

Experimental Investigation to Study the Influence of Variation in Composition on Tribological Behavior and Impact Strength of Aluminium Alloy Al7068



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ABSTRACT

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Aluminium alloys have a wide variety of applications in the industrial sector due to some unique characteristics like lightweight, high strength to weight ratio, corrosion resistance, good electrical conductivity, recyclability, ductility, and formability, etc. Due to this unique combination of properties, the applications of aluminium alloys continue to increase. The tribological behavior and impact strength were studied in this research work by conducting the wear and impact tests, varying the composition of two major alloying elements, Magnesium (Mg) and Zinc (Zn) of Al7068 aluminium alloy. The specimens were prepared as per ASTM standards for wear and impact tests, four compositions each for Mg% varying b/w (2.2 to 3%), and Zn % varying b/w (7.3 to 8.3%). The results of the wear test on the alloy Al7068 shows that the specimens with 3% Mg and 7.6% Zn compositions gives least wear rate at loads 2 kg and 3 kg respectively whereas the specimens with compositions of 2.75% Mg and 7.3% Zn give highest wear rate at a low load of 1 kg. The impact test results indicate that specimens with compositions of 2.2% Mg and 7.6% Zn of the alloy Al7068 give the highest impact strength which in turn improves its performance.

1. INTRODUCTION

Wear is a measure of progressive material loss as a result of relative motion between the operating surfaces in contact. In the industrial sector, wear is a paramount problem and its direct cost is estimated to vary between 1 and 4% of the net gross national product [1]. Huge amount of research is progressed to produce highly durable materials and vivid techniques are developed for wear reduction of tools and engineering components. The wear behavior of materials is evaluated by using Pin on disc wear test apparatus. Wear rate is a quantity generally used to measure the wear process and defined as the volume or mass of material that is removed in the unit time quantity or per unit sliding distance.

Charpy V-Notch (CVN) impact test is a mechanical method to evaluate the notch toughness value or impact strength of a given test specimen and named after one of its main theorists and developer Georges Charpy (1865-1945), a French engineer. This method is one of the popular, cost-effective, simpler and more reliable methods in the present world commonly used by regulatory and other codes for testing fracture critical structures such as bridges, pressure vessels and pipelines.

2. LITERATURE REVIEW

Choubey et al. [2] in their work studied the tribological

characteristics of commercially used pure (CP) metals such as Ti-6Al-4V, Ti, and Ti-5Al-2.5Fe in a simulated body fluid solution called Hank's solution. The results of their investigation revealed different wear mechanisms such as tribo-mechanical abrasion, cracking and transfer layer formation. They observed that the predominant wear mechanism was tribo-mechanical abrasion. Li et al. [3] studied the influence of heat treatment, surface modification and content effect on wear characteristics for the alloys Ti-Nb-Ta-Zr and Ti-6Al-4V (TAV1). The authors in their work observed that the wear resistance improved by increasing the Nb content. The resistance to wear is enhanced by heat treatment for the alloys Ti-29Nb-13Ta-4.6Zr (TNZT1) due to oxide particle formation from Nb₂O₅.

Chiba et al. [4] studied the wear characteristics in high carbon content forged Co-Cr and cast Co-Cr alloys. The results indicated that wear resistance was considerably higher for forged Co-Cr alloy than that of cast Co-Cr alloy. The precipitation of carbide accounted for higher wear loss in the Co-Cr alloy.

Fischer et al. [5] investigated the wear characteristics of low-carbon Co-base alloy such as Co-Cr29-Mo, Cr-Ni-Mn-Mo-N steel, Cr-Ni-Mo steels, and Ni-free Cr-Mn-Mo-N steel alloys in sliding wear. In this work, authors estimated wear characteristics in sliding wear by using the tests such as torsional fatigue and pin-on-disk tribometer followed by electron microscopy. The results indicated that wear behavior exhibited by Ni-free Cr-Mn-Mo-N steel alloys was superior to

Cr-Ni-Mo steels. Xu et al. [6] examined the wear resistance of the alloys Ti-15Mo-xNb (with x = 5%, 10%, 15%, and 20%) under dry condition state. The authors observed that enhancing the Nb content resulted in increase of the friction coefficient. The primary wear mechanism was observed to be adhesive wear in this work.

Ajithkumar et al. [7] investigated the dry sliding behavior of pure Mg, hypereutectic, and hypoeutectic Mg-Si alloys manufactured with the help of gravity casting technique. From their observations the authors reported that due to morphology change of primary Mg₂Si from polyhedral to coarse dendrite the wear resistance of hypereutectic Mg-Si alloys is greater compared to hypoeutectic alloys.

According to ASTM E23, Charpy impact test determines the amount of energy absorbed by a standard sample during fracture [8]. The fracture energy absorbed is a measure of the material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. This technique is extensively used in the industrial field, owing to its simplicity of experimentation. Another advantage of the method is results can be obtained rapidly and economically. The major limitation is some results are only comparative. The apparatus consists of a pendulum of known mass and length that is dropped from a known height to impact a notched specimen of material.

The impact test results are affected by a notch in the sample and thus it is required for the notch to be of regular dimensions and geometry [9]. The sample size also significantly affects the results since the dimensions determine whether or not the material is in plane strain. Amardeepak et al. studied the effect of variation of alloying elements on the hardness and impact strength characteristics of aluminium alloy Al6463. The results of the experiments showed that the highest impact strength was obtained for the specimens having 0.750% Mg and 0.2% Si compositions of the alloy Al6463. Highest hardness values were obtained for specimens having 0.5% Mg, 0.875% Mg, and 0.575% Si compositions of the aluminium alloy Al6463.

Nearly about four decades ago, the main prerequisite for the usage of the verification specimens was added to the standard for impact testing of metals, American Society for Testing and Materials (ASTM) Standard E 23. This happened because the metals impact testing community discovered that by conducting verification tests of impact machine performance using reference specimens were able to detect certain energy loss mechanisms which otherwise could not be observed during traditional physics-based measurements of machine performance (pendulum period, mass, mechanical friction, etc.) [10, 11].

Abouei et al. [12] studied the effect of Fe-rich intermetallic on the wear behavior of eutectic Al-Si alloy (LM13). The wear rate of the eutectic Al-Si alloy, 1.2Fe (addition of 1.2% Fe to the eutectic Al-Si alloy, 1.2FeMn alloys (addition of Mn to the 1.2Fe alloy) at different applied loads was calculated. The results showed that 1.2FeMn alloy had the highest wear rate compared to other alloys at all applied loads. Mamatha et al. [13] addressed thermal effect, viscosity variation in tribological Squeeze film with Reynolds's equation. The load effect between two moving surfaces minimizes wear and reduces energy loss, friction between them.

Subramanian and Senthilkumar [14] evaluated the mechanical properties of aluminium alloy LM25 matrix reinforced with fused silica-SiO₂ particulates (metal matrix composite). The composites were cast by stir casting route.

The results indicated an improvement in mechanical properties such as tensile strength, hardness, and impact strength due to the addition of SiO₂ particulates as the reinforcement. Amardeepak et al. [15] studied the compression and hardness characteristics of aluminium alloy Al7068 by varying the Mg and Zn compositions. The results showed that the lowest strain was obtained for the specimens with 2.5% Mg and 7.6% Zn compositions and highest hardness for specimens with 3% Mg and 8% Zn compositions of the alloy Al7068.

Murthy and Rao [16] studied the impact on mechanical properties of hybrid aluminium metal matrix composites fabricated by stir casting technique. The reinforcements aluminium oxide (Al₂O₃), silicon carbide (SiC) and boron carbide (B₄C) were varied in different proportions in the base alloy matrix Al6061. Mechanical tests such as tensile, flexural, charpy impact, and brinell hardness tests were conducted on the fabricated composites. The results showed that the variation of reinforcement proportion in the alloy had a significant impact on the mechanical properties of the hybrid composite.

Narasimma et al. [17] studied the artificial aging effect on mechanical properties and wear behavior of Aluminium LM4 alloys. The specimens were prepared as per ASTM standards for wear, hardness and tensile tests. The results of the investigation showed that with the increase in aging time hardness and tensile strength increased. Increase in hardness, applied load and aging time resulted in decreased rates of wear. Periasamy et al. [18] studied the effect on friction and wear by addition of (10% wt. of SiC) and (10% wt. of Graphite) as the reinforcement by Friction Stir Processing method. Using SEM and EDS analysis the distribution of reinforcement was observed. The results of the investigation showed improved tribological and mechanical properties of the composite compared to the base metal aluminium alloy Al7075.

Prasad and Ramachandra [19] investigated the influence of process parameters such as squeeze pressure and reinforcement content on the tribological behavior and mechanical properties of squeeze cast LM6 Al-flyash composite. The reinforcement added to aluminium metal matrix composite was flyash (5-12.5% wt.). The experimental results showed improved wear resistance of the composite compared to the base alloy. The examination of the microstructure revealed uniform distribution of the reinforcement (flyash particles) in the aluminium metal matrix. Wahab et al. [20] carried out preparation and characterization of reinforced aluminium nitride in aluminium metal matrix composites. The samples were prepared by using a graphite crucible and a stainless steel permanent mould. Optical microscopy technique was employed to observe the particle distribution in the composite [21]. The results of the investigation showed that increase in the hardness of the aluminium metal matrix was due to the addition of AlN (aluminium nitride) as reinforcement particles.

3. EXPERIMENTATION

The aluminium alloy was cast using the basic composition with a variation in the composition of the two major alloying elements that have a significant effect on the properties of the alloy. Magnesium percentage was varied from 2.2% to 3% and the zinc percentage from 7.3% to 8.3%. The specimens for the wear and impact tests were prepared as per the ASTM standard and experimentation conducted [22, 23]. The chemical composition of Al7068 is shown in Table 1.

Table 1. Chemical composition of Al7068 aluminium alloy in weight percentage

| Weight% | Al | Si | Fe | Cu | Zr | Mg | Zn | Others each |
|---------|-----|-------|-------|---------|-----------|-------|---------|-------------|
| 7068 | Bal | <0.12 | <0.15 | 1.6-2.4 | 0.05-0.15 | 2.2-3 | 7.3-8.3 | 0.05-0.12 |

3.1 Wear test

The wear test was conducted by using Ducom pin-on-disc apparatus as shown in Figure 1 and the wear rate calculated. The test was conducted as per the ASTM Standard Code ASTM G99 - 17 which is the standard test method for Wear testing. The specimen dimensions were length 50 mm and diameter 9 mm with a constant track radius of 60 mm. The speed was maintained constant at 1000 rpm and time was set to 180 seconds. The loads were varied from 1, 2, and 3 Kg respectively and the Frictional force values noted down.



Figure 1. Ducom pin-on-disc apparatus for wear test

3.1.1 Wear test apparatus

Tables 2 & 3 give the experimental details of wear test of the aluminium alloy Al7068 by varying the magnesium and zinc percentage composition. Figures 2 and 3 show the graphical representation of wear test results of aluminium alloy Al7068 with Mg and Zn% variation.

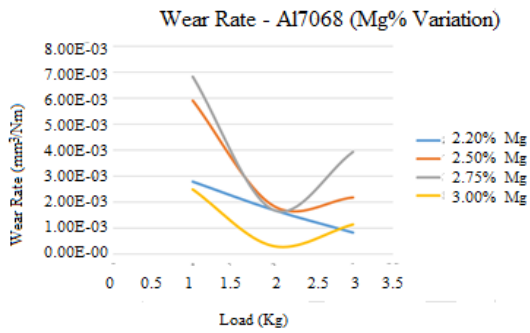


Figure 2. Graphical representation of wear test results for Al7068 specimens with Mg% variation

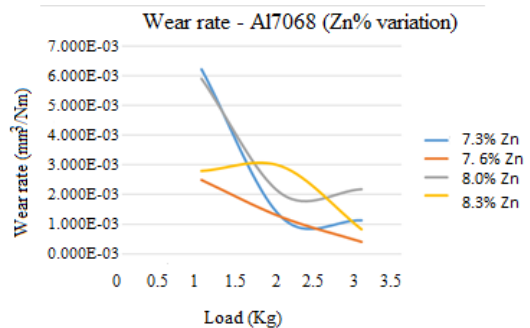


Figure 3. Graphical representation of wear test results for Al7068 specimens with Zn% variation

Wear is defined as accelerated loss of material from the operating surfaces as a result of relative motion and is calculated by the difference of initial and final weights of the specimen. It is generally expressed as grams (g) or milligrams (mg) and can be converted into volume loss by considering its density. It can be computed by using these formulae with the help of various parameters.

Let, V_l be the Volume loss/Volume of material removed (mm^3), then it is defined as:

$$V_l = \frac{\text{Weight loss}(g)}{\text{Density}(g/\text{mm}^3)}$$

Wear rate is calculated by Volume loss method using the formula:

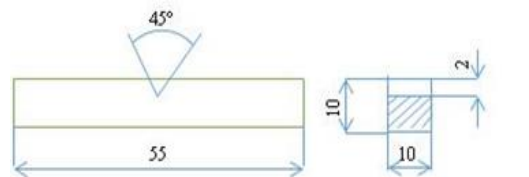
$$\text{Wear Rate} = \frac{\text{Volume of material removed } (\text{mm}^3)}{\text{Frictional force} * \text{Sliding Distance } (N - m)}$$

3.2 Impact test

The Charpy impact test apparatus IT-30(ASTM) was used in the present work as shown in Figure 4(a). The test was performed in compliance with ASTM E23 standard on a specimen of size 10mm x 10mm x 55mm with a notch of dimensions 2mm x 2mm x 45° as shown in Figure 4(b) and the impact energy absorbed by the specimen was recorded.



(a)



All dimensions are in mm.

(b)

Figure 4. (a) Charpy impact test apparatus IT-30 (ASTM); (b) Impact test specimen ASTM E-23 Standard

4. RESULTS AND DISCUSSIONS

4.1 Wear test

Table 2 shows the experimental results for wear test

conducted on the aluminium alloy Al7068 with Mg% variation. Figure 2 shows the graphical representation of the experimental values shown in Table 2. It shows that the specimen with a composition of 2.75% Mg gives the highest wear rate compared to other specimens at a low load of 1 kg. Also, it indicates that the specimen with 3% Mg gives the least wear at a load of 2 kg. The wear rate of the specimen with 3% Mg composition decreases by 87.5% as the load is increased from 1 kg to 2 kg with an increase by 33.47% as the load is further increased to 3 kg. This shows that higher composition of Magnesium in the aluminium alloy Al7068 gives the least wear at moderate loads.

Table 2. Wear test results for Al7068 specimens with Mg% variation

| Specimen (Mg%) | Load(kg) | Initial Weight(g) | Final Weight(g) | Wear Rate(mm ³ /Nm) |
|----------------|----------|-------------------|-----------------|--------------------------------|
| 2.200% | 1 | 8.750 | 8.741 | 2.79E-03 |
| | 2 | 8.741 | 8.730 | 1.71E-03 |
| | 3 | 8.730 | 8.722 | 8.27E-04 |
| 2.500% | 1 | 8.612 | 8.593 | 5.89E-03 |
| | 2 | 8.593 | 8.581 | 1.86E-03 |
| | 3 | 8.581 | 8.560 | 2.17E-03 |
| 2.750% | 1 | 8.345 | 8.323 | 6.83E-03 |
| | 2 | 8.323 | 8.312 | 1.71E-03 |
| | 3 | 8.312 | 8.274 | 3.93E-03 |
| 3.000% | 1 | 8.792 | 8.784 | 2.48E-03 |
| | 2 | 8.789 | 8.787 | 3.10E-04 |
| | 3 | 8.787 | 8.776 | 1.14E-03 |

Table 3. Wear test results for Al7068 specimens with Zn% variation

| Specimen (Zn%) | Load(kg) | Initial weight(g) | Final weight(g) | Wear Rate(mm ³ /Nm) |
|----------------|----------|-------------------|-----------------|--------------------------------|
| 7.300% | 1 | 8.425 | 8.405 | 6.205E-03 |
| | 2 | 8.405 | 8.397 | 1.241E-03 |
| | 3 | 8.397 | 8.386 | 1.138E-03 |
| 7.600% | 1 | 9.161 | 9.153 | 2.482E-03 |
| | 2 | 9.153 | 9.145 | 1.241E-03 |
| | 3 | 9.145 | 9.141 | 4.137E-04 |
| 8.000% | 1 | 8.757 | 8.738 | 5.895E-03 |
| | 2 | 8.738 | 8.725 | 2.017E-03 |
| | 3 | 8.725 | 8.704 | 2.172E-03 |
| 8.300% | 1 | 8.623 | 8.614 | 2.792E-03 |
| | 2 | 8.614 | 8.595 | 2.947E-03 |
| | 3 | 8.595 | 8.587 | 8.273E-04 |

4.2 Impact test

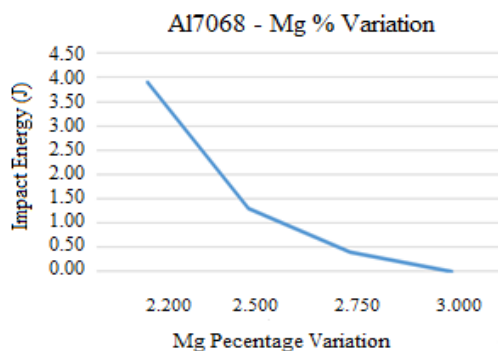


Figure 5. Graphical representation of impact test results for Al7068 specimens with Mg% variation

Table 4 gives the impact test results of Al7068 with Mg% variation and Figure 5 graphical representation of the experimental values shown in Table 4. The impact test conducted on the alloy Al7068 with Mg% variation shows that

Table 3 shows wear test results of aluminium alloy Al7068 with Zn% variation. Figure 3 shows the graphical representation of the experimental values shown in Table 3. It shows the specimen with 7.3% Zn composition gives the highest wear rate compared to other specimens at a low load of 1 kg. Also, it indicates that the specimen with 7.6% Zn has the least wear rate at a high load of 3 kg. The wear rate of the specimen with 7.6% Zn composition decreases by 50% as the load is increased from 1 kg to 2 kg with a further decrease by 33.33% with the increase in load to 3 kg. This indicates that the lower composition of Zinc in the aluminium alloy Al7068 gives the least wear at higher loads.

the lowest composition of 2.2% Mg gives the highest impact energy absorbed of 3.9J. The impact energy decreases by 66.7% for composition varying from 2.2 to 2.5% Mg which further decreases by 23% for composition varying from 2.5 to 2.75% Mg. For the composition varying from 2.75 to 3% Mg, the impact of energy again decreases by 10.3%. This indicates that 2.2% Mg specimen of the aluminium alloy Al7068 exhibits better impact strength compared to other specimens.

Table 5 gives the impact test results of Al7068 with Zn% variation and Figure 6 graphical representation of the experimental values shown in Table 5.

Table 4. Impact test results for Al7068 specimens with Mg% variation

| Specimen | % Mg | Impact Energy (J) |
|----------|-------|-------------------|
| Mg1 | 2.200 | 3.90 |
| Mg2 | 2.500 | 1.30 |
| Mg3 | 2.750 | 0.40 |
| Mg4 | 3.000 | 0.00 |

Table 5. Impact test results for Al7068 specimens with Zn% variation

| Specimen | %Zn | Impact Energy (J) |
|----------|-------|-------------------|
| Zn1 | 7.300 | 0.20 |
| Zn2 | 7.600 | 1.20 |
| Zn3 | 8.000 | 0.20 |
| Zn4 | 8.300 | 0.40 |

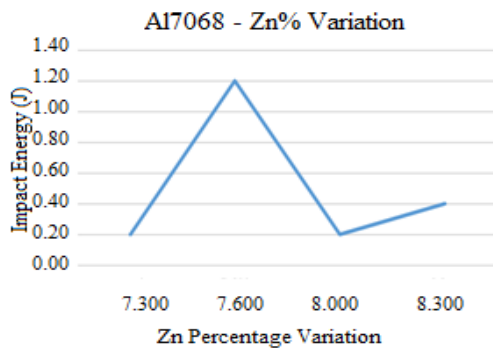


Figure 6. Graphical representation of impact test results for Al7068 specimens with Zn% variation

The impact test conducted on the alloy Al7068 with Zn% variation shows that the composition of 7.6% gives the highest impact energy absorbed of 1.2J. The impact energy increases by 83.3% for Zn composition varying from 7.3 to 7.6% Zn with a decrease in impact energy by 83.3% for composition varying from 7.6 to 8% Zn. Further increase in composition from 8 to 8.3% Zn increases the impact energy by 16.7%. This indicates that the specimen with 7.6% Zn composition of the aluminium alloy Al7068 gives the highest impact strength compared to other specimens.

5. CONCLUSIONS

The wear and impact tests were conducted as per ASTM standards on the aluminium alloy Al7068 to study the tribological behavior and impact strength by varying the percentage composition of the two major alloying elements Mg and Zn in the alloy. The specimens were prepared as per the standards for the tests and experimentation conducted. It is observed that variation in the composition of the two alloying elements Mg and Zn has a significant influence on the wear rate and impact strength of the alloy Al7068. The following conclusions can be drawn from the experimental values obtained from the tests.

- The results of wear test for Al7068 alloy with Mg% composition varying shows that the specimen of 3% Mg gives least wear compared to other specimens at a load value of 2 kg which indicates that applications requiring lower rates of wear need to have a high composition of Magnesium at moderate loads.
- The results of wear test for Al7068 alloy with Zn% composition varying shows that the specimen of 7.6% Zn gives least wear compared to other specimens at a high load value of 3 kg which means that applications requiring lower wear rates need to have a low composition of Zinc at higher loads.
- The impact test conducted on the alloy Al7068 with Mg% composition varying shows that the specimen of

2.2% Mg composition gives the highest impact energy absorbed of 3.9J which indicates that the low percentage composition of magnesium increases the impact strength of the alloy and hence improves its performance.

- The impact test conducted on the alloy Al7068 with varying Zn% composition shows that the specimen of 7.6% Zn composition gives the highest impact energy absorbed of 1.2J. This indicates that the low percentage composition of Zn increases the impact strength of the alloy and in turn improves its performance.

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