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Numerical study of the compression property for Aluminium-based (Al-4% Cu) reinforced with different carbide particulates

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Abstract. The compression characteristic of an (AL-4% CU) alloy reinforced with different particles (boron carbide, silicon carbide, and titanium carbide) was numerically studied. For this purpose, a model was performed using COMSOL Multiphysics 4.1. Hence, three samples were selected and reinforced with carbide particles equal to 20 microns' in diameter and then compared with that one not reinforced. An axial load of 20 Newton was applied for all samples from both sides. The results showed that the alloy (AL-4% CU) reinforced with boron carbide particles has the highest compressive resistance compared to the other reinforced particles. The elongation of boron carbide, silicon carbide and titanium carbide particles were $1x10^{-7}$mm, ($1.3*10^{-7}$ mm) and ($1.5*10^{-7}$ mm) respectively, while it was ($5.5*10^{-8}$ mm) for not unreinforced particles.

1. Introduction

Industrial, civilization, and technological development radically depends on progress and expansion in the field of engineering materials. In the last decades, there are several studies carried out to find different alternatives for materials could be widely used in the industry with high specifications and good quality, lightweight and acceptable mechanical properties in general, to using as raw materials in aircraft, radars, ships cars manufactures. One of the alternative materials they discovered and produced for different applications was known as composite materials. However, the overlapping materials created by mixing two or more items in the form of separate phases to obtain desirable compositions have a specific property for each of the components, with keeping the compounds are not dissolving or interacting together [1–3].

Composite materials are classified into several types depending on the bonding material such as metal, ceramic and polymeric compounds. The metal compounds are characterized by hardness, high density, the based material is iron and copper. For ceramic compounds, the bonding material is made of ceramics such as alumina and silicon carbide, whereas the polymeric compounds contain organic materials such as epoxy and polyester resins. Polyester is a superposition of a polymeric base, and it supports many types of organic and inorganic materials such as fibres, particles, sheets, and metal wire in order to improve some physical properties and insert new attributes on it [4,5].

There are several common composite materials such as aluminium alloy_ Copper is soft, tender and has weak tensile strength, therefore, it is used in the form of alloys in most industrial applications since aluminium has the ability to change its properties when heat treated due to the different solubility of the elements in aluminium. The most important alloys (Aluminium-Copper), which has a high tensile resistance with an excellent fatigue resistance, so it is used as a base material in the overlapping materials [6]. However, the silicon carbide (SIC) is a compound of silicon and carbon which consider a semi-conductor for electrical were prepared from the interaction of silicon at high temperature as shown in equation 1.

$$Si + C \rightarrow SIC \qquad (1)$$

$$SIO_2 + 3C \rightarrow SIC + 2CO \qquad (2)$$

SiC pellets are bonded together sintering process to form a very hard material that is widely used in applications required high durability (car brakes, electronic devices) moreover it can be used as reinforcing materials (particles) in the manufacture of overlapping materials [5,6]. Titanium carbide (TIC) is a grey metallic powder that is well-known by its high resistance and tolerance to high temperatures. TIC is a solid material that is widely used in thermal coatings, welding materials, military aviation materials and hard alloys which considered one of the nanoparticles of composite materials [7]. Boron carbide (B4C) is a hard black colour material used in covering the parts that require very high friction resistance. Moreover, B4C is widely used in the field of nuclear energy production and as a reinforcing material for the manufacture of composite materials. Boron carbide is prepared from the interaction of boron oxide and carbon at high temperature up to 2300 °C according to equation 3 [8]:

$$2B_2O_3 + 7C \rightarrow B_4C + 6CO \qquad (3)$$

Karakoc et al [9] investigated the mechanical and ballistic performances of Al 6061 aluminium alloy manufactured of powder metallurgy reinforced by boron carbide at hot-extruded and hot-rolled specimens. The study results have shown that the tensile strength, hardness, and transverse rupture strength improved while the impact toughness was reduced when the volume fraction of B_4C particle reinforcement increased. The main objective of this study is to investigated the compression property of Aluminium-Copper (Al-4% Cu) alloy reinforced with 20 microns as diameter of boron, silicon and titanium carbide under axial load of 20 Newton. Moreover, this work could provide a simple method to understand the compression behaviour of composite materials used in manufacturing.

2. Numerical procedure

First case: The sample without any reinforcing was applied in the program as following:

1- Open the COMSOL Multiphysics 4.1 program and define the procedures in sequence (three-dimension 3D, solid mechanic, stationary).
2- Draw a sample of length x width (25*25 mm) and the thickness is 5 mm as shown in Figure (1).
3- Define the sample material (AL-4% CU) as composite materials to the COMSOL Multiphysics 4.1 program.
4- Supplied an axial load in opposite directions of 20 N (as start point which effects on the select material) , as shown in Figure (2).
5- Divided the samples to smooth mesh.
6- The program was run and collect the results.

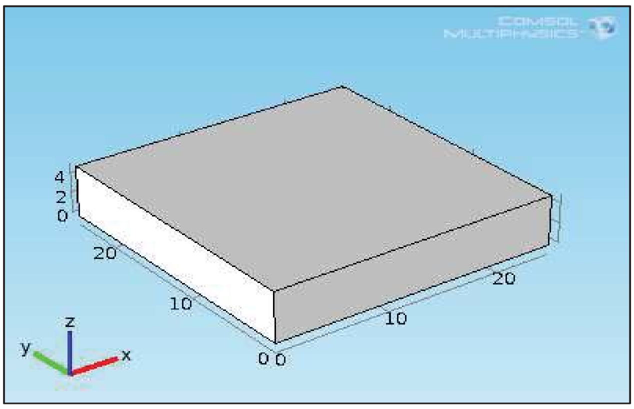

Figure 1. Dimensions (mm) of the sample.

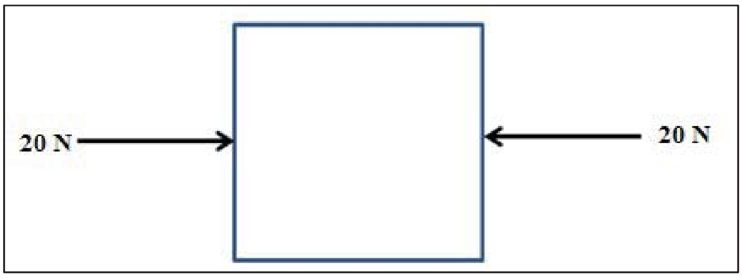

Figure 2. An axial load (N) applied on the sample.

Second case: The sample is reinforced with particles of boron carbide (B_4C) where the same steps in case one are repeated with drawing the stiffening particles randomly by assuming their number equal to (5000) and a diameter of (20) microns as shown in Figure (3). A smooth mesh was chosen for accurate results in the program work place as in Figure (4), and then the program running and the results were saved.

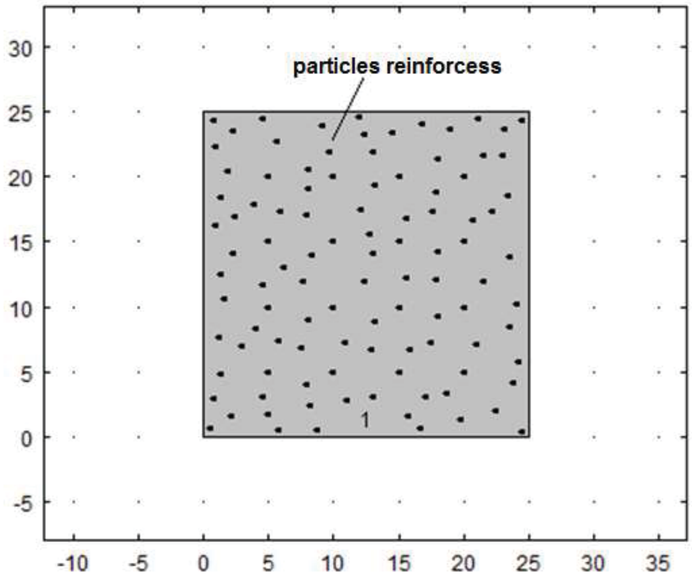

Figure 3. The sample with dimensions (25*x*25 mm) contains reinforced particles.

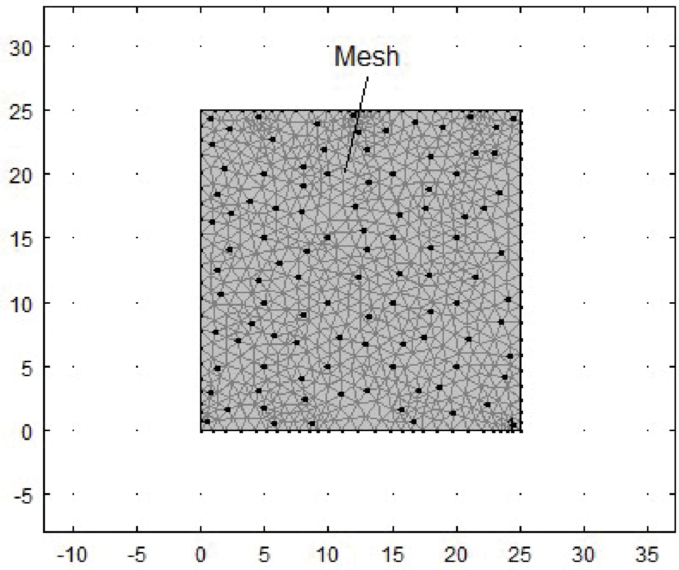

Figure 4. Mesh action of the sample.

Third case: The sample is reinforced with silicon carbide particles (SIC). The same steps in the second case with a change in the number of particles to be equal to (3925) according to the following equation 4.

$$\text{Number of particles(TIC)} \frac{\text{Density of particles* the number of the minutes particles is assumed}}{\text{density of particles}} \quad (4)$$

$$\text{Number of particles (TIC)} \frac{5000 * 2.52}{3.21} \ 3925$$

Fourth case: The sample is reinforced with titanium carbide (TiC). Repeated the same steps above with a change in the number of particles to be (2556) according to equation (4).

$$\text{Number of particles (TIC)} \frac{5000 * 2.52}{4.93} \ 2556$$

3. Results and Discussion
Figure (5) draws the amount of elongation change that represents the gradation of colours from red to blue when a load of 20 Newton is applied from both sides for an unreinforced sample (in particles) alloy (AL-4% CU). The trend between the elongation and the length of the unreinforced alloy (AL-4% CU) when applied the axial load is shown in figure 6. This load leads to increases in elongation gradually until it reaches ($5.5*10^{-8}$ mm) and then it stops due to the fact that the load applied equally to the unreinforced alloy (AL-4% CU) resistance.

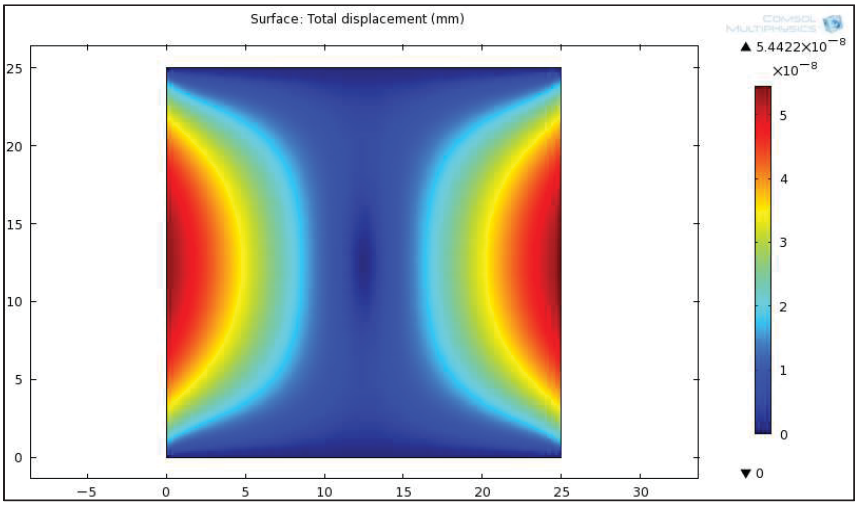

Figure 5. Variation of length with axial load for a non-reinforced sample.

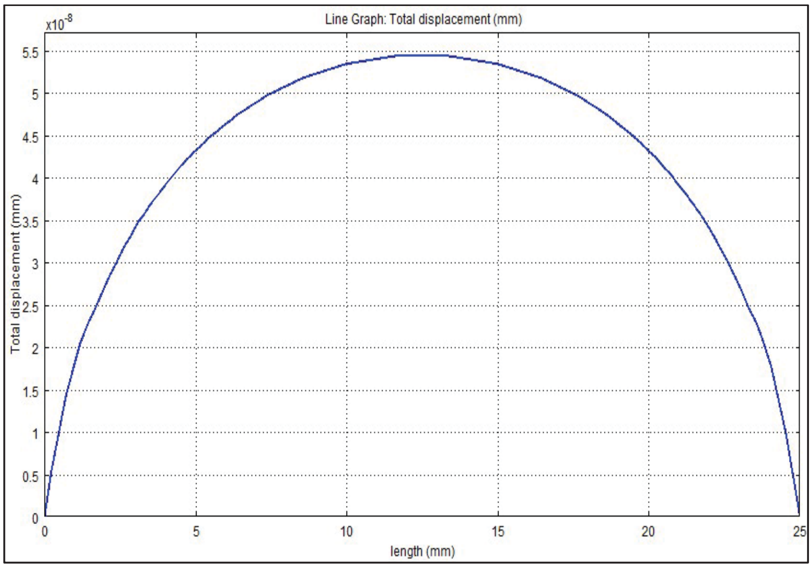

Figure 6. Elongation curve at a force of 20 Newton for a non-reinforced sample.

Regarding the reinforced titanium carbide on alloy (AL-4% CU), The variation of the elongation represents when the shift of colours from red to blue when a load of 20 Newton applied from both sides shown in figure 7. Figure 8 shows the track between the elongation and the length of the reinforced titanium carbide when the load was applied, it will increase the elongation up to ($1.5*10^{-8}$ mm), and then discontinuing, because the resistance of the unreinforced alloy (AL-4% CU) will be equal to the applied load.

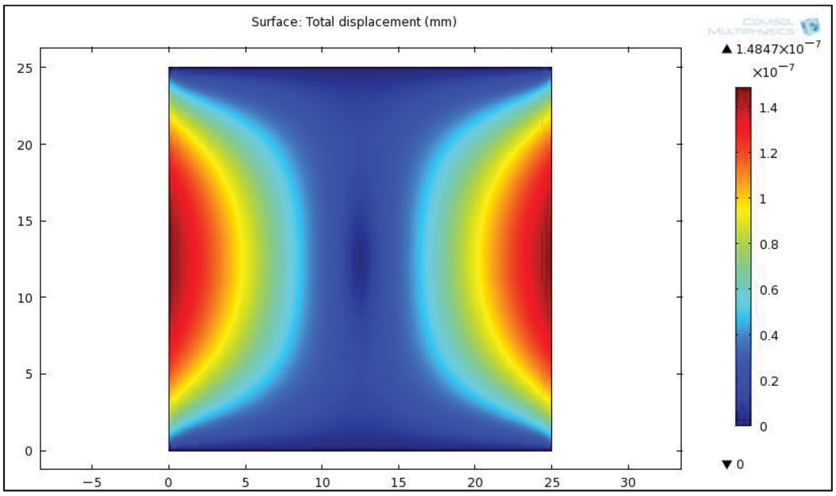

Figure 7. Variation of length with axial load for a sample reinforced with TiC.

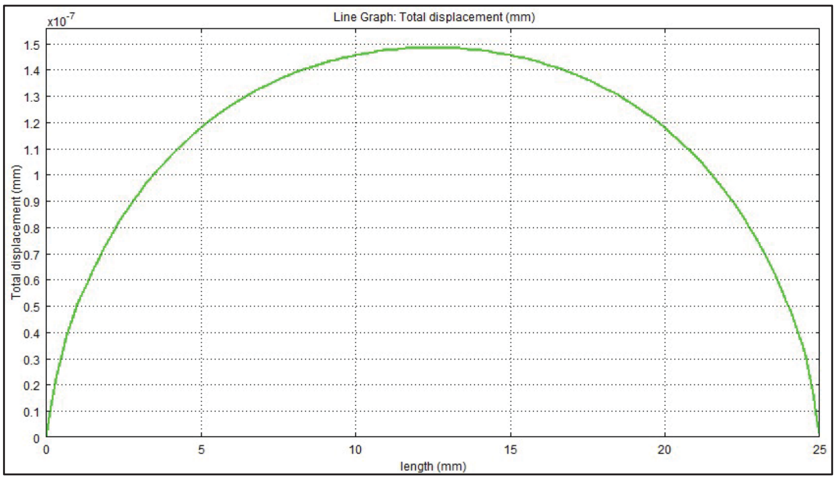

Figure 8. Elongation curve at a force of 20 Newton for a sample reinforced with TIC.

Related to sample reinforced of silicon carbide on both sides of the alloy (AL-4% CU), the amount of change in elongation when shedding axial load force of 20 Newton from both sides and the direction between the elongation and the length represents in figure 9 and figure 10 respectively. As shown in these figures there are increases in elongation gradually up to ($1.3*10^{-7}$ mm) and it stops due to equal axial load applied to the reinforced of silicon carbide alloy (AL-4% CU) resistance.

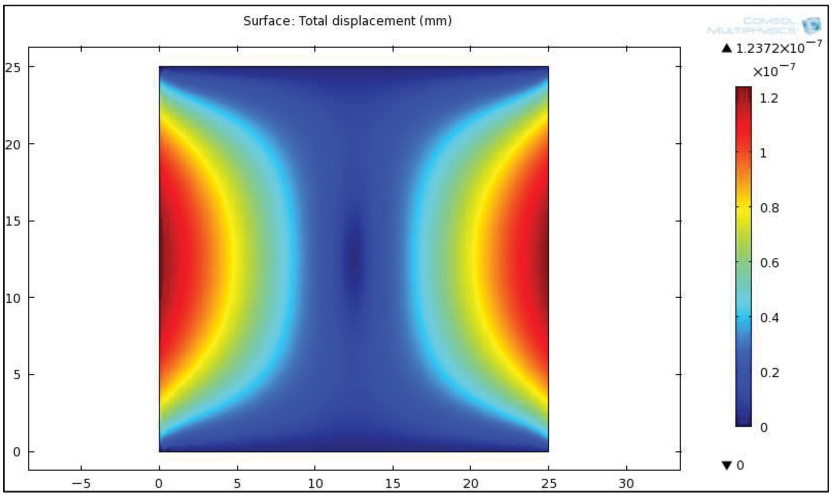

Figure 9. Variation of length with axial load for a sample reinforced with SIC.

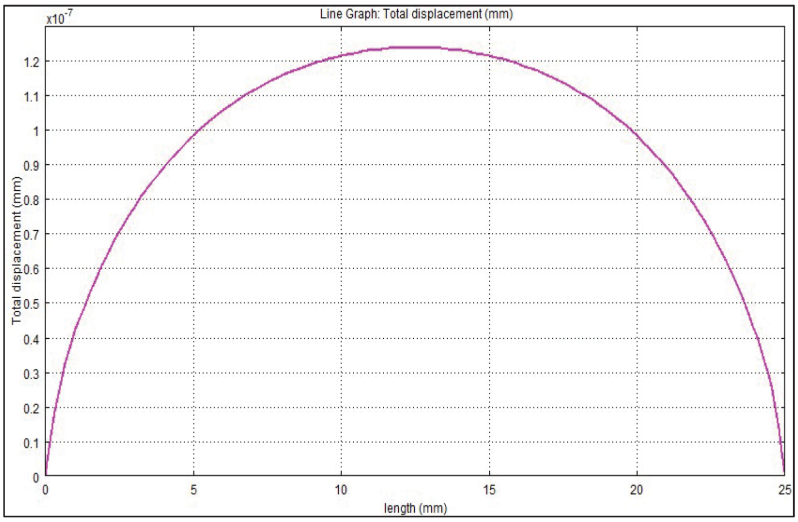

Figure 10. Elongation curve at a force of 20 Newton for a sample reinforced by SIC.

Finally, the gradation of colours from red to blue represents the amount of change in elongation when applied axial load force of 20 Newton from both sides for a reinforced sample (in particles) of silicon carbide of the alloy (AL-4% CU) as shown in figure 11. Whereas, figure 12 shows the direction between the elongation and the length of the silicon carbide alloy (AL-4% CU) when the same axial load is applied, which will lead to an increase in elongation gradually until it reaches ($1*10^{-7}$ mm) and then it stops because the axial load applied will be equal to the alloy resistance.

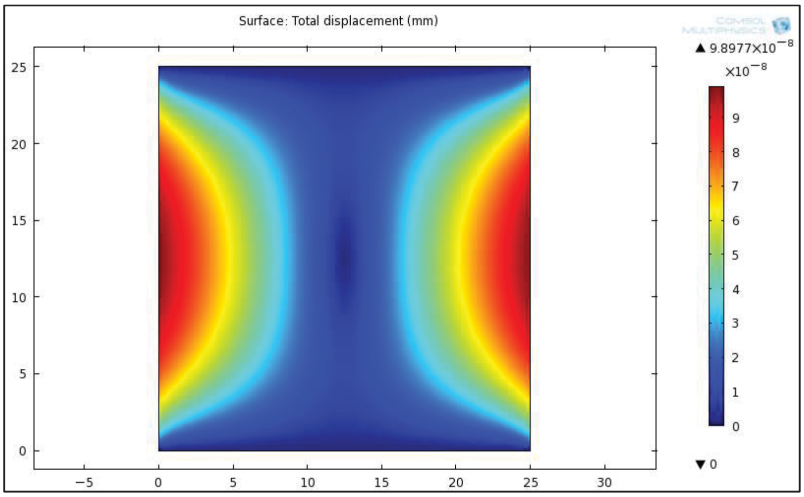

Figure 11. Variation of length with axial load for a sample reinforced by B_4C

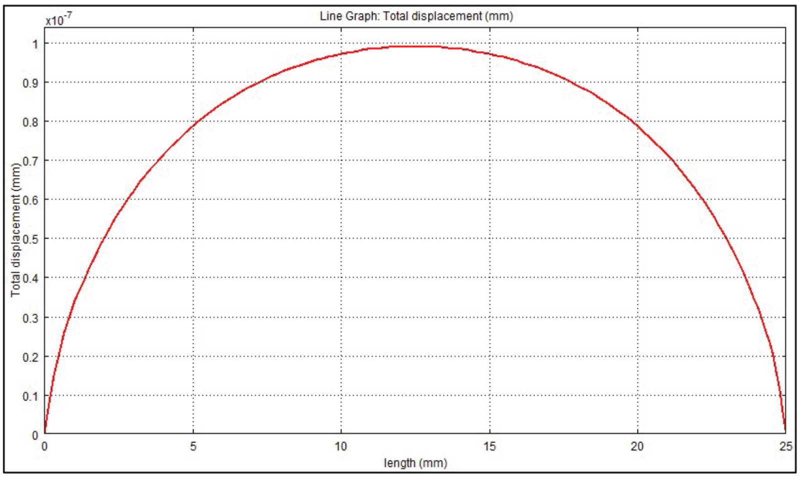

Figure 12. Elongation curve at a force of 20 Newton for a sample reinforced by B_4C

It is clearly shown from the above figures that the alloy (AL-4% CU) reinforced with boron carbide particles have a lower elongation those reinforced with particles (silicon carbide, titanium carbide, and the non-reinforced sample). This may be because the density of boron carbide is less than that of silicon carbide and titanium carbide, therefore, the number of particles randomly distributed to boron carbide could be enhancement the strengthening phase and the resistance samples to deformation. Considering the elongation as a measure of the sample's compressibility, the (AL-4% CU) alloy strengthened with boron carbide particles is less compressible than the rest of the samples.

4. Conclusion
A numerical study was conducted to investigate the compression property for (AL-4% CU) alloy reinforced with different particles (boron carbide, silicon carbide, and titanium carbide) with diameter of 20 microns. The axial load of 20 Newton was applied for all samples. The main conclusions of this study are the following:

- It is possible to simulate the superposed material in particles.

- The alloy (AL-4% CU) reinforced with boron carbide particles provided the lowest elongation than the other samples strengthened with particles (silicon carbide, titanium carbide, and non-reinforced).
- The compression resistance of the reinforced (AL-4% CU) alloy with particles of boron carbide is higher than the other samples.

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