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Laser Power Effect on Mechanical Properties of AL-7075 With/Without Additive Nano Silica Carbide

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ABSTRACT

The purpose of the study was to experimentally analyze the impact of a laser beam on the mechanical properties, such as tensile strength and wear, of aluminum alloy 7075 and aluminum alloy 7075 reinforced with 1% nano-silicon carbide. The study aimed to examine the effect of different laser powers (50 watts, 75 watts, and 100 watts) on the mechanical properties of aluminum samples. According to this study, found that adding 1% nano silicon carbide can significantly reduce the specific wear rate in a range of distances. Specifically, the wear rate was reduced by 86.53% between 600-1200 m and 51.74% between 1200-1800 m. In addition, the specific wear rate of pure AL-7075 also decreased by 64.28% between 600-1200 m and by 67.07% between 1200-1800 m. These findings showcase the potential of nano silica carbide as a viable solution for reducing wear rates in various applications. According to the results, increasing the laser power from 50 to 75 watts resulted in a decrease of the specific wear rate by 24.24% for the 600-900 m range and by 8.25% for the 1200-1800 m range. At 75 watts, the specific wear rate was reduced by 9.25% for the 600-900 m range, and it remained constant for the 1200-1800 m range. This study provides valuable insights for industries that utilize aluminum alloy 7075 in their products, such as aerospace, automotive, and construction sectors. By exposing the alloy to different laser powers, these industries can increase the tensile strength and, in turn, improve the overall performance of their products. The inclusion of nano silicon carbide is an added advantage that can further enhance the tensile strength properties of the alloy. Overall, the results of this study can lead to more efficient and effective use of aluminum alloy 7075 in various applications. Further research can be conducted to explore other potential benefits of utilizing different laser powers and nano-silica carbide in the alloy. A study found that exposing pure aluminum alloy 7075 to different laser powers can increase tensile strength. At 50 watts, it increased by 6 %, at 75 watts by 11.11%, and at 100 watts by 14.11%. Adding 1% of nano silicon carbide to the alloy increased tensile strength even more, with the alloy experiencing a 30.4 % increase at 50 watts, 42.6 % at 75 watts, and 52.2% at 100 watts.

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1. Introduction

Laser technology can be used to direct energy into small areas of a material in a precise manner, resulting in the desired reaction. This energy is absorbed at the surface of opaque materials, which alters their multiscale morphology, surface chemistry, and/or crystal structure without affecting their bulk properties [1]. As industrial development has increased, there is a growing need to develop resources that can enhance the mechanical, physical, thermal, chemical, and electrical properties of materials [2]. Hybrid composite materials, which have at least two or more reinforcements, represent the latest generation of multiphase heterogeneous materials [3-6]. One study focused on using nano-silica granules at different weight ratios to improve the mechanical properties of a composite material made of carbon fibers and polyester, which is used in building ship hulls. The study found that increasing the weight of silica particles from 0.2 to 0.24 resulted in a 33.53% improvement in tensile strength [7]. The study examined the AlSiMn alloy's high-temperature properties after CO_2 laser remelting. The findings showed an 80% improvement in mechanical properties due to the formation of fine dendrite microstructure and sound metallurgical bonded morphology. The maximum laser modified thickness achieved was 2.23 mm [8]. Aluminum alloys are commonly used in various industries for their excellent properties. Laser cleaning is an effective method for removing oxide films and old paint from aluminum surfaces. The impact of processing parameters, such as laser power and scanning speed, on cleaning is discussed. Laser cleaning improves the corrosion resistance, welding, and adhesive performance of aluminum alloys. The study also discusses real-time detection technologies and provides a summary and development trends [9]. A study examined the effect of scanning speed, laser power, and strategy on mechanical properties. Results showed that laser power and scanning speed have a significant impact on mechanical properties, while laser strategy has a limited effect.

A region of higher mechanical properties was found when using 50 µm thick layers for energy densities between 25 and 35 J/mm3. To create parts with good microstructure and limited defects, mid-speed and power should be used. Heat-treating AlSi7Mg0.6 parts to T6 temper negatively affected mechanical performances, requiring adapted tempering conditions for any improvements sought through tempering [10]. Light metal alloys, like aluminum, are ideal for technical applications due to their low density and high corrosion resistance. However, their mechanical properties limit their use in parts requiring high surface hardness and wear resistance. Laser processing has greatly improved the surface treatment of aluminum alloys by introducing alloying elements, such as a mixture of titanium and iron powders, which increases hardness and abrasion resistance [11]. The properties of aluminum compounds are influenced by various factors such as microstructure, composition ratio, particle size, agglomeration tendency, and secondary processes, which are associated with powder-based additive manufacturing (PAM) processing [12-14].

The study investigates laser beams of varying powers and speeds on an acrylic sample to analyze their effect on tensile stress. The shape of cracks was generated with a six-degree polynomial function. Results showed that increasing the power and speed of the laser beam led to a 12.25% improvement in stress and strain. Comparing different sample types revealed an average increase in tensile stress of 14.088% [15]. The explored how different laser paths, created using varying power and speed, affected the mechanical properties of acrylic. The paths were designed using three different functions, and the researchers investigated how each function affected the acrylic's micro-structure. Additionally, the study looked at the impact of crack shape, laser power, and speed on the acrylic's mechanical characteristics. The researchers were able to predict mathematical equations for the three crack shape functions, and found that the maximum increase in stress was around 28% [16]. It has been investigated how using nano-silica particles affects the properties of composite materials. They found that adding 5% of nano SiO_2 to 4% woven glass fiber produced specimens with improved mechanical properties, such as ultimate tensile strength, impact strength, fracture toughness, and hardness[17]. An investigation was conducted to compare the erosion resistance of micro and nanocomposites. The study revealed that as the volume fraction of the composites increased, their resistance to erosion also increased. Nanocomposites made of GF/EP with SiO2 were found to have several advantages over micro composites, particularly in wear and hardness tests. Scanning electron microscopy (SEM) showed that unfilled composite systems suffered more severe damage to the matrix and glass fiber compared to SiO_2-filled composites [18]. Aluminum composite alloys are commonly used in many industrial applications such as railways, marine, automobiles, and building materials due to their durability and suitability for such applications [19].

Aluminum alloys that are reinforced with silicon additives are preferred as they have increased fluidity and are easily castable. Furthermore, increasing the percentage of silicon in their composition enhances the hardness properties of the castings [20]. Researchers have found that the addition of silicon granules can improve the corrosion resistance and coefficient of friction of castings, as well as their micro-hardness, homogeneity of microstructure, and durability [21-23]. The laser cladding performance depending on geometry dimensions and microstructure. These features are correlated with laser processing parameters like specific power to determine coating quality. The data obtained can distinguish between cladding and highly alloyed tracks based on specific power and coating geometry dimensions[24]. They found that the setting of laser power at 280 W and scanning speed at 500 mm/min led to crack-free material deposition with the highest density among all conditions investigated. Compared with the as-built Al 7075, the average micro-hardness of the alloy increased from 91.73 to 144.91 HV, and the ultimate tensile strength increased from 233.18 to 342.16 MP after heat treatment [25].

The objective of the present study is to conduct an experimental investigation on the impact of the laser beam on the tensile strength of AL-7075 alloy, with and without the addition of nano silica carbide. The focus of this research is to improve the properties of AL-7075 alloy as a casting, without the need for subsequent manufacturing operations, while keeping the costs at a minimum. The AL-7075 alloy has garnered a significant amount of attention in various industrial sectors, particularly in aircraft and structures due to its exceptional properties. Consequently, several research studies have been conducted to explore ways of enhancing its properties and further developing it.

2. Methodology

2.1 Tensile Analysis

The change in the instantaneous length of the specimen relative to its original length represents the amount of strain occurring in the specimen during the tensile test:

$$e = \frac{\Delta L}{L_o} = \frac{L_f - L_o}{L_o} \tag{1}$$

Where e, is the strain of the specimen, L_o is the original length of the specimens (mm), and the instantaneous length of the specimen (mm).

Calculation of tensile strength using the equation below [26]:

$$\sigma = \frac{P}{A} \tag{2}$$

Where, (σ) is a maximum tensile strength (MPa), (P) is a maximum load (N), and (A) is a cross-section area of specimen mm^2.

2.2 Wear Analysis

The study conducted a wear test for samples of pure 7075 aluminum alloy and aluminum alloy with the addition of 1% nano silicon carbide. The wear rate was determined by weight loss using the following equation [27]:

$$W.R = (\frac{W_1 - W_0}{W_1}).t \tag{3}$$

where W_o is initial sample weight and W_1 is the sample weight at end of the test. The specific wear rate (mm^3/N.m) at slide velocity (*V*) of the wear device 2 m/sec was calculated as follows:

$$Slide\ distance\ L = V\ * \mathrm{t} \tag{4}$$

$$Specific\ Wear\ Rate\ (S.W.R) = \frac{\Delta W}{L.\ \rho.\ F} \tag{5}$$

Where, ΔW is the weight loss (grams), L is the sliding distance (m), ρ is the density of material's sample, F is the applied load in (N).

3. Materials and Methods

One of the important factors influencing the mechanical properties of any alloy is the characteristics of the materials involved in its manufacture and the method of preparing them so that a homogeneous microstructure leads to improved properties and prolongs its working life before failure occurs.

3.1 Materials

The study was based on a aluminum alloy, type AL 7075, with the weight percentages of its chemical composition shown in Table 1. The components were melted at the percentages indicated for each of them, and mixing continued for 5 minutes until they became homogeneous in their internal composition as shown in Fig. 1 . An alloy of AL-7075 was prepared with the addition nano silicon carbide (SiC), the specifications of which are shown in table 2 at a weight percentage of 1% of the total weight of the molten using a high-precision balance.

Fig. 1. Casting special alloy of AL 7075

Table 1
Chemical composition of special Al-7075

Material	Weight ratio %
Silicon (Si)	0.0
Iron (Fe)	0.0
Copper (Cu)	0.015
Manganese (Mn)	0.0
Magnesium (Mg)	0.026
Chromium (Cr)	0.003
Zinc (Zn)	0.054
Titanium (Ti)	0.0
AL is Other Elements	0.902

Table 2
Specifications of the nano silicon carbide

Nano silicon carbide (5 nm)	
Chemical symbol	SiC
Form	Powder
Purity	99 %
Color	Black
Density	3.22 g/cm^3
Melting Point	2730°C

3.2 Methods

Tensile specimens were prepared according to the standard dimensions ASTM-E8M-16a, shown in Figs. 2-a and b The Auto CAD program was used to draw the specimens and transfer them to the turning CNC machine to run the standard specimens, followed by the process of smoothing the surfaces. Tensile device type Laryee is used for tensile specimens that are loaded at a speed of 0.1 mm/s. Shown in Fig. 3 to conduct tensile tests, The study conducted a hardness test using the hardness testing of pure AL-7075 and AL-7075 reinforced with the addition of nano silicon carbide

(SiC). The study also conducted a surface smoothness test using the roughness testing device shown in Fig. 4. The wear test was conducted using a device shown in Fig. 5 for samples of pure AL-7075 and an AL-7075 with the additive of nano silicon carbide. The test was conducted at a load of 5 N for different time intervals. The tensile samples made of AL-7075 alloys were subjected to a laser beam with the specifications mentioned in table 3. The fiber laser device shown in Fig. 6 was used to generate the laser beam at power levels of 50 watts, 75 watts, and 100 watts.

Table 3
Specification of laser beam

Specifications	Details
Speed	280 (mm/sec)
Power	50, 75, and 100 (watt)
Frequency	20 (Hz)

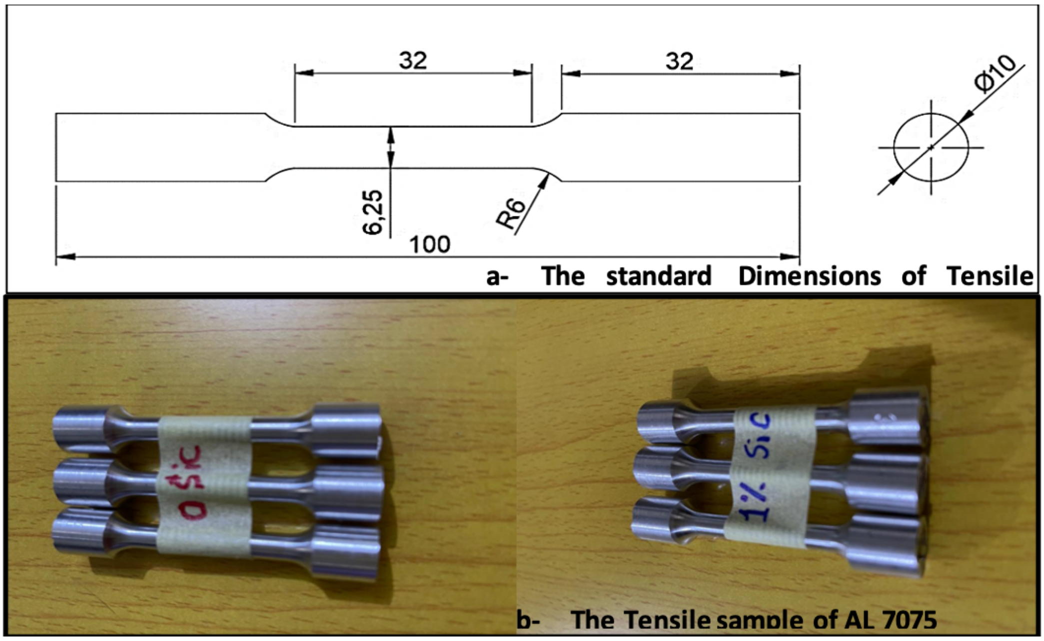

Fig. 2. a and b:The standard dimensions of tensile specimens ASTM-E8M-16a

Fig. 3. The tensile test device **Fig. 4**. The roughness test device

Fig. 5. The wear test device

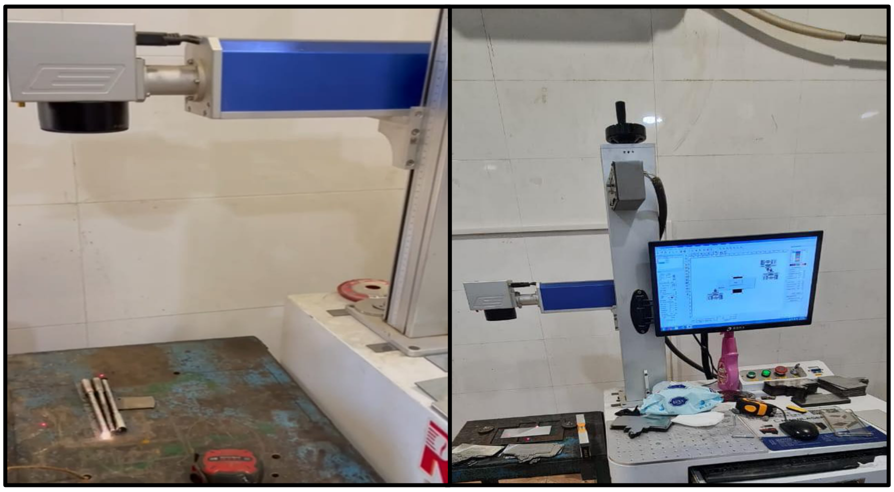

Fig. 6. The Laser test device

4. Results and Discussion

Laser energy is considered a clean form of energy that can be easily controlled. As a result, the trend of using laser energy in heat treatments and improving mechanical properties is on the rise. When a low-frequency laser beam is focused on a sample, the energy of the beam raises the temperature of the sample's surface, which results in a thermal treatment that enhances the surface hardness and increases its resistance. The characteristics of the laser beam during operation, such as speed, frequency, laser energy, and beam angle, are influencing factors that can affect the overall process.

4.1 The Waer of Spacimens With and Without Additive

In Fig.7, the wear test experiment results revealed that adding nano silicon carbide to the alloy resulted in a higher specific wear rate than that of the AL-7075. However, it was observed that the specific wear rate decreased for both alloys as the distance increased, but at varying rates. Specifically, for the pure AL-7075 alloy, the specific wear rate decreased by 64.28% between the linear distances of 600 to 1200 meters, and by 67.07% between the linear distances of 1200 to 1800 meters. When nano silicon carbide was added to AL-7075 alloys, the specific wear rate decreased significantly. The specific wear rate decreased by 86.53% between linear distances from 600 to 1200 m and by 51.74% between linear distances from 1200 to 1800 m.

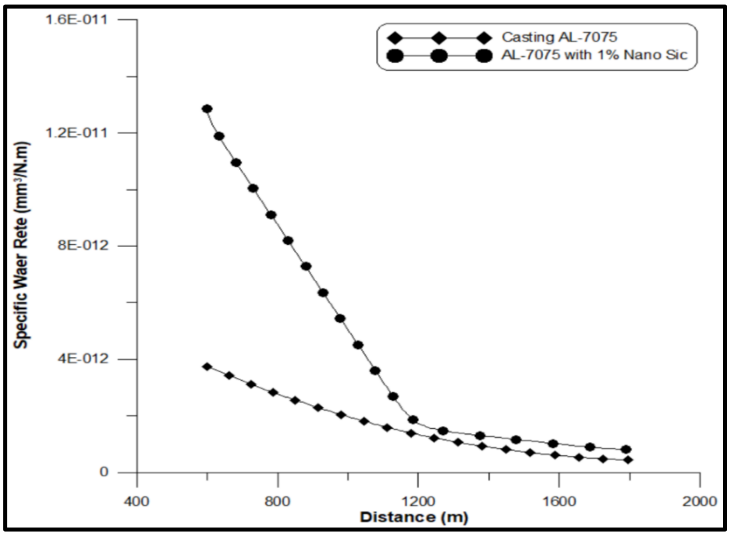

Fig. 7. Compare the specific wear rate of casting AL-7075 and AL-7075 with 1% Nano Sic

4.2 The Effect of Laser Power on the Wear of Spacimens with Additive

Figure 8 illustrates the relationship between the specific wear rate and the distance traveled, demonstrating how altering laser energy affects the AL-7075 alloy with the inclusion of 1% nano silicon carbide. The study conducted wear tests on AL-7075 sample 7075 by adding nano silicon carbide exposed to different laser energies (50, 75, and 100 watts) and measuring its specific wear rate and linear distance. The study found that at a laser power of 50 watts, the specific wear rate decreased by 50% between a distance of 600 and 900 meters. Meanwhile, the rate decreased to 62.96% for the distance between 1200 and 1800 meters. When the sample was exposed to 75 watts laser power, its specific wear rate decreased by 66 % for the distance between 600 and 900 meters. However, the specific wear rate decreased by 68.62 % for the distance between 1200 and 1800 meters. Finally, when the sample was exposed to 100 watts laser power, the results showed that the specific wear rate decreased by 72.72% for the distance between 600 and 900 meters, while the decreased was 70.37% for the distance between 1200 and 1800 metres.

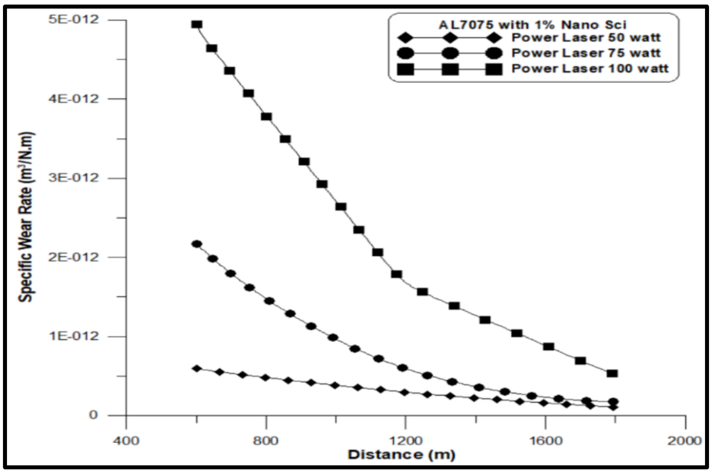

Fig. 8. Compare the specific wear rate of casting AL-7075

4.3 The Effect of Laser Power on Tensile Strength of Spacimens Without Additive

In Fig. 9, the impact of the laser beam on the tensile strength of pure AL-7075 alloy. The results indicate that the tensile strength level increased significantly by 6.0 % when exposed to laser power at 50 watts compared to pure AL-7075 alloy. Similarly, when exposed to laser power at 75 watts, the tensile strength increased by 11.11%, and at 100 watts, the increase was 14.11 % compared to pure AL-7075 alloy. The reason for the increase in tensile strength is due to the laser power, which heats the surface of the sample and hardens its surface due to the heat of the laser beam, which improves the sample's resistance to failure. The enhancement of the mechanical properties of aluminum alloys has paved the way for their use in various industrial applications, especially in aviation, space, and construction industries. Such improvements have also encouraged the development of new and innovative uses of this alloy, making it more versatile and suitable for a broader range of applications.

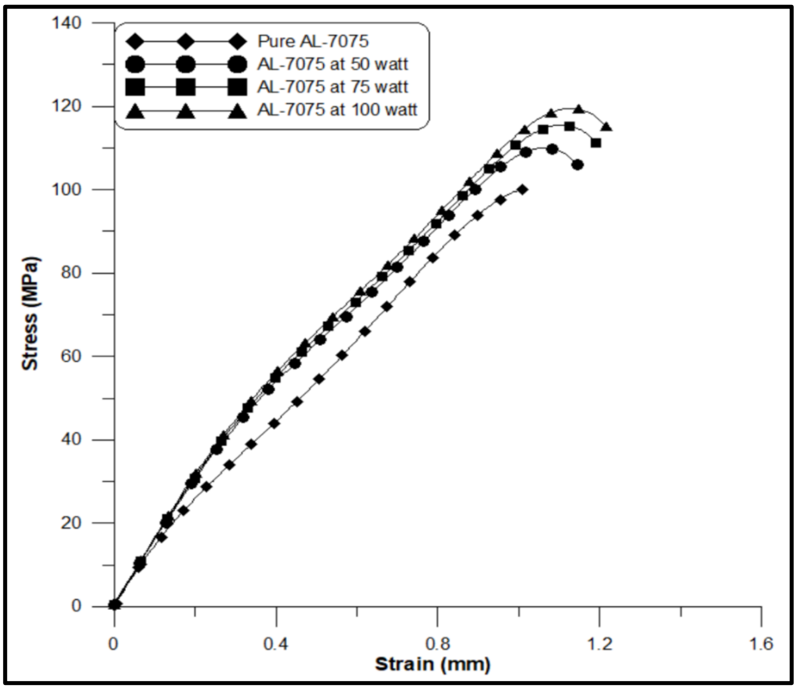

Fig. 9. Compare the result of the tensile test of specimen's number 1, 2 and 3

4.4 The Effect of Laser Power on Tensile Strength of Spacimens with Additive

In Fig. 10, the experiment tested the influence of laser beam power on the tensile strength of AL-7075 alloy with the introduction of 1% nano silicon carbide. The results indicate that the tensile strength grew by 30.4 % when the sample was exposed to a laser beam with a power of 50 watts, and it increased by 42.6% when the sample was exposed to a laser beam with a power of 75 watts. At 100 watts, the increase in tensile strength was 52.2%. The study has revealed that incorporating silica carbide nanoparticles into an aluminum alloy enhances its mechanical properties. The properties can be further improved by increasing the laser energy, which leads to enhanced homogeneity of the particles and the alloy. The laser beam energy also affects the microstructure of the surface of the casting, resulting in increased resistance to failure. As a result, the mechanical properties of the alloy are improved, rendering it a suitable material for various applications.

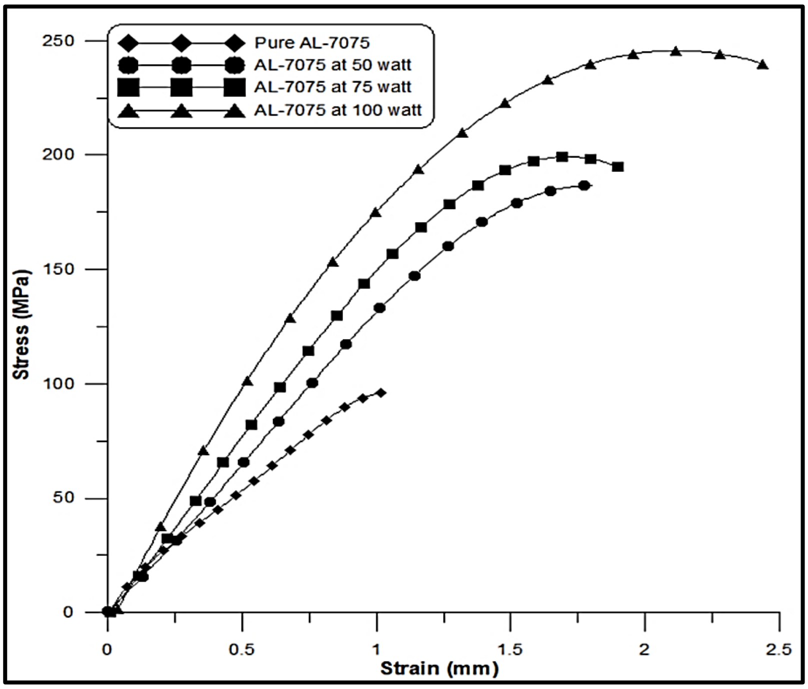

Fig. 10. Compare the result of the tensile test of specimen's number 4, 5

4.5 The SEM of the Microstracture

In Fig. 11, there are SEM images that show the fracture zone of a tensile specimen that was reinforced with nano silicon carbide and exposed to 75 W laser power. The SEM images in Fig. 11-a were taken at 200 µm with 600x magnification for 14.9 mm at 5 kV power, while the image in Fig. 11-b was taken at 400 µm with 300x magnification for 14.9 mm at 5 kV. These images reveal the distribution of nano silicon carbide (SiC) in the AL-7075 alloy throughout its fracture cross-section. The nanoparticles are uniformly spread throughout the composition of the alloy, without forming any agglomerations. This is likely due to the good mixing that occurred during the casting process of the samples.

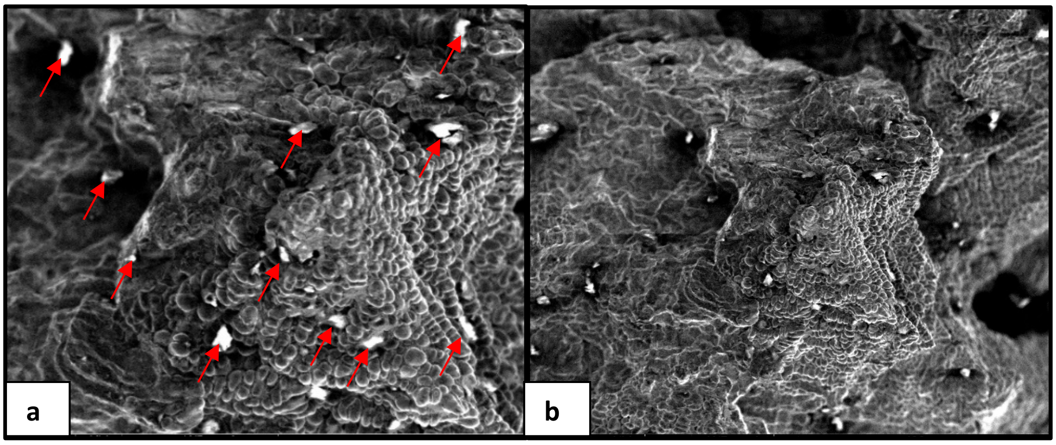

Fig. 11-a and b: The SEM images of fracture region of tensile test specimen of casting AL 7075 with additive 1% nano silicon carbide (SiC) exposed to laser beam

When the power of the laser beam was increased from 50 W to 75 W, the rate of erosion decreased by 24.24% for distances ranging from 600 to 900 meters. However, this decrease was only 8.25% for distances between 1200 and 1800 meters. It was also observed that increasing the exposure of an AL-7075 sample to a laser beam with a power of 75 to 100 watts resulted in a decrease of specific corrosion rate by 9.25%. However, the rate remained constant for distances between 1200 and 1800 meters. The SEM images of the homogeneity of the compound of the AL-7075 alloy with nano silicon carbide indicate the possibility of benefiting from the mechanical properties, which showed an improvement in the mechanical properties of tensile tests on the one hand, with an increase in hardness and wear resistance affected by the properties of the nano silicon carbide that were added to the AL-7075 alloy, which is essentially considered a hard alloy were used in many industries applications.

5. Conclusions

The study was concluded from the results of the experimental tests:

- The findings of a recent study indicate that the specific wear rate of pure AL-7075 alloy decreased by 64.28% for the linear distance ranging from 600 to 1200 meters. Similarly, it showed a reduction of 67.07% between the linear distances from 1200 to 1800 meters. Furthermore, the addition of 1% nano silicon carbide resulted in a significant decrease of the specific corrosion rate by 86.53% and 51.74% for the linear distances ranging from 600 to 1200 meters and 1200 to 1800 meters, respectively. According to the study, the specific wear rate of the AL-7075 casting with an additive of 1% of nano silicon carbide decreased by 50% at a laser power of 50 watts for the distance between 600 and 900 meters, and by 62.96% for the distance between 1200 and 1800 meters. These findings suggest that the use of nano silicon carbide as an additive has a significant effect on reducing the specific wear rate of the AL-7075 casting. These results suggest that the introduction of nano silicon carbide could be a promising solution for reducing the wear and corrosion rates of AL-7075 alloy. Consequently, this additive could have practical applications in various industries where reducing wear is a crucial factor.
- The research study conducted on the AL-7075 casting with an additive of 1% of nano silicon carbide reveals that specific wear rate can be significantly reduced through laser beam exposure. The study found that at a laser power of 50 watts, the specific wear rate decreased by 50% for the distance between 600 and 900 meters and by 62.96% for the distance between 1200 and 1800 meters. Similarly, at a laser power of 75 watts, the specific wear rate decreased by 68.62% for the distance between 1200 and 1800 meters, while for the distance between 600 and 900 meters, it decreased by 68.62%. The results were even better with a laser power of 100 watts, where the specific wear rate was reduced by 72.72% for distances between 600 and 900 meters and by 70.73% for distances between 1200 and 1800 meters.
  In conclusion, the findings of the study suggest that the addition of 1% of nano silicon carbide to the AL-7075 casting and its subsequent exposure to a laser beam can significantly reduce the specific wear rate. This could have important implications for industries that rely on the durability and longevity of their materials. A recent study concluded that treating pure AL-7075 alloy and exposing it to 50 watts of laser power resulted in a 26.693% increase in tensile stress. When exposed to 75 watts of laser power, the increase in tensile strength was 29.350%. Additionally, at 100 watts, the increase was 33.066%.
- The additive of nano silicon carbide at a rate of 1% to AL-7075 alloy has been shown to increase tensile strength under laser beam exposure. Specifically, exposure to a laser beam with a power of 50 watts resulted in a 30.4 % increase in tensile strength, while exposure to a laser beam with a power of 75 watts resulted in a 42.6% increase. At 100 watts, the increase

in tensile strength was highest, at 52.2 % compared with pure AL-7075. Furthermore, an increase in laser power from 50 to 75 watts reduced the specific wear rate by 24.24% for the 600-900m range and by 8.25% for the 1200-1800 m range. At 75 watts, the corrosion rate decreased by 9.25% for the 600-900m range and remained constant for the 1200-1800m range. These findings suggest that the incorporation of nano silicon carbide in AL-7075 alloy can enhance its mechanical and corrosion resistance properties, particularly under laser beam exposure.

- The SEM images of the microstructure of AL-7075 alloy exhibited homogeneity of nano silica carbide grains. This presents a promising avenue for utilizing these grains as effective additives to achieve uniform reinforcement of the mechanical properties of the final casting. Furthermore, it opens up new research opportunities in this field, based on the specific applications that are best suited for their use.
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