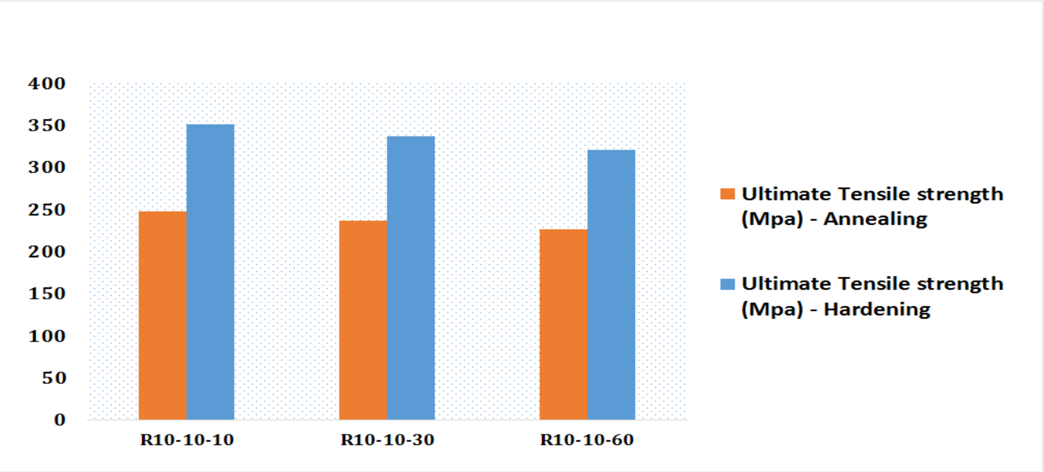

Fig. 4: Comparison according to ultimate tensile strength for different heat treatment process at 10% Alumina Whiskers

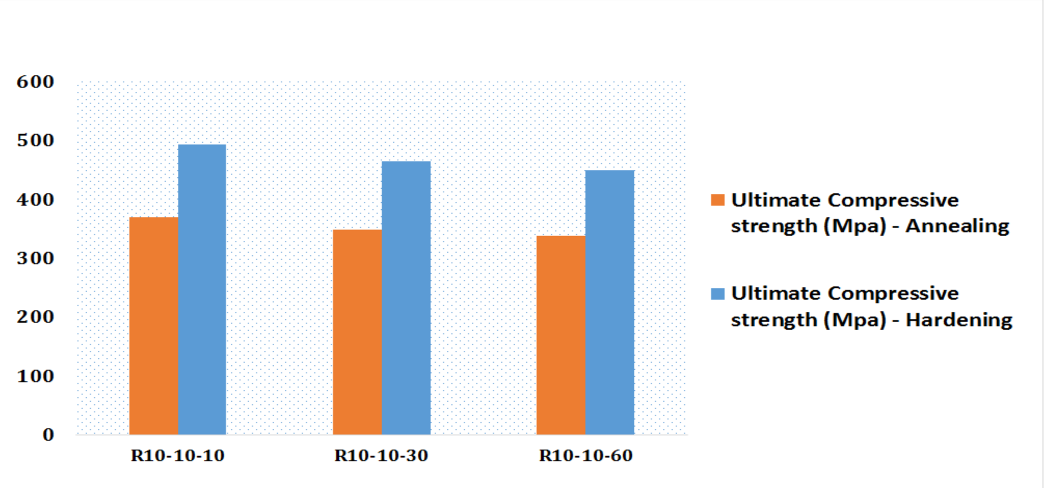

Fig. 5: Comparison according to ultimate compressive strength for different heat treatment process at 10% Alumina Whiskers

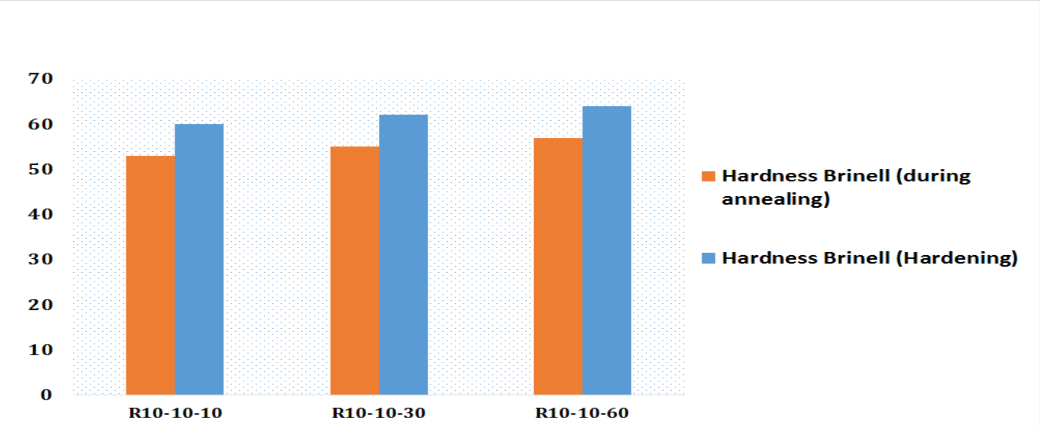

Fig. 6: Comparison according to hardness for different heat treatment process at 10% Alumina Whiskers

On the other hand, the material ductility decrease significantly with hardening due to the same reasons mentioned before. So, the elongation percentage increased with annealing heat treatment as shown in figure 7.

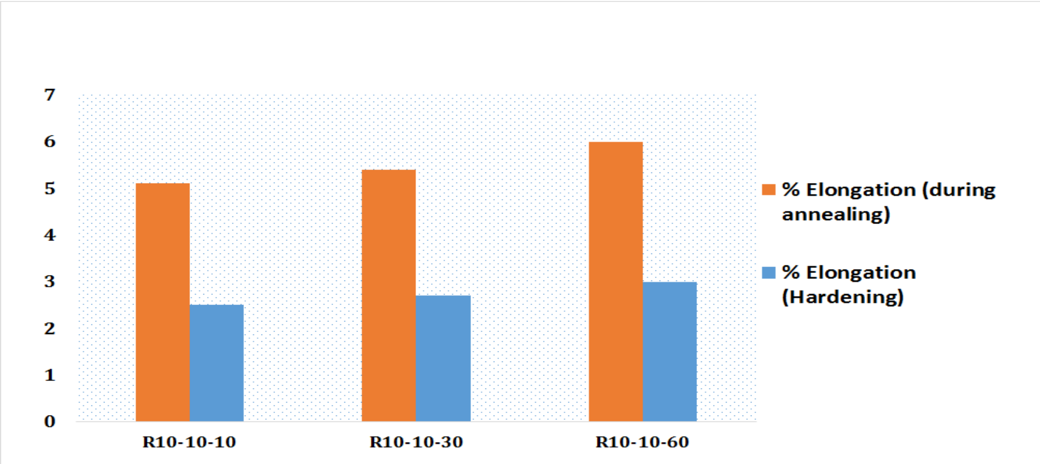

Fig. 7: Comparison according to %elongation for different heat treatment process at 10% Alumina Whiskers

A. %wt percentage of Alumina whiskers

As shown in figure 8, both of ultimate tensile and compressive strength were increased with increasing the % wt of Alumina Whiskers. This is due to increasing the percentage of the Alumina that have high tensile and compressive strength as a ceramic material.

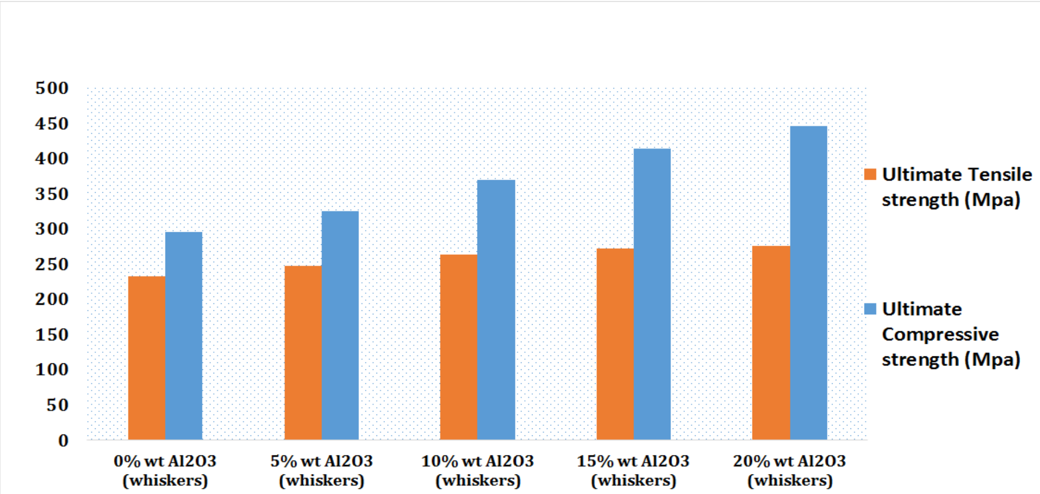

Fig. 8: Comparison according to ultimate tensile and compressive strength for different %wt Alumina Whiskers

On the other hand, the hardness was decreased with increasing the % wt of Alumina Whiskers as shown in figure 9. This is due to the bad crosslinking and dispersion between the reinforced Alumina whiskers and the matrix phase during heat treatment process. This is generally weak the metal composite. Finally, as shown in figure 9; there was no significant change in material ductility represented in % elongation.

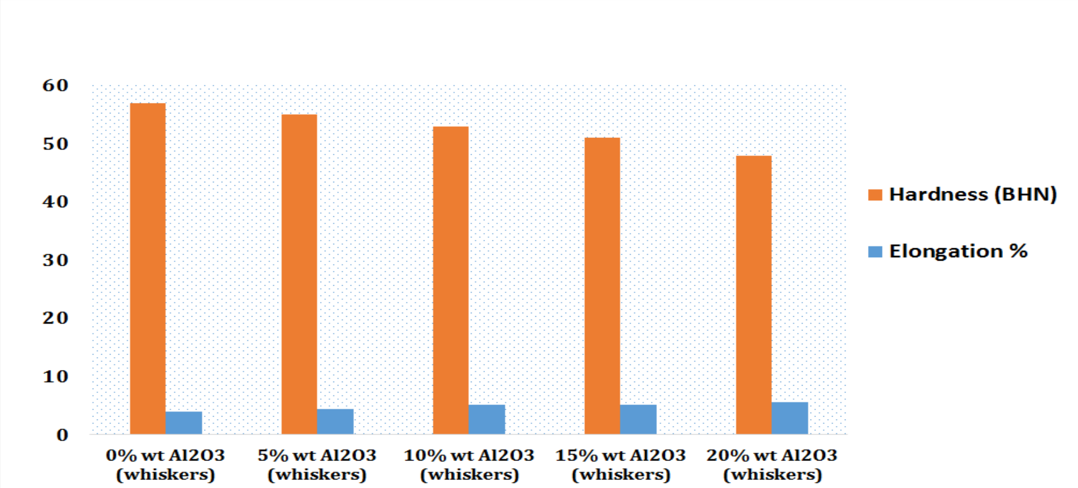

Fig. 9: Comparison according to hardness and % elongation for different %wt Alumina Whiskers

B. Alumina particle sizes

As shown in figure 10, both of ultimate tensile and compressive strength were decreased with increasing the particle size of Alumina Whiskers. Increasing the Alumina particle size means less Alumina grains numbers in the matrix phase. Hence, pores were increased and lower ultimate tensile and compressive strength were obtained.

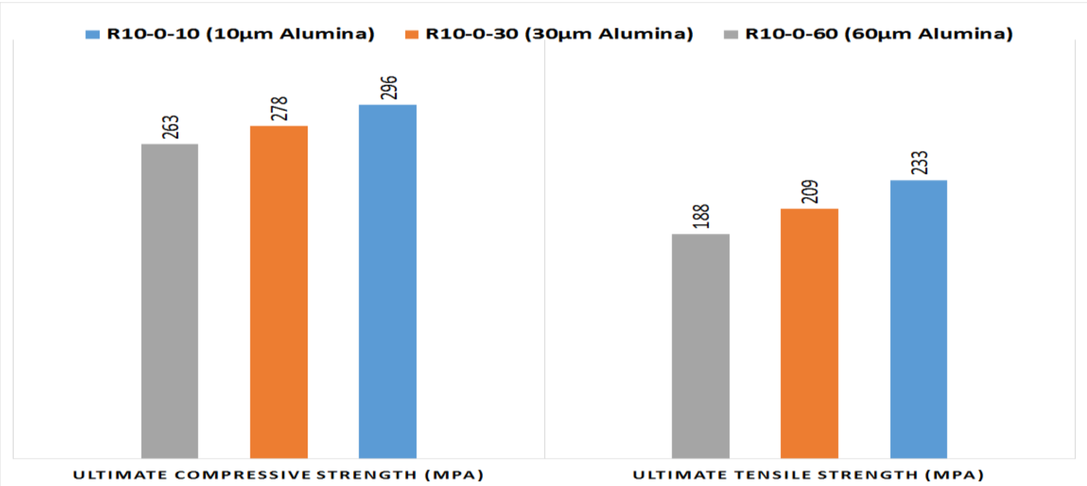

Fig. 10: Comparison according to ultimate tensile and compressive strength for different particle sizes of Alumina Whiskers

On the contrary, hardness was foundincreased with increasing the particle size of Alumina Whiskers. Increasing the Alumina particle size means larger hard material (Alumina grains) in the matrix phase. However, there was no significant change in material ductility represented in % elongation with increasing the particle size of Alumina.

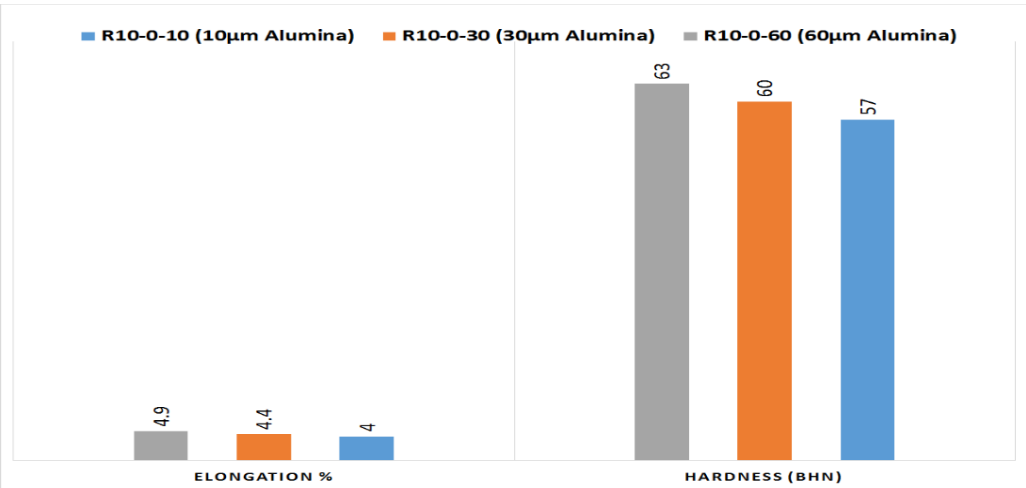

Fig. 11: Comparison according to hardness and % elongation for different particle sizes of Alumina Whiskers

IV. CONCLUSION

Finally and after completion the experiments; It was noted that heat treatment process have sever and significant effect on the mechanical properties of the metal composite. It was found that the ultimate tensile, compressive strength, and hardness were increased during hardening heat treatment process compared with the annealing process. This is due to random crystalline structure and grains dislocation which lead to increase the surface rigidity. However, the material ductility was decreased with hardening due to the same reasons mentioned. So, the elongation percentage was increased with annealing heat treatment.

According to increasing the weight percentage of Alumina Whiskers; the ultimate tensile and compressive strength were increased with increasing the % wt of Alumina. This is due to good mechanical properties of the Alumina as reinforced material.On the other hand, the hardness was decreased with increasing the % wt of Alumina Whiskers. This is due to the bad dispersion between the whiskers and the matrix phase during heat treatment process.

In respect of the Alumina particle size, both of ultimate tensile and compressive strength were decreased with increasing the particle size of Alumina Whiskers.This is due to increasing the matrix porosity with increasing the Alumina particle size. On the contrary, hardness was foundincreased with increasing the particle size of Alumina Whiskers. Increasing the Alumina particle size means more hard material (Alumina grains) in the matrix phase.

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