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Development and Characterization of Mechanical Properties of Al 6063 Aluminum Alloy Based Composites

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Abstract:

Aluminium-based alloys have a significant role in the structural aspects of the automobile and aero industries in fabricating various components. This alloy is formed by combining multiple other materials in varying proportions. This work forms the aluminum alloy by combining Al2O3, CeO2, and Sic. Aluminium alloys are basically used for casting purposes because of their lattice structure, and mostly noncombustible Aluminium alloy is preferred for the purpose and enhance the material's heat-withstanding capability CeO2 is necessary in alloying with Aluminium because of its combining property. The presence of Sic in this alloy always helps to enhance the hardness of the alloy in which it is being embossed. Further, it also plays a significant role in resistance to corrosion under all aspects. The presence of Sic in the alloy also helps to enrich the die-casting possibility of the alloy. Each metal particle is combined and is then converted to alloy; on the other hand, the balance of similar materials are hot extruded and cut into specimens of standard size. The alloying materials are then used as the base material, blended with reinforcements such as aluminium oxide in the form of micro and nanoparticles, and converted to alloy composite. These are then stir casted and hot extruded as above. Once these fabrication processes are accomplished, followed by mechanical characteristics evolution has to be carried out in the aspect of strength, toughness and hardness. The result shows the chart in which metal particles' enhanced property when blended with the reinforcing materials is obtained with the casted alloy. This material also proves to be very effective in the case of aeronautical-based applications, such as on the surface of bearings, brackets, engine cylinder liners, piston surfaces, cranks, etc. The combination of composites and alloys fabrication enhances the material's performance characteristics.

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Introduction

Aluminium alloys are always preferred for its better properties. Much preference is given to this material mainly due to its lower density, and also it acts as an electromagnetic shield in the application of aircraft manufacturing units (Urena et al., 2000). Researchers studied and experimented on the characterization of aluminum matrix composites reinforced with silicon carbide. The project's scientists aim to examine the matrix's microstructures, mechanical qualities, and wear characteristics. Wear resistances were enhanced by the porosities in the reinforcing Al matrix containing SiC particles (Ajmal Hussain et al., 2020). Because the other material's positive qualities might offset the original material's bad characteristics, so their properties improve when alloying. Not only does this material weigh less, but it also makes the vehicle easier to move, lowering the entire project cost (Ramchurn, 2025; Zhang & Rodriguez). The primary drawbacks of this material are its low corrosion resistance and extremely low flexibility in terms of deformation. When they are converted to alloy, their properties increase because the negative features of this material can be compensated for by the positivity of the other material with which it is being alloyed. Besides the lower weight of this material, it also helps ease the movement of the vehicle, which helps reduce the overall cost of the purpose (Papadopoulos & Konstantinou, 2025; Kim et al., 2022).The primary setback of this material is that it has the problem of poor corrosion resistance and is also very poor in the plasticity of the material as far as deformation is concerned (Kim et al., 2022; Acharya & Shetty, 2019; Liu et al., 2019)However, because of their poor fracture toughness, ductility, and weldability, these composite materials have specific disadvantages when used in industrial settings for component manufacture and in-use applications. These composite materials have particular demerits when used in industrial settings for component manufacturing and applications because of their low fracture toughness and weldability (Ahearn et al, 1982; Pattenon & Mahin, 1990; Zhang & Rodriguez, 2023).

Additionally, including SiC lessens the alloy's abrasive wear (Papadopoulos & Konstantinou, 2025; Yılmaz & Buytoz, 2001). Al–SiC MMC was explored using solid-state diffusion welding and transient liquid-phase bonding, with positive outcomes (Zhang et al., 1999). Altering weld strength in Al-MMC is achieved by adding ternary elements, like magnesium, to the weld metal and then age-hardening it (Rathi et al., 2024; Lee et al., 2019) Yet, no substantial research is currently on Al–SiC weld aging when magnesium is added. Al–Mg–Si supplemented with SiC particles previously demonstrated encouraging age-hardening effects, with processing significantly increasing the composites' strength. Age hardening the weld metal pool after adding ternary alloying elements like magnesium can change the weld strength in Al-MMC (Mehdizadeh & Ravanshadniya, 2018; Dahotre et al., 1991). However, no significant research exists on how magnesium affects the aging of Al–SiC weld. SiC-supplemented Al–Mg–Si alloys have shown promising age-hardening properties in the past, and processing significantly increases the strength of the composites. A thermal difference between the reinforced SiC and the aluminum alloy matrix happens as the solutionizing temperature is cooled, increasing the dislocation density along the interfaces and residual stresses. This is the primary reason behind this a thermal difference between the reinforced SiC and the aluminum alloy matrix occurs upon cooling from the solutionizing temperature, leading to a greater dislocation density along the interfaces and residual strains. This is the leading cause of this. (Lienert et al., 1993; Dutta & Bourrell,1989; Christman & Suresh, 1988; Nieh & Karlak, n.d.). Research on novel and economical welding technologies is constantly being conducted to expand the variety of uses for MMC. Several researchers have previously examined various techniques including plasma welding, electron and laser beam welding, and fusion welding (Ahearn et al., 1982; Lienert et al., 1993). Conversion of the alloy into a composite gives immense strength and toughness to it by reinforcing it with reinforcements (Raimondi et al., 2021; Liu et al., 2019). These materials are combined together by stir casting to convert into the finished product.

The microstructure of Al/CeO2 has not yet been thoroughly investigated, and measuring the capacity of the different chemical components experimentally in small size is challenging. As computer technology and computational materials science advanced, it became possible to properly assess the gain or loss of electron in different components using first-principles computations. The Al/CeO2 interface's microstructure has not yet been fully studied, and it is hard to measure the potentials of chemical components experimentally at such a small size. Using first-principles calculations, it became feasible to accurately evaluate the electron gain or loss of various components as computer technology and computational materials science developed. (Ling et al., 2025)

The Al/CeO2 heterogeneous nucleation interface's interface energy was just 0.07 J/m2, which offers a solid foundation for crystallization kinetics. The wettability between CeO2 and the Al matrix was notably excellent (Hallstedt et al., 1990).

Materials and Methods

The aluminium alloy is made in different combinations. The base material, the Aluminium 6063 Alloy, is considered AL1 for the study and has been tested with various reinforcements. In AL2, Al 6063 +5 %(SiC+Al2O3) has been considered, where the alloy volume percentage is about 95 percent, and the reinforcement volume percentage of 5 percent is added from the combination of SiC+Al2O3. The next matrix combination is the 10-percentage reinforcement volume of SiC and Al2O3, and the base alloy fills the remaining volume percentage. Further, Al 6063 is combined with SiC+Al2O3, occupying a volume percentage of 5 along with 0.5% of CeO2 and mentioned in Table 1 as AC2. Also, Al 6063 is combined with SiC+Al2O3, occupying a volume percentage of 10 along with 1.5% of CeO2 and mentioned in Table 1 as AC3.

These are formed with the help of a powder metallurgy process in which these metal powders are blended together with the help of a metal alloying machine under a pressure of 50 to 60 N/m2. This provides uniform mixture with and without aluminum oxide powder. Then, these materials are subjected to sintering using a muffle furnace at a temperature ranging around four hundred to four hundred and fifty degrees centigrade, finally allowed to settle down at room temperature (Ellis et al., 1994,). The test is classified on varying sintering temperatures, as shown in Table 1. These are created via the powder metallurgy technique, which involves blending metal powders with metal alloying equipment at pressure. This produces a consistent mixture with and without powdered aluminum oxide (Gittos & Threadgill, 1991). After that, these materials are sintered in a muffle furnace at temperatures between 400 and 450 degrees Celsius before cooling to room temperature. As indicated in Table 1, the test is categorized according to different sintering temperatures. The secondary step involved in the processing, followed by sintering, is the hot extrusion of the formed alloy, and the composite is the hot extrusion. This process is carried out at a temperature ranging around four hundred degrees centigrade, which tends to give the extruded alloy a perfect surface finish with uniform grain size with greater accuracy and minimum wastage of the material. This helps the material to be formed to the desired size and shape for doing the experiments as per ASTM standards. The samples are named from AL1 to AC3 as per the combinations shown in the table.

Table 1. Various composition under varying sintering temperature

Abbreviation	Composition	Volume in %	
		Alloy	Reinforcement
AL1	Aluminium 6063 Alloy	100	-
AL2	Al 6063 +5 %(SiC+Al2O3)	95	5
AL3	Al 6063 +10 % (SiC+Al2O3)	90	10
AC1	Al 6063 +15 % (SiC+Al2O3)	85	15
AC2	Al 6063 +5 % (SiC+Al2O3) + 0.5% CeO2	94.5	5.5
AC3	Al 6063 +10 % (SiC+Al2O3) + 1.5% CeO2	98.5	11.5

Result and Discussion

Tensile Test

The sintered samples are extruded for uniaxial tensile samples as per the ASTM E8 standards. This is done by machining the extruded specimens to a cylindrical specimen with a diameter of 5 mm and an overall gauge length of 25 mm. The overall span length of the specimen is 75mm, and the diameter is 10 mm. The specimen is then tested for yield and ultimate tensile strength, followed by fracture strain in percentage. The values are displayed in Table 2 with respect to the various specimens.

Table 2. Tensile property for various compositions

Sl. No	Specimens	Yield Strength in MPa	UTS in MPa	Fracture strain in %
1	AL1	212	293	9.6
2	AL2	200	278	9.3
3	AL3	176	259	8.9
4	AC1	162	220	5.5
5	AC2	164	231	5.8
6	AC3	166	240	6.1

Figure.1 shows the chart for the yield strength with respect to the various combinations of specimens. In this accord, the specimen alloy AL1 with a sintering temperature of about 400°C possess an enhanced property, followed by 425°C and 450°C for AL2 and AL3, respectively. As for the composite, the specimen AC3 sintered under 450°C performs better when compared to 425°C and 400°C for specimens AC2 and AC1, respectively.

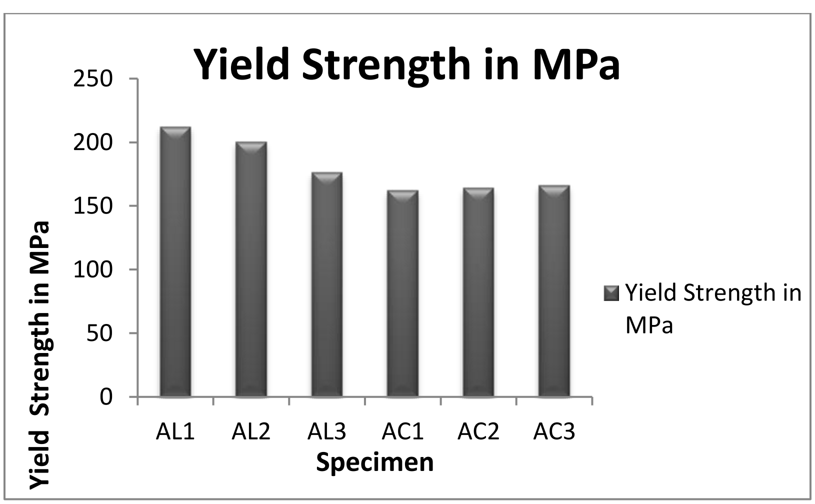

Figure 1: Specimen vs. yield strength in MPa

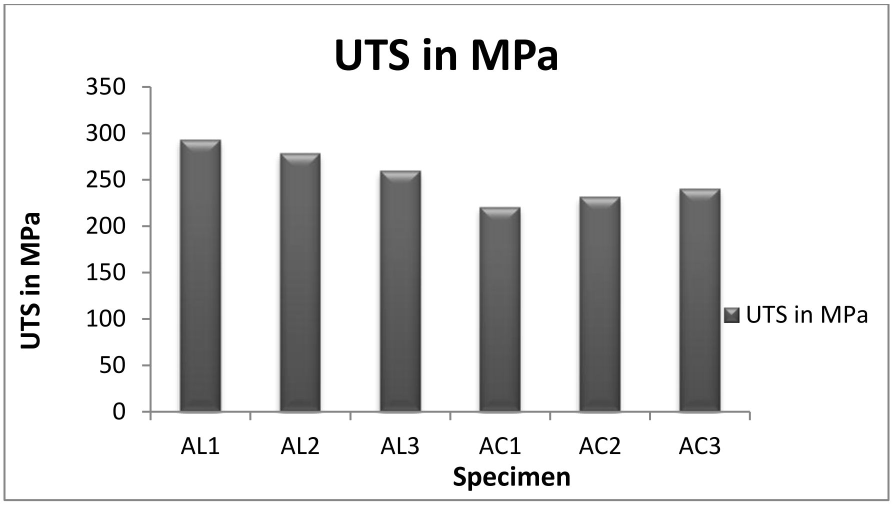

Figure. 2. Specimen Vs Ultimate tensile strength in MPa

As far as the UTS is concerned, this result shown in Fig. 2 also proves to be similar to that of the yield strength. The specimen AL1 for the sintered alloy with 400oC performed better than AL2 and AL3, followed by the composite specimens AC3, which outperformed AC2 and AC1, respectively. The results for the ultimate tensile strength and yield strength prove to be the same.

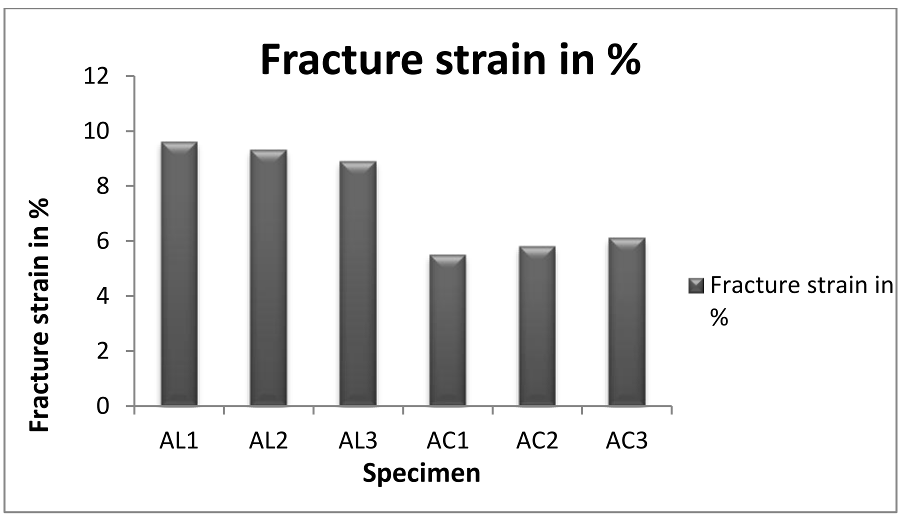

Figure. 3: Specimen vs. fracture strain in %

Figure 3 represents the specimen Vs. the elongation at break for the various composition specimens. The fracture strain or the elongation at break for specimens proves to be the same as the alloy sintered at 400oC AL1 elongates more before breakage. This is due to the more elasticity of the material at this temperature. When the temperature increases the elasticity goes on getting reduced of AL2 and AL3. This is reversed in the case of the composites with aluminum oxide reinforcement. At higher sintering temperature of about 450oC, specimen AC3 out performed AC2 and AC1 as far as strain rate is concerned.

Hardness Test:

The polished test specimen as per ASTM E384-16 is prepared with a specification of about 12 millimeter in diameter and 8millimeter in width. A diamond intender is used to evaluate the reading by keeping them at three different locations. The test results are evaluated from the mean of these readings. The micro hardness for samples are displayed in the Table 3.

Table 3. Vickers microhardness for various compositions

Sl. No	Specimens	Micro Hardness (Hv)
1	AL1	74
2	AL2	76
3	AL3	78
4	AC1	93
5	AC2	95
6	AC3	96

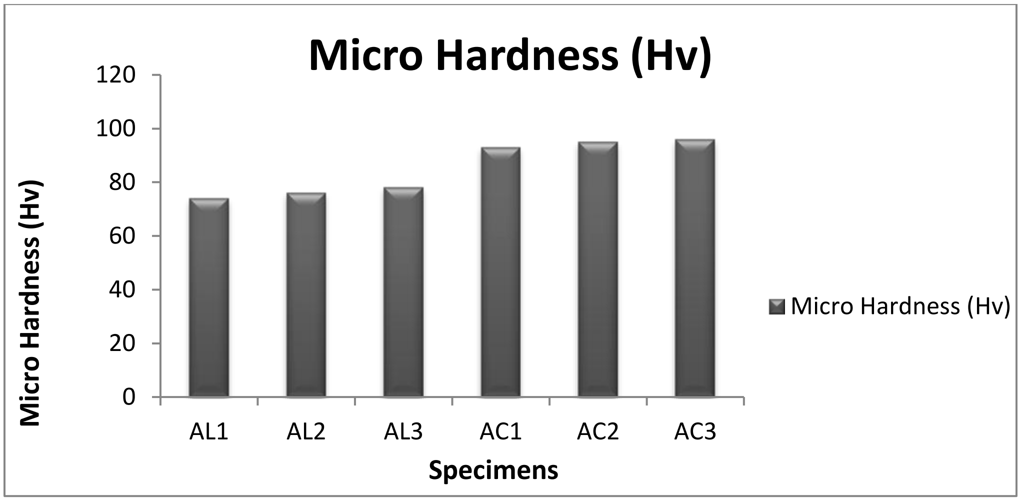

Fig. 4. Specimen Vs micro hardness (Hv)

The test results for the Vickers micro hardness Vs the different specimens are shown in the Fig.1.The hardness of the specimen proves to be just the reverse of the tensile property of the similar specimen. The hardness of the composites proves to be always higher than that of the alloys. However, the sintering temperature is still a concern, as the increase in temperature tends to increase the hardness of the specimens. The specimen AL3, an alloy sintered at a temperature around 450oC, has a higher hardness number when compared to AL2 and AL1, with lesser sintering temperatures of 425oC and 400oC, respectively. The composite AC3 follows this with a sintering temperature of 450oC, which outperforms AC2 and AC1 with lesser sintering temperatures.

Conclusion

Based on the test results, the entire conclusions are summarized as follows:

- The yield strength of the specimen AL1 proves to be higher, with a strength of about 212 MPa, which is 50 MPa more than that of the similar composite AC1 sintered at 400°C
- Similarly, the Ultimate Tensile Strength of Specimen AL1 is higher for alloys, with a strength of 293 MPa, and composite AC3 has a higher tensile strength of 240 MPa.
- The fracture strain for AL1 is 9.6%, and for the composites, it is 6.1 % for AC3. This shows that alloys elongate better than composites. The elongation of alloys is better at lower temperatures, and that of composites is greater at higher temperatures.
- The hardness of AC3 is about 96 Hv which proves to be higher among all the materials. The hardness number for composites proves to be higher when compared to all the alloys and also the increase in temperature increases the hardness of the material.

Conflict of Interest

The authors declare that they have no competing interests**.**

Author Contributions

All authors' contributions are equal for the preparation of research in the manuscript.

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