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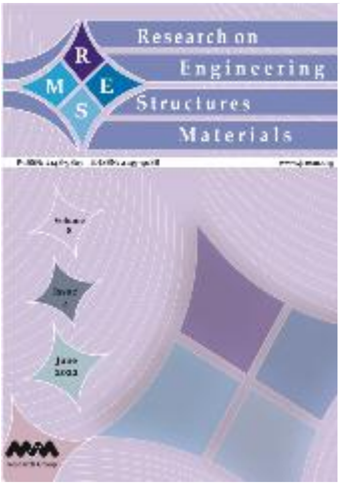


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*Research Article*

# Tensile and compressive mechanical properties of ZA27/ molybdenum disulfide, metal matrix composite

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**Abstract**

The present investigation aims to study the mechanical properties of ZA-27alloy/ Molybdenum disulfide composites containing Molybdenum disulfide ($MoS_2$) particles of size 40 µm. 1% and 2% of molybdenum disulfide are reinforced with ZA 27 alloy (which mainly consists of Aluminium 27%, Copper 0.5%, Tin 1-2% balance is Zinc) through the stir casting method. In this method, $MoS_2$ particles are poured into the molten ZA 27 alloy, for the uniform distribution of the particle stirrer used. The results of the present investigation showed that as $MoS_2$ composition increased, there were significant monotonic increases in the elastic load strength, plastic load strength, ultimate tensile strength (UTS) and compressive strength of $MoS_2$-reinforced ZA27 alloy as compared to unreinforced ZA 27 alloy. The present work gives explanations for these obtained results with the help of Scanning Electron Microscope (SEM) images.



## 1. Introduction

Among zinc-based cast alloys, the ZA family has enjoyed great popularity in recent years. Compared to aluminium-based alloys, The increased strength and lower casting temperature of ZA alloys are significant advantages [1,2,3]. It has been proposed that adding silicon carbide reinforcement to zinc alloys will increase the alloys' strength-to-weight ratio and dimensional stability while taking advantage of their low processing temperatures and low cost [4]. Similar to graphite, Alumina, and silicon carbide, $MoS_2$ is a reinforcing material and can likely be used to strengthen zinc-based matrixes [5]. In recent years, remarkable work has happened on $MoS_2$ as reinforced material in the metal matrix composite. Molybdenum-reinforced material exhibits good anti-sizing characteristics, low friction and less wear [6,7,8]. The $MoS_2$ projected out from the specimen during pin-on-disc wear testing, from the tribo layer which prevents wear loss of the specimen, as result composite presumably imparts enhanced tribological properties, in other words, it acts as a solid lubricant. $MoS_2$ particles of sizes ranging from 1µm to 100 µm are generally used for dry lubricating purposes. It is also used in an automotive engine, coating rifle barrels to easily pass bullets, etc. The presence of $MoS_2$ in the matrix increases the spreadability of the oil on the contact surface, thereby reducing the tendency to score or scratch or seize as result it is also used as a solid lubricant [9]. The zinc-aluminium alloy ZA-27 with the chemical composition mentioned in the abstract was used as the matrix material in this study. Among the various ZA alloy series, ZA 27 alloy has the highest ductility and strength, excellent wear properties, and good machineability and bearing properties. ZA 27 alloy is used for medium load, low speed and moderate temperature applications such as bearings and gears. The stir casting method is used in this work, in which $MoS_2$ particles with sizes

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ranging from 40 μm to 50μm are preheated and added to molten ZA 27 alloy that has been heated above its melting temperature. The mechanical stirrer is used for the proper mixing of matrix and reinforcement material. The elastic strength, Plastic strength, ultimate tensile strength (UTS) and ultimate compressive strength of the composite material and unreinforced ZA 27 alloy are studied. The present investigation aims to study these properties in the ZA 27 alloy/$MoS_2$ particle composites.

## 2. Experimental Procedure

### 2.1. Preparation of Composite

To prepare tensile and compressive specimens, the stir casting method has been adopted [10]. The measured quantity of ZA 27 alloy was placed in the furnace's crucible. The crucible is heated at a constant temperature of 600°C until the solid ZA27 changes to a liquid phase. The molten matrix is brought to a temperature of 485-490°C at which the calculated amount of (1% weight of taken ZA 27) preheated $MoS_2$ is poured. At this temperature, the mixing of both molten matrix and $MoS_2$ is carried out at the speed of 320-340 rpm with the help of a mechanical stirrer for 5 minutes. The molten composite is poured into a circular preheated mould of cast iron. The molten metal matrix composite inside the mould allowed it to solidify at room temperature. A casted circular specimen was taken out from the mould. The same procedure was repeated to prepare ZA 27 alloy reinforced with 2% Molybdenum disulfide, but instead of 1% weight of ZA 27 alloy, 2% weight of ZA 27 alloy, $MoS_2$ is used. The Same procedure repeats to prepare base ZA 27 alloy.

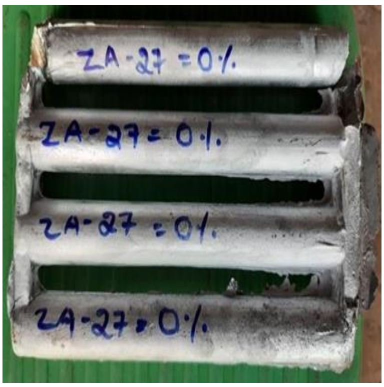



Fig. 1 ZA27 without $MoS_2$ moulded specimen

Fig. 2 ZA 27 with 1% $MoS_2$ moulded specimen

### 2.2. Preparation of Tensile and Compressive Specimens

Specimens obtained after removal from the mould are shown in Fig. 1 and Fig. 2 From these figures, it has been observed that moulded specimens are irregular in shape, and are surrounded by an oxide scale. The size of the specimen in terms of length and diameter is greater than the required dimension. All moulded specimens are machined and turned as per the requirement of ASTM (American Society for testing material) Standards. For the tensile test, specimens are prepared as per ASTM E 8 standard [11], the specification of the tensile specimen as per ASTM E8 is given in Table 1. schematic representation of the tensile specimen is given in Fig. 3 Similarly, for the compressive test, moulded specimens are machined as per the ASTM standard E 9 which is the ASTM standard for compressive test [12,13]. The compressive specimen should be a 1.5 to 2 length-to-diameter ratio as per

ASTM standard E9 A schematic representation of the compressive specimen is given in Fig. 5 and the prepared compressive specimen as per ASTM standard E9 is shown in Fig. 6.

Table 1. Specification of tensile specimen as ASTM standard E8

| Specification | Dimension(mm) |
|---|---|
| G—Gauge length | 62.5 + 0.1 |
| D—Diameter | 12.5 + 0.2 |
| R—Radius of fillet | 10 |
| A—Length of reduced section | 75 |

Fig. 4 Prepared tensile specimen as per ASTM standard E8

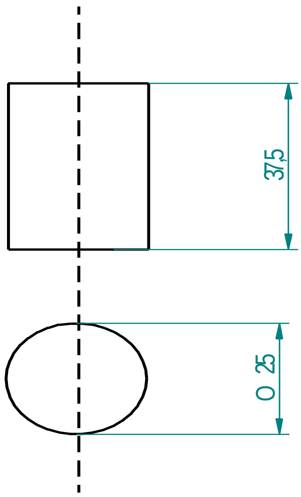



Fig. 5 Schematic representation of compressive specimen as per ASTM standard E 9

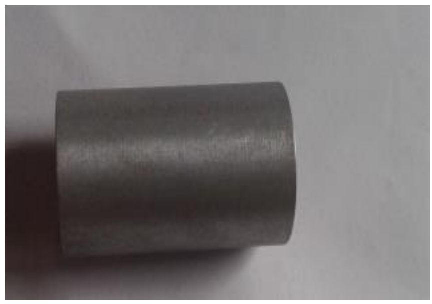


Fig. 6 Prepared compressive specimen asper ASTM standard E 9

### 2.3. Procedure to Perform the Tensile and Compressive Test

At room temperature, both tensile and compressive tests are conducted using the universal testing machine. The standard procedure was followed to conduct both tensile and compressive tests.

- The tensile specimen is held between the jaws of the UTM machine in such a way that the test specimen is held by both jaws perfectly

- The extensometer is fixed within the gauge length marked on the specimen dial of the extensometer is adjusted and the dial of the machine scale is set to zero and further load indicator also is set to zero.
- A suitable increment of load selected is applied so that corresponding elongation is measured in the case of a tensile specimen and reduction is measured in the case of the compressive specimen from dial gauge by keeping the speed of the machine uniform to record all displacement points for applied load till break or failure of specimen takes place.
- From each composition, 3 tensile specimens are tested, and from the average values of ultimate tensile strength, young's modulus and plasticity are represented in form of a graph. Similarly, from each composition, three compressive specimens are tested for compressive strength and the average values of the ultimate compressive specimen is calculated.
- A gradual load in KN is applied in UTM for both tensile and compressive and the corresponding displacement in mm is recorded Based on the results obtained load v/s displacement graph was plotted to analyze the mechanical properties of the specimen both for tension and compression [13,14].

## 3. Result and Discussion

Young's modulus in terms of elastic load, ductility (in terms of plastic load) or plastic load ultimate tensile strength (UTS) in terms of breaking load and ultimate compressive strength in terms of breaking load are determined for the ZA 27 alloy and ZA 27 alloy reinforced with 1% and 2% $MoS_2$ with help of a universal testing machine. For each composition, three tensile and compressive specimens are tested to find out the tensile and compressive strength the of specimen respectively. The average value of three tests is taken for each composition. The repeatable results are obtained. The individual results do not deviate more than 5% from their mean value. All mentioned parameter results are represented graphically from Fig. 7 to Fig. 10

### 3.1 Elastic Behavior

Average three values of elastic loads are plotted for both ZA 27 base alloy and 1%, as well as 2% $MoS_2$, reinforced ZA27 alloy as shown in Fig. 7. Generally, young's modulus is defined, as stress is proportional to strain within the elastic limit. the specimen comes to its original position after the removal applied load, that load is called elastic load. In the current study, for the applied load, if zero deflection is shown on the extensometer, that load is referred to as elastic load. From the plotted graph shown in Fig. 7, it can be seen that the elastic load range increases for an increase in the quantity of $MoS_2$ in ZA 27 base alloy. It can be observed from Fig. 7, ZA 27 reinforced with 1% of $MoS_2$ has 3 times elastic strength compared to the base ZA 27 alloy. Similarly, ZA 27 reinforced with 2% of $MoS_2$ showed four times the elastic load applied as compared to unreinforced ZA 27 alloy.

### 3.2. Plastic Behavior

Average three values of plastic loads are plotted for both ZA 27 base alloy and 1%, as well as 2% of $MoS_2$, reinforced ZA27 alloy as shown in Fig 8. load at which specimen does not return to its original size after removal applied load, such load is called plastic load. plastic load of ZA 27 base alloy and ZA 27 reinforced with 1% and 2% of $MoS_2$ are given in Fig. 8. In the present research work, the load at which the specimen starts to elongate which can be indicated through deflection in the extensometer which is fixed to the tensile specimen during tensile testing. Such load is referred to as plastic load. It can be seen from Fig. 8, ZA 27 alloy has experienced a plastic load of around 4000N, ZA 27 alloy reinforced with 1% of $MoS_2$ has experienced a plastic load of around 7900N which is twice that of the base ZA 27 alloy. ZA 27 alloys reinforced with 2% $MoS_2$ have experienced a plastic load of around

9800N, which is around 3 times greater than ZA 27 base alloy. This substantial increase in ductility is probably because zinc, with its compact hexagonal crystalline structure, is a relatively brittle material in the solid state, while added $MoS_2$, as an effective solid lubricant, facilitates the movement of grains, along with the slide planes, a similar observation made while graphite is added instead of $MoS_2$[15].

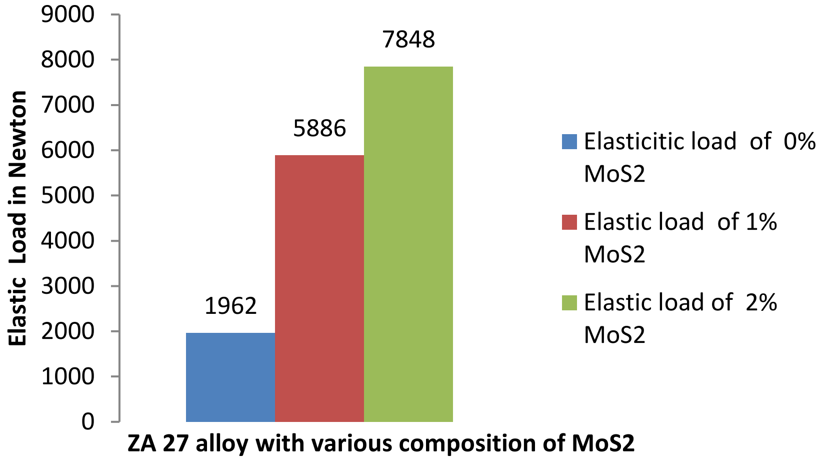



Fig. 7 Change of elastic behaviour of ZA 27 alloy with the addition of $MoS_2$ particle

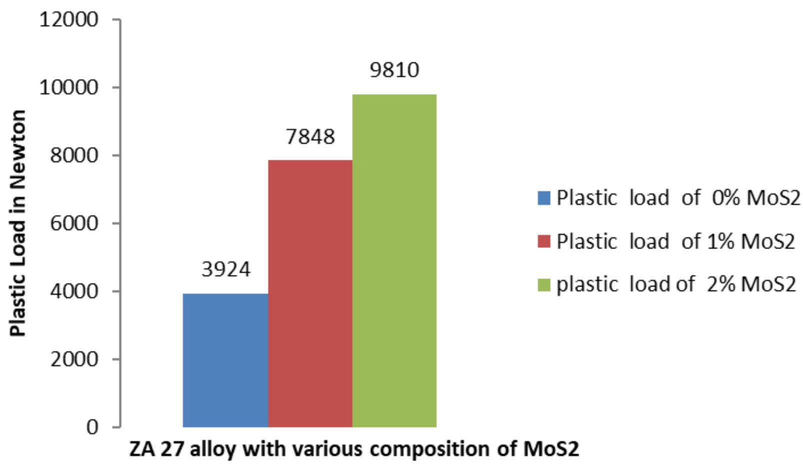



Fig. 8 Change of plastic behaviour of ZA 27 alloy with the addition of $MoS_2$ particle

### 3.3. Ultimate Tensile Strength

Average three values of ultimate tensile loads are plotted for both ZA 27 base alloy and 1%, as well as 2% of $MoS_2$, reinforced ZA27 alloy as shown in Fig. 9. Ultimate tensile load is the maximum load applied to a specimen during tensile testing, at which the testing specimen will break. The ultimate tensile load of ZA 27 base alloy and ZA 27 reinforced with 1% and 2% of $MoS_2$ are given in Fig 9. In the present work, the load at which the specimen breaks, that load is referred as the ultimate tensile load. It can be observed from Fig. 9, ZA 27 alloy is broken at a load of around 22500N, ZA 27 reinforced with 1% $MoS_2$ is broken at a load of around 25500, and ZA 27 alloy reinforced with 2% $MoS_2$ is broken around 28400N. It is observed from Fig. 9 that the Ultimate tensile strength of ZA 27 alloy increased with an increase in the composition of $MoS_2$. This increase in tensile strength may be due to the $MoS_2$ particles acting as barriers to dislocations in the microstructure as a similar observation made by other researchers. [16,17,18]

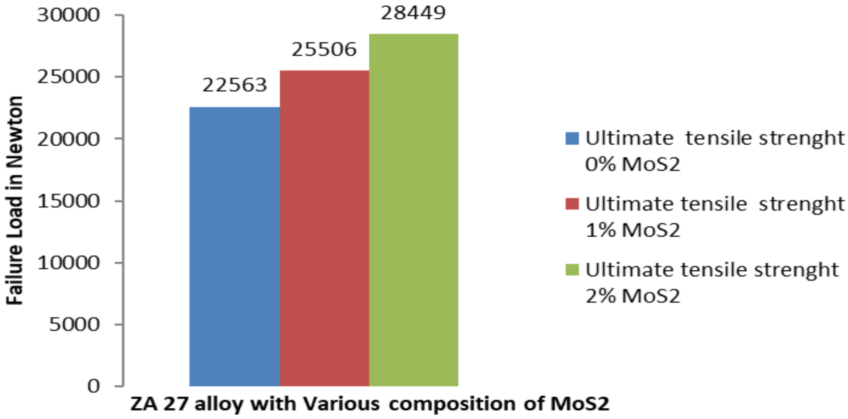



Fig. 9 Ultimate tensile strength of ZA 27 alloy with addition of $MoS_2$ particle

### 3.4 Ultimate Compressive Strength

Fig. 10 is a graph showing the effect of $MoS_2$ content on the compressive strength of cast ZA-27 base alloy. Effects of elasticity, plasticity and ultimate tensile strength of ZA 27 alloy and ZA 27 reinforced with 1% and 2% of $MoS_2$ are discussed in the previous section. It can be seen from Fig. 10 that as the $MoS_2$ content increases, the compressive strength of the composite material increases significantly. As the $MoS_2$ content is increased from 0% to 2%, the compressive strength increases by about 45%. As in the case of UTS described above, this increase in compressive strength may be due to the $MoS_2$ particles acting as barriers to dislocations in the microstructure as the same thing was observed by the other researcher for graphite reinforcement, the same explanation can be given as explained for ultimate tensile strength [16,17,18].

### 3.5 SEM Analyses

The SEM images of the middle portion of a tested surface of ZA 27 alloy, ZA 27 alloy reinforced with 1% $MoS_2$ and ZA 27 reinforced with 2% $MoS_2$ are shown in Fig. 11(a, b, c). All SEM images are taken at the magnification of 200X. It can be seen in Fig. 11(a), a relatively large void is formed on the surface of the tensile tested specimen for the base ZA27 alloy. A weak spot within the specimen will create a small internal void when a tensile load is applied. As the load rises, this void will progressively get bigger. The material cross-section area cannot withstand high loads when the internal resistance of the specimen exceeds the applied load and the specimen ultimately fails by ductile fracture as a result of significant plastic deformation and the formation of a micro void. After reinforcement of 1% $MoS_2$ in ZA 27 alloy, there is a change in the size of the void can be seen in Fig. 11(b). It showed that due to the addition of $MoS_2$ particle, the size of the void decreased between ZA 27 particles, and the more refined structure of ZA 27 alloy can be seen from the same Fig. 11(b), further increase in the percentage of $MoS_2$ to 2% further reduction in size and depth of void of ZA 27 alloy can be seen in Fig. 11 (c). So, SEM images give more support to the interpretation given for all tensile results. To check the presence and distribution of $MoS_2$ inside the ZA 27 alloy EDX analysis is carried out which is shown in Fig. 12.

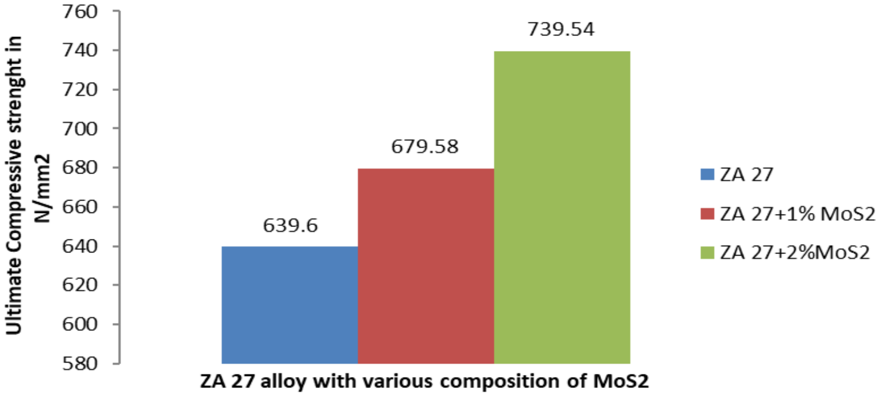
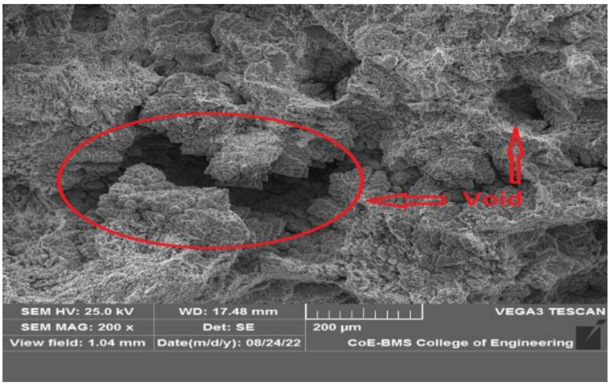
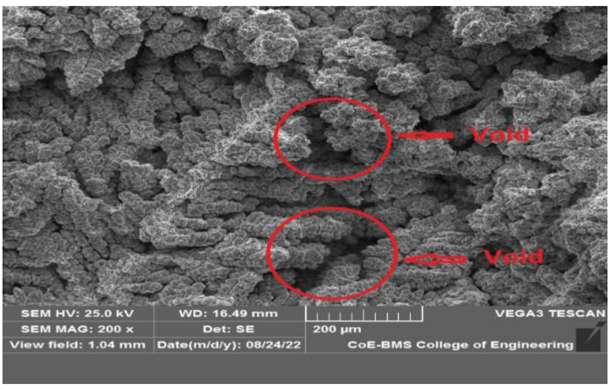


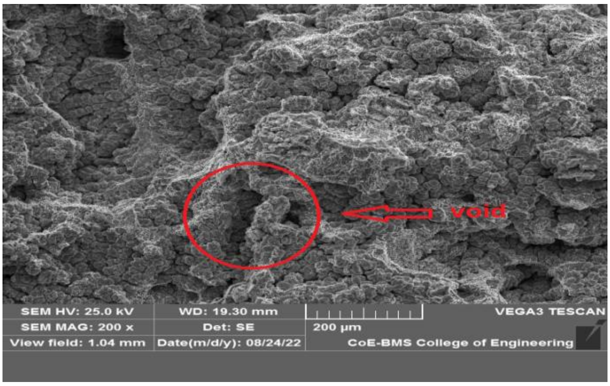

Fig. 10 Ultimate compressive strength of ZA 27 alloy and its $MoS_2$ reinforcement




(a) SEM image of ZA 27 alloy without reinforcement




(b) SEM image of ZA 27 alloy with 1% of $MoS_2$




(c) SEM image of ZA 27 alloy with 2% of $MoS_2$

Fig. 11 SEM images

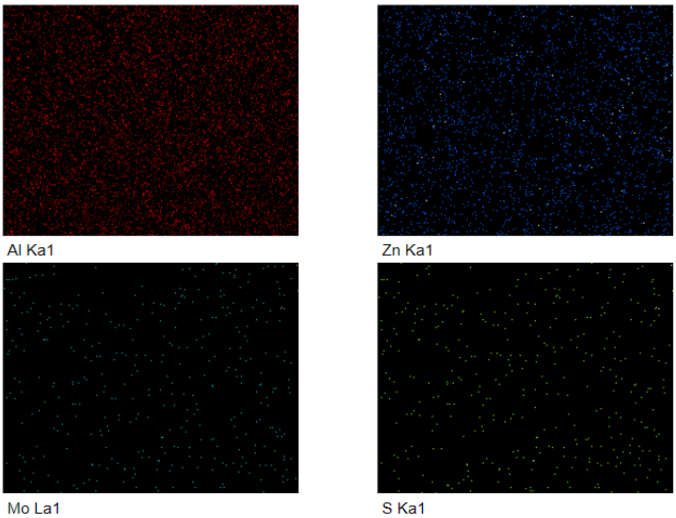



Fig. 12 EDX image of the distribution of $MoS_2$ in ZA 27 base alloy

## 4. Conclusions

The ZA 27 alloy possesses excellent physical, mechanical and tribological properties such as low weight, high strength, excellent foundry castability fluidity, good machining properties, low initial cost, and environmentally- friendly as compared to plastics, cast iron, or even steels when being applied under conditions of high mechanical loads and moderate sliding speeds under moderate operation temperatures. Many researchers tried to improve its mechanical, tribological and other physical properties trough reinforcing it with various reinforced materials such as silicon carbide, graphite, zircon, Manganese, Magnesium, Aluminium oxide, short glass fibre, Titanium and titanium diboride etc. Some Researchers tested the same ZA 27 alloy by subjecting it to various heat treatment processes to check the change in its mechanical properties. In the present investigation, important mechanical properties such as tensile strength and compressive strength of ZA 27 alloy and ZA 27 alloy reinforced with one percentage (1%) and two per cent (2%) of $MoS_2$ were investigated. To get repeatability, each composition is tested three (3) times.

The comparative studies were carried out with unreinforced ZA 27 base alloy with ZA 27 alloy reinforced with 1% and 2% $MoS_2$ particles. Mechanical analyses or tensile and compressive analyses indicated that the presence of the $MoS_2$ particles in the Zinc aluminium alloy remarkably changed through reinforcing 1% and 2% amounts of $MoS_2$. It was found that increasing the $MoS_2$ content within the ZA-27 matrix results in significant increases in the elasticity or elastic strength, plasticity or plastic strength, ultimate tensile strength and ultimate compressive strength. This change in the result is completely attributed to the presence of $MoS_2$ inside the ZA 27 alloy. Scanning Electron Microscopic images showed the changes in surface structure and decrease in the size of voids due to the addition of $MoS_2$ particles and the Energy Dispersive X-ray (EDX) image showed the distribution of reinforced particles inside the ZA 27 alloy. Both SEM and EDX images also support the explanation of the positive effect of $MoS_2$ particles in the Mechanical properties of ZA 27 alloy. Compressive strength is increased as a result of $MoS_2$ particles acting as barriers to dislocations occurring due to the application of compressive load. So, it can be concluded that $MoS_2$ particles positively influence the tensile and compressive properties of ZA 27 alloy. The good mechanical characteristics of $MoS_2$ and their adequate facial interaction with the matrix surface can be used to explain this behaviour.

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