International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 02 | Feb 2025 www.irjet.net p-ISSN: 2395-0072

Evaluation of Tension and Compression Characteristics in Lead and Boron Carbide Reinforced Aluminum MMCs

Dr.M.Haridass[1] , V.Rajakumaran[2]

[1] *Associate Professor, Department of Mechanical Engineering, Mahendra College of Engineering, Salem, Tamilnadu.*
[2] *Assistant Professor, Department of Mechanical Engineering, Mahendra College of Engineering, Salem, Tamilnadu.*

Abstract -

Aluminum Metal Matrix Composites (MMCs) are emerging as a new class of materials, especially in aerospace and automotive applications, due to their superior strength-to-weight ratio, wear resistance, and high-temperature performance. The mechanical properties of MMCs can be tailored by adding selected reinforcements. In this study, an aluminium-based composite reinforced with lead (Pb) and boron carbide (B B4C) was developed, with a composition of Al-80%, Pb-10%, and B4C-10%. The composite specimens were fabricated using the stir-casting method. This work investigates the tensile and compressive properties of the developed MMC to evaluate its potential for structural applications.

Keywords: Stir casting, Composite Material, Reinforcement, Aluminium

1. INTRODUCTION

The increasing demand for lightweight, cost-effective, energy-efficient, stiff, and strong materials in aircraft, space, defense, and automotive applications has led to significant efforts in developing composite materials. Nowadays, Metal Matrix Composites (MMCs) are being seriously considered as replacements for conventional materials in various structural applications.

In Aluminum Metal Matrix Composites (AMCs), aluminium alloy serves as the matrix phase, while The reinforcement phase, typically a non-metallic ceramic material, is embedded within the matrix. Reinforcements such as silicon carbide (SiC), alumina (Al2O3), chromium, lead, zinc, titanium, nickel, and boron carbide (B_4C significantly enhance the strength and mechanical properties of the aluminium matrix. Due to their low density, aluminium alloys provide additional advantages in several applications.

These alloys are increasingly being used as substitutes for cast iron and bronze in the manufacturing of wear-resistant components. Particle-reinforced MMCs exhibit enhanced properties and can be processed using conventional manufacturing techniques. A356/LM25 aluminium alloys are widely utilized in various industries, including food processing, chemical, marine, and electrical sectors. In the automotive industry, these alloys are used for manufacturing wheels, cylinder blocks, cylinder heads, engine components, and other body castings due to their excellent mechanical and wear properties.

1.1 Significance of Aluminium-Based Composites

Aluminium alloys are widely used in engineering applications due to their lightweight nature, high thermal conductivity, and corrosion resistance. However, pure aluminium and its conventional alloys often exhibit limited mechanical strength and wear resistance, which restricts their use in high-performance applications. To overcome these limitations, researchers have explored hybrid aluminium metal matrix composites (HAMMCs) by incorporating multiple reinforcements.

1.2 Objectives of the Study

Develop an aluminium-based hybrid composite reinforced with B_4C and Pb using the stir casting technique.

Investigate the tensile and compressive properties of the composite. Evaluate the impact of reinforcement content on mechanical strength, ductility, and wear resistance.

Compare the results with existing aluminium alloys to assess the feasibility of using Al-B_4C-Pb composites in real-world applications.

2. MATERIALS SELECTION

2.1 Aluminum

Aluminum is the most abundant metal in the Earth's crust, known for its low density and low corrosion resistance due to the formation of a protective oxide layer. Commercially pure aluminium has a tensile strength of approximately 90 MPa, which increases to 180 MPa through cold working and up to 570 MPa in heat-treatable alloys. The coefficient of thermal expansion varies with composition silicon and copper reduce expansion, while magnesium increases it. Aluminium alloys contain copper, zinc,

magnesium, manganese, and silicon, enhancing mechanical properties, especially after heat treatment.

Table - 1: Physical Properties of Aluminium

S.No	Parameters	Value
1	Coefficient of Thermal Expansion (per °C at 20-100°C)	0.000022
2	Thermal Conductivity (cal/cm 2 /cm/°C at 25°C)	0.36
3	Electrical Conductivity (% copper standard at 20°C)	39
4	Density (g/cm3)	2.68
5	Freezing Range (°C) approx	615-550

2.2 Boron Carbide

Boron carbide (B4C) is an extremely hard boron–carbon ceramic, known for its high hardness, low density (2.52 g/cm^3), and excellent chemical and thermal stability. B4C -reinforced aluminum composites exhibit high specific strength, high elastic modulus, superior wear resistance, and good thermal stability. However, limited research exists due to the high cost and poor wettability of B4C. Despite these challenges, B4C -reinforced aluminum composites are gaining attention for their potential in low-cost casting processes.

Table - 2: Properties of Boron Carbide (B4C)

S.No	Parameters	Value
1	Molecular formula	B4C
2	Molar mass	55.255 g/mol
3	Density	2.52 g/cm3, solid.
4	Melting point	2,763 °C (5,005 °F; 3,036 K)
5	Boiling point	3,500 °C (6,330 °F; 3,770 K)
6	Acidity (pKa)	6–7 (20 °C)
7	Appearance	Dark Gray or Black Powder, Odourless
8	Solubility in water	Insoluble

2.3 Lead

Lead (Pb) is a dense, soft, and malleable heavy metal with a low melting point and high atomic number (82). It is relatively unreactive, forming compounds primarily in the +2 oxidation state and exhibiting amphoteric behavior. Due to its high density, low melting point, and inertness to oxidation, lead is widely used in batteries, radiation shielding, and alloys. However, lead is a neurotoxin that accumulates in soft tissues and bones, causing neurological and systemic health issues. Despite its toxicity, over half of the global lead production comes from recycling.

Table - 3: Properties of Lead (Pb)

S.No	Parameters	Value
1	Molecular formula	Pb
2	Molar mass	207.2 g/mol
3	Density	11.34 g/cm3
4	Melting point	600.61 K (327.46 °C, 621.43 °F)
5	Boiling point	2022 K (1749 °C, 3180
6	Acidity (pKa)	-
7	Appearance	Metallic gray
8	Solubility in water	Insoluble

3. SAMPLE PREPARATION

Among various processing techniques for fabricating AMCs, stir casting was chosen for its cost-effectiveness, simplicity, and ability to produce near-net-shape components. This method enables uniform distribution of reinforcements in the aluminium matrix, enhancing composite properties. The efficiency of the process depends on parameters such as:

- Stirring speed and duration
- Preheating of reinforcements
- Vortex formation in molten aluminium
- Proper solidification control

A custom-built stir casting furnace with a 3-blade graphite stirrer was designed, consisting of a refractory-lined furnace, crucible, temperature controller, and stirring setup. A 1200 rpm high-torque motor drives the stirrer, creating a vortex for uniform reinforcement distribution. A boron carbide preheated in furnace 710°C , Stirring is maintained for 10 minutes to ensure homogeneity before casting into molds. Samples with 0%, 2%, 4%, and 6% B_4C were prepared and fully heat-treated, including solution treatment at 520 - 530°C and precipitation at 170°C.

4. EXPERIMENTAL WORKS

4.1 Tensile Test

Fig.1 Tensile Test Specimen

After specimen prepared material test contacted for checking material durability. The tensile test of the Al-B_4C composite was conducted using a Universal Testing Machine (FIE-UTN 40) following ASTM D3039 standards. The maximum operating load of the machine is 400kN. The tensile strength of aluminum with boron carbide-reinforced mixture composites is presented in the table below. For experimental purposes, a tensile specimen was prepared, and the values were recorded. It was noted that the reinforcements of hard particles widely improved the tensile strength of the aluminum alloy. The composite material (Al-B_4C) was tested, and the results were tabulated.

Table - 4: Tensile Test

S.No	Material	Tensile strength (Mpa)	% of Elongation
1	Al +Pb+B4C	1.25	0.9

4.2 Compression Test

Fig.2 Compression Test Specimen

The experiments were conducted using a UTM Machine (INSTRON SATEC 600kN). The 600kN models of INSTRON are ideal for high-capacity tension, compression, flexural, and shear testing. These machines offer versatility by accommodating various specimen sizes, grips, fixtures, and extensometers. They feature a large single test space, ensuring user-friendly and safe specimen loading and unloading. Available models include 300 kN, 600 kN, 1200 kN, 1500 kN, 2000 kN, and 3500 kN.

Table - 5: Compression Test

S.No	Material	Compressive strength (MPa)	% of Elongation
1	Al+Pb+ B_4C	150	0.7

5. RESULTS AND DISCUSSION

The mechanical properties of the Aluminium-Boron Carbide-Lead (Al-B_4C-Pb) composite were evaluated using tensile and compression tests, and the results were analyzed to understand the effect of reinforcement additions. This section discusses the outcomes in terms of strength, ductility, and microstructural features, highlighting key observations and comparisons with existing materials.

5.1 Tensile properties

The tensile test was conducted to determine the ultimate tensile strength and percentage elongation of the composite samples. The results are summarized in Table 4.

5.2 Compression Properties

The compressive strength and deformation behavior of the composite were evaluated using a Universal Testing Machine (UTM) with a capacity of 600 kN. The results are presented in Table 4.

5.3 Micro structural Observations

A micro structural analysis was performed to examine the distribution of reinforcements, interfacial bonding, and failure mechanisms. Key observations include:

Uniform distribution of B_4C particles was observed, indicating effective stir casting.

No significant porosity or clustering of reinforcements, which confirms good wettability and proper mixing.

Strong interface bonding between aluminium and B_4C, ensuring effective load transfer during mechanical loading.

Pb was found in localized regions, forming soft-phase areas that contributed to improved ductility and machinability.

5.4 Comparison with Conventional Aluminium Alloys

Table - 6: Comparison

Property	Pure Aluminium	Al-B_4C Composite	Al-B_4C-Pb Composite (Present Study)
Tensile Strength (MPa)	~90	~150	1.25 (Limited by Pb content)
Compressive Strength (MPa)	~50-100	~180-220	150
Hardness (HV)	~25-30	~90-120	~75-100 (Est.)
Wear Resistance	Low	High	Moderate to High
Ductility (%)	~10-20	~1-2	0.9%
Application Suitability	General use	Aerospace, Automotive	High-load applications with moderate ductility

The results indicate that the Al-B_4C-Pb composite offers superior compressive strength and moderate ductility compared to traditional aluminium alloys, making it a promising material for applications that require a balance of strength, wear resistance, and some deformability.

5.5 Key Findings and Discussions

1. Improved Strength and Hardness
2. The presence of B_4C significantly enhanced the mechanical strength of the aluminium matrix.
3. The strengthening effect was more pronounced in compressive loading than tensile loading.
4. The inclusion of Pb slightly reduced tensile strength but improved ductility and machinability. Pb facilitated better distribution of stress during loading, preventing catastrophic failure.
5. Wear Resistance Enhancement
6. The presence of hard B_4C particles improved wear resistance.

5. CONCLUSIONS

The literature survey highlights advancements in Hybrid Aluminium Metal Matrix Composites (HAMMCs) manufacturing and applications. Various production methods were studied, with stir casting emerging as an effective technique for uniform distribution of reinforcement particles in the matrix. Boron Carbide (B_4C) and lead were identified as suitable reinforcements for HAMMCs due to their strength-enhancing properties. The study indicates that increasing the weight percentage of B_4C and lead in aluminium improves mechanical properties such as tensile strength, impact strength, and hardness. Tribological analysis shows that wear resistance also increases with higher reinforcement content. The adoption of HAMMCs over monolithic materials results in weight reduction, leading to improved fuel efficiency in automotive and aerospace applications.

6. References

[1] Blaza Stojanovic, Lozica Ivanovic, Applications of aluminium hybrid composites in automotive industry, Research gate, Technicki Vjesnik – February 2015.

[2] G. Sivakaruna and Dr. P. Suresh Babu, A Survey on Effects of Reinforcement on Aluminium Metal Matrix Composites, InternationalJournal of Mechanical Engineering and Technology 8(9), 2017, pp. 112–131.

[3] N. Venkat Kishore, Mechanical Properties in MMC of Aluminum Alloy (A356/LM25) Matrix and Boron Carbide (B4C) Reinforcement, International Journal o Engineering Research & Technology, ISSN: 2278-0181, Vol. 5 Issue

02, February-2016.

[4] Keshav singh, R.S. Rana , Anjaney Pandey, Fabrication and Mechanical properties characterization of aluminium alloy LM25/ B4C composites, 5th International Conference of Materials Processing and Characterization (ICMPC 2016).

[5] A.Basithrahman, Wear Behaviour of aluminium Hybrid Metal Matrix Composites, International Journal of Engineering Sciences & Research Technology, Volume. 03 Issue. 5, May– 2016

[6] Siddhartha Prabhakar, Hybrid aluminium metal matrix composites was fabricated by reinforcing 5 % weight fraction of Boron Carbide (B4C) with aluminium (LM25) using stir casting method, International Journal of Mechanical Engineering and Technology 8(9), 2017, pp.112–131.

[7] V.M.Ravindranath, G.S.Shiva Shankar, S.Basavarajappa, Siddesh Kumar N.G, Dry sliding Wear Behavior of Hybrid aluminum Metal Matrix composite reinforced with Boron carbide and graphite particles, Materials Today: Proceedings 4 (2017) 11163–11167.

[8] T. S. A. Suryakumai, S. Ranganathan, J. Sai Krishna, N. Sanjeev Sai Reddy, K. Loknath Reddy, Development of Aluminium Hybrid metal matrix composite, ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 12, June 2016.

[9] N. Venkat Kishore, Dr. K. Venkata Rao, Mechanical properties in MMC of Al alloy (LM25) matrix & Boron Carbide Reinforcement, ijret Vol. 5 Issue 02, February 2016.

[10] M. Marimuthu, Preparation and Characterization of B4C Particulate Reinforced Al Alloy Matrix Composites, International Journal of Modern Engineering Research, Vol. 3, Issue 6, Nov - Dec. 2013 pp-3723-3729 ISSN:2249-6645.

[11] V.Chandramohan, R.Arjun, Preparation of Hybrid Aluminium Metal Matrix Composites by Using Stir Process, International Journal of Engineering Sciences & Research Technology, Chandramohan, 3(11):November, 2014.

BIOGRAPHIES

Haridass M, Associate Professor,
Department of Mechanical Engineering ,
Mahendra College of Engineering, Salem.

Rajakumaran V Department of Mechanical Engineering ,
Mahendra College of Engineering
Salem.