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A Study on Mechanical and Tribological Properties of Aluminum 7068 MMCS Reinforced with Silicon Carbide and Biochar by Stir Casting Process

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ABSTRACT

The present study focuses on the development and characterization of Aluminum 7068 metal matrix composites (MMCs) reinforced with Silicon Carbide (SiC) and Biochar using the powder metallurgy process. Aluminum 7068, known for its high strength-to-weight ratio, was selected as the base material, while SiC was introduced to enhance hardness and wear resistance, and Biochar was added as a sustainable reinforcement to improve mechanical and tribological behavior. The fabricated composites were subjected to microstructural analysis, hardness testing, tensile strength evaluation, and wear studies. Results are expected to demonstrate improved hardness, strength, and wear resistance with the hybrid reinforcement, highlighting the potential of combining SiC and Biochar as effective reinforcements. This study contributes to developing lightweight, eco-friendly, and high-performance materials for aerospace, defense, and automotive applications.

KEYWORDS: Al708, Silicon Carbide (Sic), Bio Char, Powder Metallurgy Mechanical Properties, Tribological Properties

INTRODUCTION

1.1 BACKGROUND OF COMPOSITE

Many modern technologies demand materials with unique combinations of properties that cannot be fulfilled by conventional metals, ceramics, or polymers alone. This requirement is especially critical in aerospace, underwater, and transportation applications. For instance, in the aviation sector, engineers seek structural materials that combine low density with high strength, stiffness, abrasion and impact resistance, and corrosion resistance. Achieving such a combination of properties is a formidable challenge, as strong materials are often dense, and increasing strength or stiffness usually reduces impact resistance.

To address these challenges, composite materials have emerged as a promising alternative. A composite is generally defined as a multiphase material that integrates the properties of two or more distinct constituent phases, resulting in a superior combination of characteristics. According to the principle of combined action, composites provide tailored properties that cannot be achieved by any single material alone. However, property trade-offs are often necessary, depending on the intended application.

Over the past four decades, the development and production of synthetic composites, particularly those incorporating fine fibers within polymer matrices, have grown rapidly and dominate the global market. Future projections indicate that the demand for composites will continue to rise, with metal- and ceramic-based composites playing an increasingly significant role.

The selection of engineering materials is a crucial stage in designing machine components, as the chosen material directly influences both manufacturing processes and performance. While metals have traditionally dominated in manufacturing and construction due to their strength, their use is gradually being replaced by composites. This shift is evident in the automotive, marine, and aerospace industries, where composites are increasingly preferred over metals because of their advantages, including excellent mechanical properties, superior corrosion resistance, and lower density.

1.2 OVERVIEW OF COMPOSITES

Composite materials are essential in various industries due to their high stability, low density, and specific strength-to-weight ratio. They are lightweight and robust, offering design flexibility and cost reduction. However, the high cost of raw materials and manufacturing remains a challenge. Composites have diverse mechanical and physical properties, including resistance to corrosion, oxidation, and wear. Aluminum-based metal matrix composites (MMCs) are popular due to their affordability and improved strength, stiffness, and wear resistance. Composites have expanded in applications beyond aerospace, with the transportation sector providing larger opportunities. High-performance fiber-reinforced plastics (FRPs) are widely used in various applications, including composite armoring, natural gas fuel cylinders, wind turbine blades, industrial drive shafts, bridge support beams, and rollers in paper manufacturing. Composites have proven cost- and weight-efficient alternatives to metals, and are increasingly used to rehabilitate or retrofit existing structures. Composite materials consist of two or more physically and/or chemically distinct phases, separated by an interface, to yield properties not exhibited by individual components alone.

1.3 DEFINITION OF COMPOSITE

A composite material is generally defined as a combination of two or more distinct materials that, when combined, form a new material system with superior properties compared to the individual constituents. Most commonly, composites consist of two phases:

Matrix Phase – The continuous bulk phase, usually more ductile and less hard, which binds and holds the reinforcement in place. The matrix shares the load with the reinforcement, transfers stresses, and protects it from mechanical and environmental damage.

Reinforcing (Dispersed) Phase – The discontinuous, harder, and stronger phase embedded within the matrix. It provides strength, stiffness, and other enhanced mechanical properties. Reinforcements are commonly in the form of fibers (glass, carbon, aramid) or particles (silicon carbide, alumina).

1.4 MANUFACTURING PROCESSES OF COMPOSITE MATERIALS

The manufacturing of composite materials involves combining a matrix (generally a polymeric resin, metal, or ceramic) with a fiber or particle reinforcement. Since the orientation and distribution of fibers directly influence the final properties of the composite, the selection of a suitable manufacturing process is critical. An efficient process should ensure:

- Proper alignment of fibers in the desired direction.
- High and uniform fiber volume fraction.
- Dimensional accuracy with repeatability.
- Cost-effectiveness and scalability for large volume production.

1.5 STIR CASTING

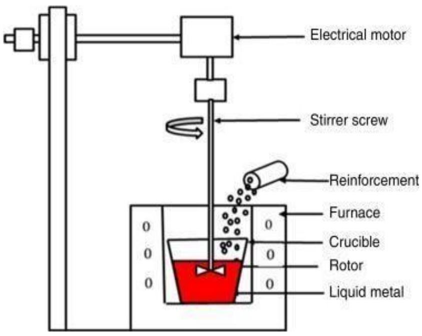


Fig.1.13 Stir casting process

Stir casting is the most commonly used liquid-state method for fabricating metal matrix composites due to its simplicity and cost-effectiveness. In this process, the matrix metal, usually aluminum or its alloys, is first melted in a crucible furnace, and the reinforcement particles such as silicon carbide, alumina, or graphite are preheated to remove moisture and enhance wettability. A mechanical stirrer is then introduced into the molten metal to create a vortex, into which the reinforcement particles are gradually added. Continuous stirring helps to distribute the particles within the matrix, although complete homogeneity is difficult to achieve and clustering or segregation may occur due to density differences. The molten composite slurry is finally poured into molds and allowed to solidify into the desired shape. Despite limitations like non-uniform distribution and possible porosity, stir casting remains the most economical and widely practiced technique, especially when reinforcement content is limited to below 30% by volume, and distribution can be further improved if the matrix is processed in a semi-solid state (rheocasting).

Fabrication Methods of MMCs

These involve introducing the reinforcement into the molten metal matrix.

- Stir Casting
- Dispersed phase content limited to ~30 vol.%
- Distribution of reinforcement is not perfectly homogeneous
- Local clusters or segregation may occur due to density differences
- Simple and cost-effective method
- Semi-solid state stirring (Rheocasting) improves particle distribution due to higher viscosity of the slurry.

Pressure Infiltration

- Molten metal is infiltrated into pre-placed reinforcement using external pressure (e.g., gas pressure).

Squeeze Casting

- Molten metal is squeezed into a mold containing pre-placed fibers/particles using high pressure.

Spray Deposition

- Molten metal is atomized and sprayed onto a continuous fiber substrate, forming a composite coating.
- Reactive Processing
- In-situ chemical reaction produces both the matrix and reinforcement simultaneously, improving bonding.

2. Semi-Solid State Methods

- Semi-Solid Powder Processing
- Powder mixture is heated to a semi-solid state.
- Pressure is applied to consolidate and form the composite.

3. Vapor Deposition

- Physical Vapor Deposition (PVD)
- Fiber is passed through a vapor cloud of metal.
- Metal atoms condense on the fiber surface, forming a uniform coating.

4. In-Situ Fabrication Technique

- Controlled Unidirectional Solidification
- Eutectic alloys are directionally solidified.
- One phase solidifies in lamellar or fibrous form, embedded within the matrix.
- Produces strong interfacial bonding and uniform distribution.

The following are some of the important mechanical characteristics of composite materials:

- High strength-to-weight ratio
- High stiffness-to-weight ratio
- Fatigue resistance
- Corrosion and wear resistance
- Tailored thermal expansion and conductivity
- Good dimensional stability
- Design flexibility and customization

1.12 PROPERTIES OF ALUMINIUM AND ITS ALLOYS

Aluminium and its alloys are essential in modern engineering and manufacturing due to their unique combination of mechanical, physical, and chemical characteristics. They are highly formable, allowing for various processing methods, and have a strength-to-weight ratio that makes them ideal for aerospace, automotive, and military applications. They also have strong cryogenic properties, making them valuable in cryogenic storage tanks, pipelines, and space applications. Aluminium also provides excellent corrosion resistance, high electrical and thermal conductivity, and high reflectivity across various wavelengths. Its finishability allows for various surface finishes, enhancing durability, aesthetics, and corrosion resistance. Overall, aluminium is a versatile and versatile material.

LITERATURE SURVEY

1) Md. Mehtab Alam and Prof.B.S.Motgi: In this paper a study on microstructure and mechanical properties of Al7068 reinforced with Silicon Carbide and fly ash by powder metallurgy was conducted. In this study aluminium7068, Silicon carbide and fly ash were taken in powder form of required size and mixed together in varying proportion according to specification and compacted with pressure of 400MPa using hydraulic press to make samples and then samples were sintered at 600°c for 2 hours, the samples were tested for density, compressive strength, hardness and microstructure was analyzed using scanning electron microscope, energy dispersive x-ray study was carried out in order to confirm presence of silicon carbide and fly ash in aluminum matrix. The author reported that the density is more for sintered samples than that of green samples. With the addition of fly ash the compressive strength increases but hardness decreases and with the addition of Silicon Carbide hardness is increased. Scanning electron microscope (SEM) analysis shows microstructure and binding of silicon carbide and fly ash with aluminum matrix. Energy Dispersive X-Ray (EDX) Study analysis of samples confirms the presence of silicon carbide and fly ash in Aluminum matrix.

2) Seshappa Angadi et al: This research focuses on developing a modified microstructure in the Al-7068/Al2O3 (Aluminum oxide) combination using powder metallurgy techniques. The goal was to vary the sizes of reinforcement particles within the substrate to investigate their effects taking place this total nano-composite mechanical property. Specifically, nano composites among 9 vol.% alumina 40 nm were fabricated in an aluminum matrix, and a separate set of micro-composites with a similar composition (average size of 20 μm) was created for comparison. The result showed that the alumina nano particles exhibited strong physical bonding with the aluminum matrix, leading to reduced aggregation and no new phases being formed during the powder metallurgy process, even at relatively low operating temperatures. This incorporation of micro along with nano particles as reinforcement in the aluminum matrix led to significant improvements in mechanical properties such as hardness, tensile strength, and compressive strength. This can be attributed into an overall escalation mechanism with granule modification found into the composites. The nano composite demonstrated superior properties compared to the micro composites. The nano composite

exhibited higher strength and hardness, which can be attributed to its overall escalation mechanism also the observed granule modification in Al-7068/Al2O3.

3) Prashant. S. N, K.V.Sharma: In this paper it is aimed to present the experimental results of the studies conducted regarding hardness and density and tensile strength of Al7068- Graphite nano particulates. The composites are prepared using the liquid metallurgy technique in which 3-9 wt.% age of particulates were dispersed in the base matrix in steps of the obtained cast composites of Al7068- nano Graphite and the castings of the base alloys were carefully machined to prepare the test specimens for density, hardness and as well as mechanical studies as per ASTM standards. The experimental densities of composites are less than when compared to the theoretical density. Hardness of the composite Decrease with increasing amount of Gr nano particulate in 7068Al Alloy. The addition of Gr nano particulates has resulted in increase in tensile strength of Al7068 alloy when compared to unreinforced alloy.

4) Md Amir Sohail,Prof B.S.Motgi and Prof Dr.G.K.Purohit: In this work, Al7068 reinforced with Tur husk ash(THA) and Alumina(Al2O3) hybrid metal matrix composite is prepared from sintering of mechanically alloyed powder (ball milling) in powder metallurgy process. Different combinations of compositions (Al7068 reinforced with 0%,4%,8%,12% of THA and Al2O3) were taken with total 16 combinations. Hardness was found to be increasing with increasing percentage of Al2O3 but was decreasing with increasing percentage of

THA. XRD report shows that the tur husk ash (THA) has 26.1% of MgO in it. The ash content of tur husk was obtained through Thermogravometry(TG) analysis and was found to be 3.2% of raw husk. The density was measured before and after sintering, and was found to be increasing. The EDX of samples confirmed the proper mixing of reinforcement in it. The microstructure analysis (SEM) of sintered sample showed that it was partially sintered as pores were identified. As sample reported to be partially sintered, it was observed that the compressive strength was found to be varying and was significantly low.

CHAPTER 3

PROBLEM STATEMENT & OBJECTIVES

- **PROBLEM STATEMENT**

The extensive review of literature carried out for present study reveals that lot of work has been reported to enhance properties of Aluminium metal matrix composites.

After the review of literature the following gaps were found:

1. No research has been done on AL-7068 with SiC and Biochar.
2. Very limited amount of work has been done which explains the factor effecting properties of Aluminium metal matrix composite (AL-7068 with Sic and Biochar) by Stir Casting.
3. There is no detailed chemical composition available of Biochar.
4. No amount of work has been done on combined effect of silicon carbide (SIC) and Biochar with Aluminium metal matrix by Stir Casting. Due to the following gaps this work is done to develop the new material using

Aluminium alloy composites, so that it should be lighter in its weight and with improved properties which can be used for industrial purpose such as automobile and aircraft industries.

- **PROPOSED WORK**

The problem is associated with the study of mechanical and tribological behaviour of aluminium alloy 7068 with addition of varying percentage composition of Silicon Carbide (SiC), Biochar(CF) by Stir Casting technique. The mechanical behaviour and the change in wear properties were taken into consideration. An experimental set up was prepared to facilitate the preparation of required MMCs. The aim of the work is to study mechanical and tribological properties of variation of the percentage composition to predict the Yield Load, Yield Stress, Elongation, Ultimate Load and Ultimate Tensile Strength. The work was carried out by preparing the samples of different percentage. Compressive strength test is carried out on digital hydraulic press machine, hardness test is carried out on Brinnel hardness tester and wear subjected to computerized Pin on disc wear testing machine under dry sliding condition.

OBJECTIVES

- Objective of the model is chosen as low cost and give the better result characteristics to analyze the strength and stiffness.
- To prepare high quality hybrid composite by Stir Casting process
- To study the influence of heat treatment of hybrid composite on mechanical and tribological properties
- To obtain overall stiffness and strength of hybrid metal matrix composites (HMMC)
- To prepare hybrid composites of Al7068 alloy reinforcing with Silicon Carbide (SiC), biochar by Stir Casting process.
- To study the effect of different weight percentage of reinforcement on compressive strength, Hardness and wear rate of metal matrix composites.

CHAPTER 4

MATERIALS, METHODOLOGY AND EXPERIMENTATION

4.1 MATERIALS

- Aluminum Alloy 7068
- Silicon Carbide(Sic)
- Biochar

4.2 METHODOLOGY

Preparation of samples: The samples were prepared by Stir Casting method as shown below:

i. Procurement of raw materials
ii. Addition of Preheated powder
iii. Stirring with the help of Eddy Current
iv. Pouring
v. Melting
vi. Solidification
vii. Finishing and Machining

i) Procurement of raw materials:

a) AL7068 Metal

Fig 4.2.1: AL7068 Metal

b) Silicon carbide 40µ size powder:

Fig 4.2.2: Silicon carbide 40µ size powder

c) Biochar

Fig 4.2.3: Biochar

4.3 TESTING AND EXPERIMENTATION

For performing the experiment and testing of composites the following Machines/equipment were used:

1. Yield Load
2. Yield Stress
3. Elongation
4. Ultimate Load
5. Ultimate Tensile Strength

CHAPTER 5

RESULT

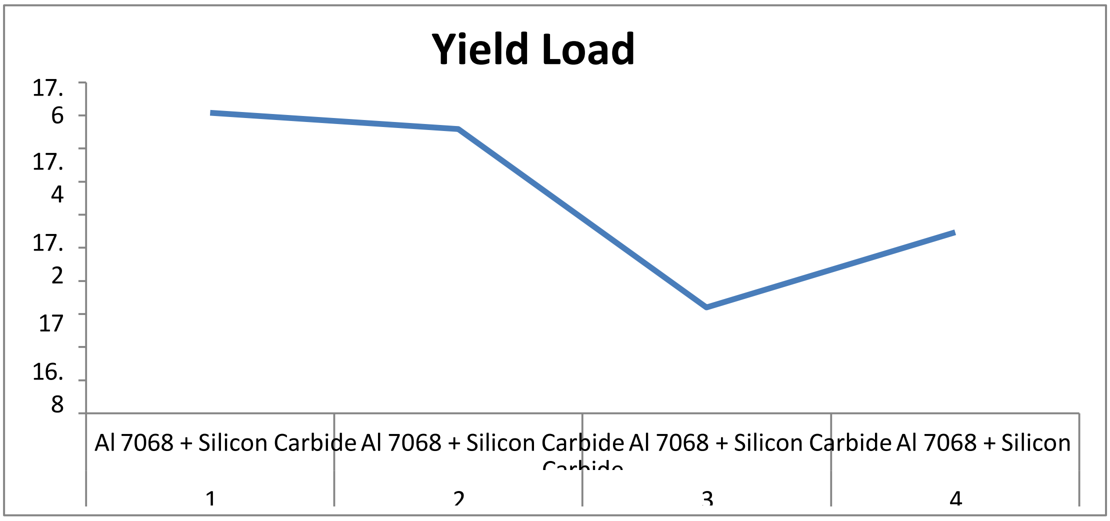
1.1 Yield Load

The yield load results represent the maximum load each Al 7068 composite can withstand before it begins to deform plastically. Sample 1, reinforced with 2% Silicon carbide and 2% biochar, recorded the highest yield load of 17.415 kN, indicating that this moderate reinforcement provided excellent load-bearing capacity and efficient stress transfer between the matrix and reinforcement particles. Sample 2 (3% Silicon carbide + 4% biochar) showed a slightly lower yield load of 17.319 kN, suggesting that the increased biochar content may have created minor inconsistencies or micro-voids in the matrix, slightly reducing strength. Sample 3 (4% Silicon carbide + 3% biochar) experienced a further decrease in yield load to
16.239 kN, possibly due to higher Silicon carbide content introducing brittleness or uneven particle distribution. Sample 4 (5% Silicon carbide + 4% biochar) showed a slight increase to 16.695 kN, indicating that while reinforcement helps improve mechanical strength, excessive reinforcement can sometimes cause particle agglomeration or stress concentration, limiting further improvement.

Overall, the results indicate that moderate reinforcement levels provide the best balance between load-bearing capacity and structural integrity, while too much or uneven reinforcement can reduce the material's ability to resist plastic deformation. These observations are important for optimizing the composition of Al 7068 composites to achieve maximum mechanical performance.

Table-5.1: Results of Yield test

Sample No.	Composition	Yield Load kN
1	Al 7068 + Silicon Carbide 2% + Biochar 2%	17.415
2	Al 7068 + Silicon Carbide 3% + Biochar 4%	17.319
3	Al 7068 + Silicon Carbide 4% + Biochar 3%	16.239
4	Al 7068 + Silicon Carbide 5% + Biochar 4%	16.695



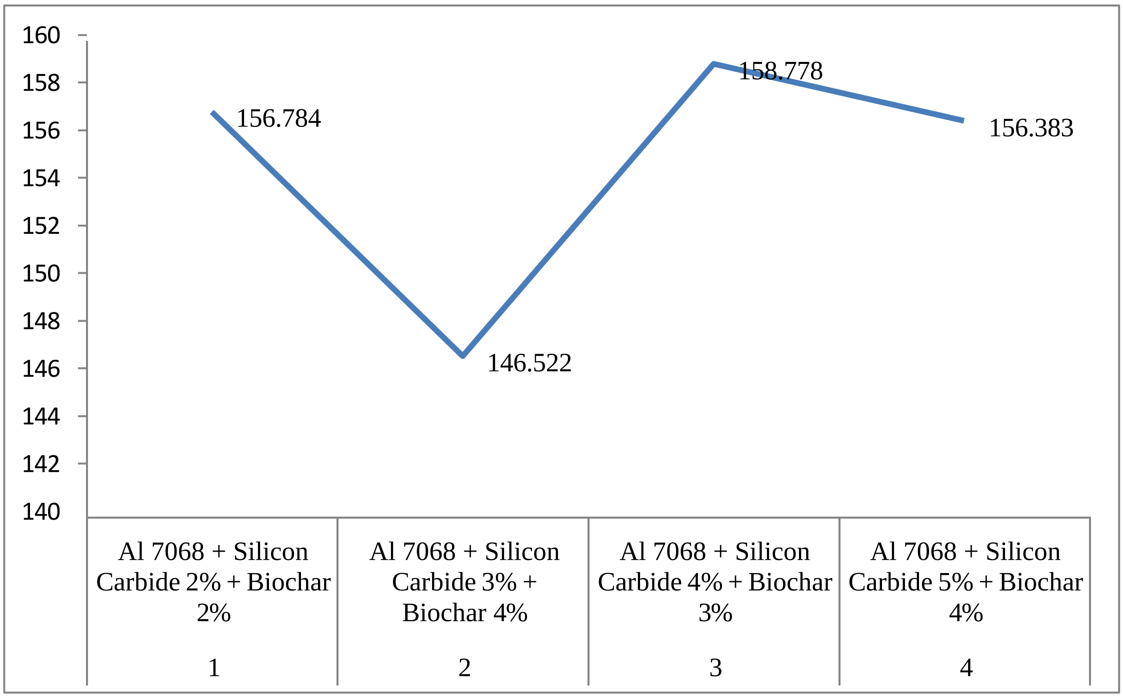
Graph 5.1: Yield Load

1.2 Yield Stress

The yield stress results show that the stress level at which Al 7068 composites undergo plastic deformation is highly dependent on the proportion of reinforcement. Moderate and well-balanced reinforcement levels enhance the material's resistance to plastic deformation, while too much or uneven reinforcement can reduce mechanical efficiency and create weak points within the structure. Optimizing reinforcement percentages is crucial for achieving maximum strength and structural integrity in Al 7068 composites.

Table No 5.2: Results of Yield Stress

Sample No.	Composition	Yield Stress N/mm^2
1	Al 7068 + Silicon Carbide 2% + Biochar 2%	156.784
2	Al 7068 + Silicon Carbide 3% + Biochar 4%	146.522
3	Al 7068 + Silicon Carbide 4% + Biochar 3%	158.778
4	Al 7068 + Silicon Carbide 5% + Biochar 4%	156.383



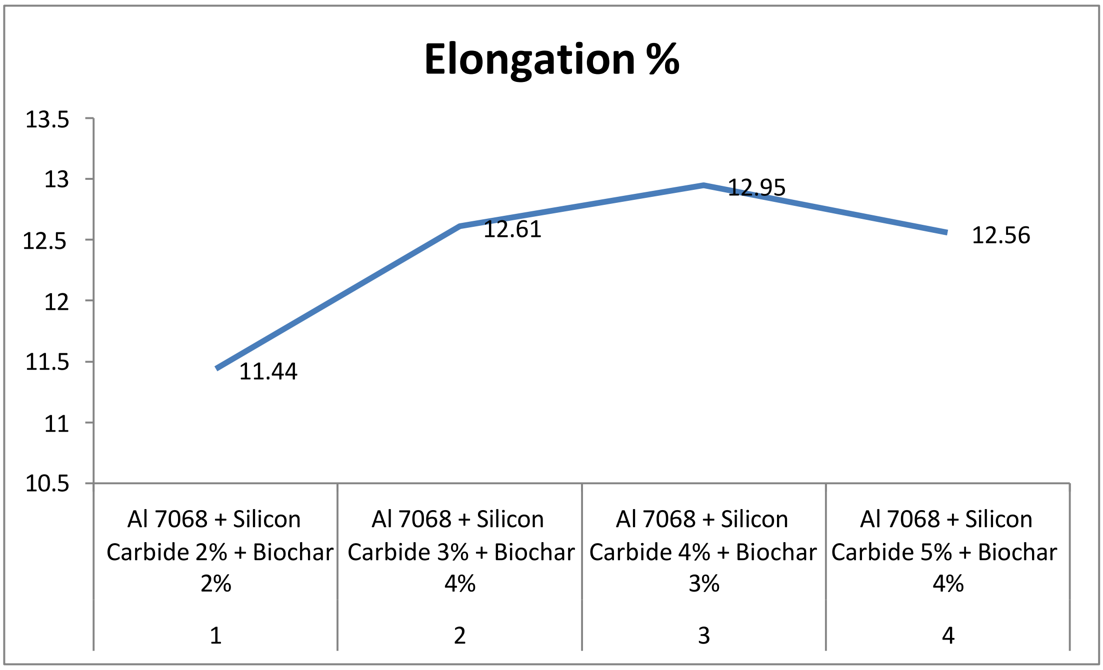
Graph 5.2: Yield Stress

1.3 Elongation

The study examines the ductility of Al 7068 metal matrix composites reinforced with Silicon carbide and biochar. Sample 1 showed the lowest elongation of 11.44%, indicating moderate deformation. Adjusting the reinforcement percentages showed improved ductility, likely due to better stress distribution and particle-matrix interaction. The highest elongation was achieved with 4% silicon carbide and 3% biochar, indicating an optimal balance between strength and plasticity. Excessive reinforcement can reduce ductility, making these findings crucial for designing composites with high strength and flexibility.

Table No 5.3: Results of Elongation

Sample No.	Composition	Elongation %
1	Al 7068 + Silicon Carbide 2% + Biochar 2%	11.44
2	Al 7068 + Silicon Carbide 3% + Biochar 4%	12.61
3	Al 7068 + Silicon Carbide 4% + Biochar 3%	12.95
4	Al 7068 + Silicon Carbide 5% + Biochar 4%	12.56



Graph 5.3: Elongation

1.4 Ultimate Load

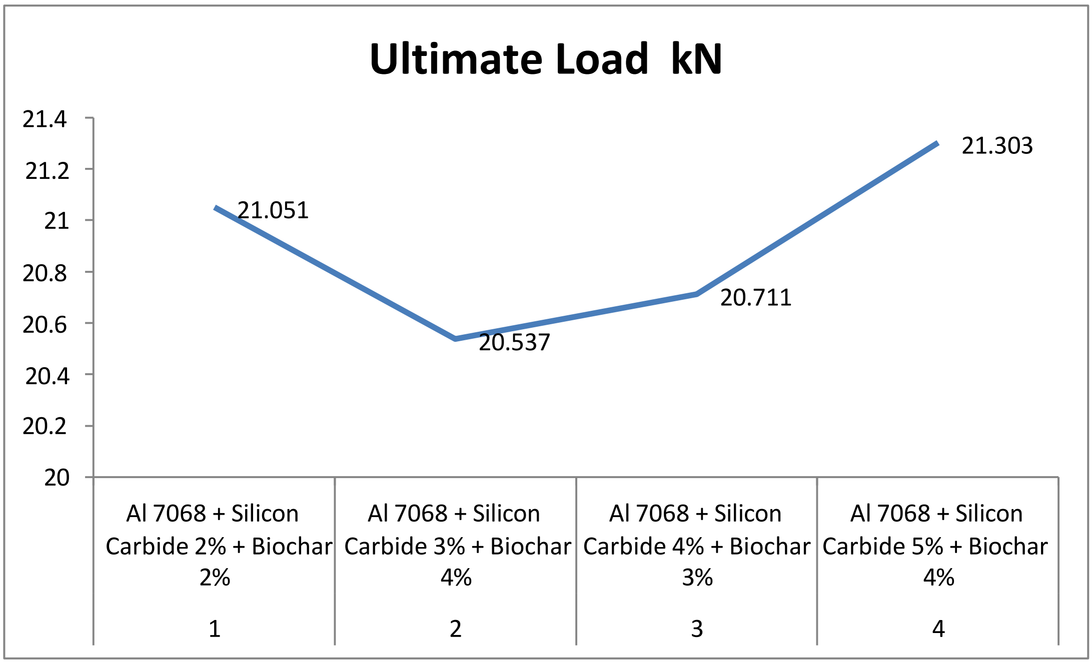
The ultimate load results represent the maximum load that each Al 7068 composite can withstand before fracture. Sample 1, containing 2% Silicon carbide and 2% biochar, recorded an ultimate load of 21.051 kN, indicating good overall strength with moderate reinforcement. Sample 2 (3% Silicon carbide + 4% biochar) showed a slightly lower ultimate load of 20.537 kN, suggesting that increased biochar content may have slightly reduced load-bearing efficiency due to microstructural inconsistencies. Sample 3 (4% Silicon carbide + 3%

biochar) exhibited an ultimate load of 20.711 kN, showing a marginal improvement over Sample 2 but still slightly below Sample 1. Interestingly, Sample 4 (5% Silicon carbide + 4% biochar) achieved the highest ultimate load of 21.303 kN, indicating that at this reinforcement combination, particle distribution and bonding within the matrix allowed the composite to withstand the greatest load before failure.

Overall, the results suggest that the ultimate load depends on both the type and proportion of reinforcement, with a balanced combination of Silicon carbide and biochar providing optimal strength. Excessive or poorly distributed reinforcement can reduce effectiveness, while an optimal composition enhances the composite's fracture resistance and mechanical performance.

Table No 5.4: Ultimate Load kN

Sample No.	Composition	Ultimate Load kN
1	Al 7068 + Silicon Carbide 2% + Biochar 2%	21.051
2	Al 7068 + Silicon Carbide 3% + Biochar 4%	20.537
3	Al 7068 + Silicon Carbide 4% + Biochar 3%	20.711
4	Al 7068 + Silicon Carbide 5% + Biochar 4%	21.303



Graph 5.4: Ultimate Load kN

1.5 Ultimate Tensile Strength

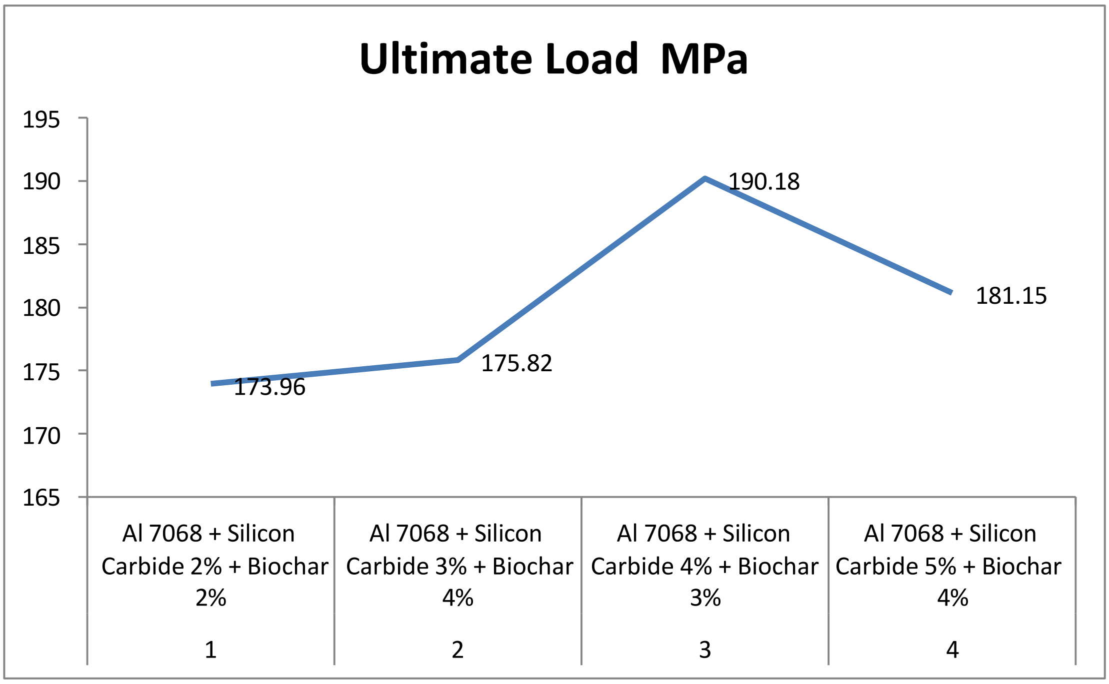
The ultimate tensile strength (UTS) values indicate the maximum stress that the Al 7068 composites can withstand before fracture. Sample 1, reinforced with 2% Silicon carbide and 2% biochar, recorded a UTS of 173.96 MPa, showing good tensile strength with moderate reinforcement. Sample 2 (3% Silicon carbide + 4%

biochar) slightly increased to 175.82 MPa, suggesting that the higher biochar content improved load transfer and bonding within the matrix. Sample 3 (4% Silicon carbide + 3% biochar) exhibited the highest UTS of 190.18 MPa, indicating that this reinforcement combination provides optimal particle distribution and strong interfacial bonding, allowing the composite to withstand the greatest tensile stress before failure. Sample 4 (5% Silicon carbide + 4% biochar) showed a UTS of 181.15 MPa, slightly lower than Sample 3, suggesting that excessive reinforcement may lead to particle clustering or microstructural stress concentration, reducing tensile performance.

Overall, the results indicate that an optimal balance of Silicon carbide and biochar significantly enhances tensile strength, while both insufficient and excessive reinforcement can slightly reduce the mechanical performance of the Al 7068 composites. These findings are essential for designing composites with high load-bearing capacity and structural reliability.

Table No 5.5: Ultimate Load MPa

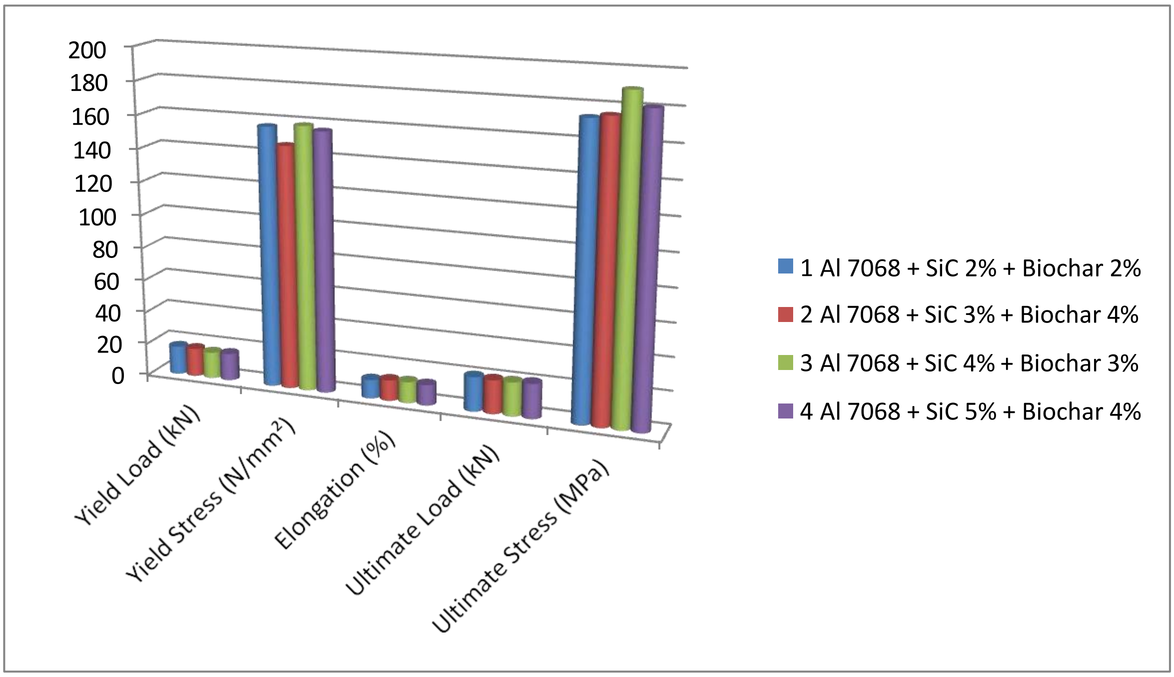
Sample No.	Composition	Ultimate Load MPa
1	Al 7068 + Silicon Carbide 2% + Biochar 2%	173.96
2	Al 7068 + Silicon Carbide 3% + Biochar 4%	175.82
3	Al 7068 + Silicon Carbide 4% + Biochar 3%	190.18
4	Al 7068 + Silicon Carbide 5% + Biochar 4%	181.15



Graph 5.5: Ultimate Load MPa

Overall result

Sample No.	Composition	Yield Load (kN)	Yield Stress (N/mm²)	Elongation (%)	Ultimate Load (kN)	Ultimate Stress (MPa)
1	Al 7068 + SiC 2% + Biochar 2%	17.415	156.784	11.44	21.051	173.96
2	Al 7068 + SiC 3% + Biochar 4%	17.319	146.522	12.61	20.537	175.82
3	Al 7068 + SiC 4% + Biochar 3%	16.239	158.778	12.95	20.711	190.18
4	Al 7068 + SiC 5% + Biochar 4%	16.695	156.383	12.56	21.303	181.15



From the overall results, it is clear that Sample 3 (Al 7068 + 4% SiC + 3% Biochar) provides the best mechanical performance, showing the highest yield stress, elongation, and ultimate stress. While Sample 1 performed best in yield load, and Sample 4 in ultimate load, their overall balance was lower compared to Sample 3. Sample 2 consistently showed the weakest values, indicating poor reinforcement efficiency at that ratio.

CONCLUSION

The experimental study on Al 7068 composites reinforced with varying percentages of silicon carbide (SiC) and biochar reveals that the mechanical properties strongly depend on the reinforcement ratio. Among the four samples tested, Sample 3 (Al 7068 + 4% SiC + 3% Biochar) demonstrated the most balanced and superior performance, achieving the highest yield stress (158.778 N/mm²), maximum elongation (12.95%), and highest ultimate stress (190.18 MPa). This indicates that a moderate reinforcement level provides the best combination of strength and ductility due to effective particle dispersion and strong interfacial bonding. While Sample 1 showed the highest yield load and Sample 4 the maximum ultimate load, their overall performance was not as consistent as Sample 3. On the other hand, Sample 2 exhibited the weakest results across most properties, suggesting poor reinforcement effectiveness at that composition.

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