MECHANICAL PROPERTIES AND CHARACTERIZATION OF AL7178 HYBRID METAL MATRIX COMPOSITE REINFORCED WITH SiC AND B_4C

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Abstract - *These days, engineers pay close attention to Metal Matrix Composites because they are strong yet light. Instead of just one additive, this study mixes two - Silicon Carbide and Boron Carbide - into Aluminium Alloy 7178. A method called stir casting shapes the new blend into a usable form. Heat brings the metal to about 750 degrees Celsius before mixing begins. Spinning the molten mix at 200 revolutions per minute helps spread the tiny particles evenly. Before adding them, the reinforcing powders get warmed up first. That extra heat makes it easier for materials to bond while lowering trapped air pockets. One batch of four samples got made, each with a different mix of added materials. Testing their strength involved pulling them apart, checking resistance to dents, along with looking closely at internal structure. Strength and firmness went up when more reinforcing stuff was included. A peak pull strength of 156.40 MPa showed up in the version holding 6% SiC together with 2%* B_4C*. This material might work well where light but strong parts are needed, like planes or cars.*

***Key Words*: Metal Matrix Composite, Al7178, Silicon Carbide, Boron Carbide, Stir Casting, Tensile Strength, Hardness**

1. INTRODUCTION

Lately, there's been a big jump in needing tough new materials for engineering jobs. Old-style stuff usually falls short when it comes to being strong but light, plus standing up to heavy use. These newer mixes of metal and reinforced bits started showing real potential where regular metals fail. Heavy but strong? Not here. These materials stay light while resisting damage better than typical metals. As Surappa pointed out, they handle stress more firmly and resist surface loss longer. Strength meets flexibility - Miracle showed how metal softness joins ceramic toughness neatly inside them.

Aluminium alloys get stronger when stuff like Silicon Carbide or Boron Carbide is mixed in. Strength goes up because tiny bits inside carry more weight, say Chawla and Chawla [3], thanks to how forces move across them.

Out of all techniques, stir casting stands out for being low cost when making MMCs. According to Hashim and team [4], consistent mixing spreads the reinforcing particles evenly throughout. Wear resistance gets a boost - so does strength - from ceramics, Rohatgi [5] pointed out.

Work lately done by Kumar and team [6] reveals how mixed reinforcements outperform those using just one type. Because of this finding, the current work looks at making and testing an aluminum 7178 mix strengthened with both silicon carbide and boron carbide.

2. LITERATURE REVIEW

Lately, Metal Matrix Composites have caught the eye of engineers thanks to better performance than standard materials. Instead of heavier options, aluminum versions stand out - lightweight yet strong when you consider their mass. Corrosion hardly affects them, while heat moves through easily, adding to their appeal. Because of these traits, planes, cars, and support structures often rely on such blends. Their role grows where durability and efficiency matter most. Aluminium composites show greater stiffness than standard alloys, also standing up better to wear plus holding their shape more reliably. Reinforcement particles boost how much weight the material can handle, along with its ability to resist bending or warping. Because of these traits, such materials fit well where heavy loads are part of daily use. Performance stays strong even when stress levels climb.

Starting off differently each time, Miracle pointed out how MMCs blend traits from both metals and ceramics. Because of this mix, they show strong performance through durability and better heat tolerance. What stands out is their ability to resist damage from friction or shape changes. On top comes the role of the metal base - it adds flexibility along with resilience. Meanwhile, hard particles within add stiffness plus load-bearing power. Under intense environments, these materials keep working without failing.

Chawla and Chawla [3] point out that how well composite materials work ties closely to how the matrix and reinforcement interact. Since the matrix holds the reinforcing particles together, it also carries the load when stress is applied. On the flip side, the reinforcement boosts both strength and rigidity. What makes reinforcement effective comes down to things like particle size, their shape, how they're spread out, and how tightly bonded they are where they meet the matrix. When those particles are evenly dispersed, mechanical traits stay steady across the whole material.

Making aluminum composite materials involves different methods like mixing powders, pressing liquid metal into molds, or swirling reinforcements into melted metal. Of these options, swirling - called stir casting - is common because it does not require complex tools, costs less, runs quickly, while handling large batches well. Research by Hashim and team [4] looked closely at this swirling method, showing how adjusting spin rate, heat levels, and duration helps spread hard particles evenly through the hot metal. When particles spread without clumping, the material gains strength and performs better under stress.

Hard particles like silicon carbide can boost how well aluminum holds up under stress. Rohatgi found these additives make the metal tougher and more resistant to wearing down. Instead of softening easily, the material resists bending when pushed. Because it handles pressure better, parts last longer even under tough conditions. Cars often use this mix in pieces that must endure constant rubbing and force - like engine cylinders, brakes, and moving rods inside motors.

Lately, scientists have turned attention toward mixtures of metals strengthened by multiple materials at once. Instead of just one additive, combining fillers like silicon carbide and boron carbide into aluminum brings better results. Work led by Kumar and team showed these mixed reinforcements boost both strength and resistance to wear beyond what single additives can do. While higher amounts of filler tend to improve toughness, too much causes clumping inside the structure. That buildup tends to weaken flexibility even as it hardens the material overall.

Looking closer, tiny structures show even spread of added particles in aluminum helps them stick well and work better together. How it's made matters just as much, with right amounts needed to avoid holes or clumping.

It shows up in research that aluminum mixes strengthened with SiC along with B_4C perform better mechanically than standard alloys. Still, how well they work ties closely to things like how much reinforcement is added, how the particles are spread out, and the way they're made. With that in mind, this work looks at producing and analyzing Al7178 hybrid composites through stir casting, checking strength traits and whether they fit real-world uses.

3. MATERIALS AND METHODOLOGY

3.1 Materials Used

Now comes a look at why Al7178 made the cut - its blend of lightness, toughness, and dependable performance stood out. Part of the 7000 group, this metal gets its edge from zinc mixed with magnesium. Because it handles stress well while staying lightweight, industries like aviation lean on it heavily. Starting off, Silicon Carbide (SiC) alongside Boron Carbide (B_4C) served as reinforcing agents. Chosen because they resist wear well, stay stable under heat, plus remain extremely hard. Known widely for standing up to heavy abrasion, SiC brings strong structural support. Meanwhile, B_4C ranks among the toughest substances found - adding serious rigidity and enhanced hardness when mixed into the material.

When mixed together, SiC and B_4C form a blend that handles stress better than materials reinforced only once. One reason they were picked? They work well inside aluminium while boosting strength. What matters most is how each part helps the other hold up under pressure.

Table 1: Chemical Composition of Aluminium Alloy 7178

Element	**Zn**	**Mg**	**Cu**	**Cr**	**Si**	**Fe**	**Mn**	**Ti**	**Al**
Percentage (%)	9.5	4.12	3	0.34	0.6	0.7	0.4	0.3	Balance

Table 2: Mechanical Properties of Aluminium Alloy 7178

Property	**Value**
Ultimate Tensile Strength	605 MPa
Yield Strength	535 MPa
Modulus of Elasticity	72 GPa
Poisson's Ratio	0.34
Shear Strength	355 MPa
Specific Heat Capacity	857 J/kg°C
Machinability	70%
Compressive Yield Strength	525 Mpa

Table 3: Mechanical Properties of Reinforcement Materials

Property	**Silicon Carbide (SiC)**	**Boron Carbide (B_4C)**
Density (g/cm^3)	3.1	2.52
Elastic Modulus (GPa)	410	450–470
Poisson's Ratio	0.14	0.18
Hardness (HV)	2500–2800	2900–3500
Compressive Strength (MPa)	~3900	—
Thermal Conductivity (W/m·K)	120–200	30–42
Melting Point (°C)	~2730	~2760

Fig. 1: Aluminium Alloy 7178 Raw Material

Fig. 2: Silicon Carbide and Boron Carbide Powders

3.2 Preheating of Reinforcement Particles

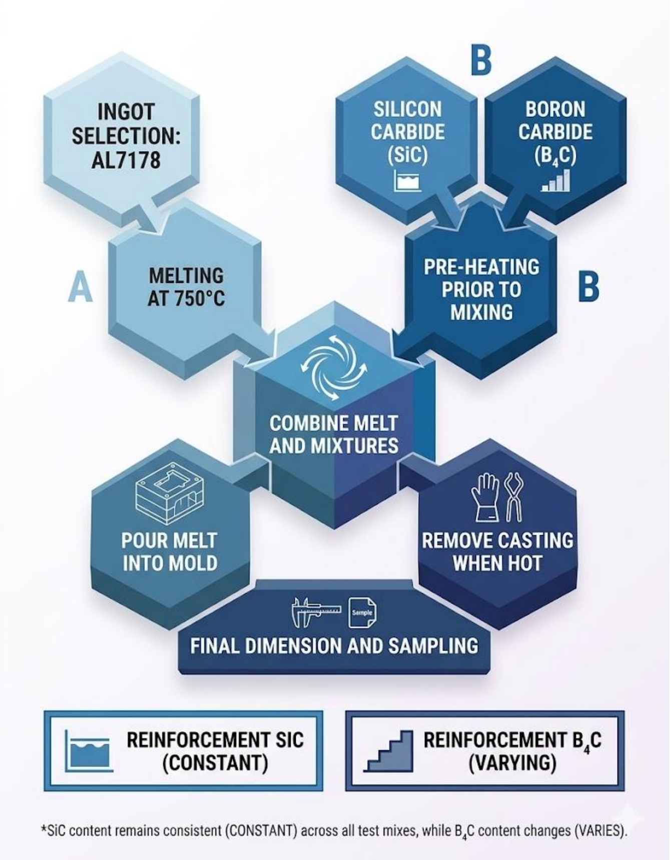
Warmth applied ahead of time makes tiny bits stronger inside metal blends. Here, particles made of silicon carbide mixed with boron carbide got heated close to 200–250°C prior to entering melted aluminum.
Preheating kicks off by driving out dampness stuck on the tiny reinforcing bits. When wet spots linger, they meet hot aluminum and form gas bubbles instead. Those pockets show up later inside the mix. Weak spots follow where air sneaks into the structure.

Warm things up first, that helps the tiny bits stick better inside melted aluminum. When they stick well, bonds grow stronger and spread out evenly across the mix. On top of that, heating ahead cuts down the gap in heat levels so nothing cools too fast or mixes unevenly.

Fig. 3: Preheating of Reinforcement Particles

3.3 Stir Casting Process

A mix of metal and hard particles took shape through stirring during melting, a common way to make aluminum blends because it works well without high costs. This method fits big batches easily, relying on straightforward steps that keep things running smoothly in factories.
Starting off, the team heated Aluminium Alloy 7178 inside a furnace until it reached about 750°C. Once liquid, they spun it with a machine-driven mixer running near 200 rpm. Spinning created a swirling motion in the melt. This swirl helped spread added particles evenly throughout the metal. Without that spin, things wouldn't mix right.
Into the stirred melt, preheated silicon carbide trickled slowly alongside boron carbide bits. Mixing stayed smooth because each handful entered one after another instead of all at once. For even spread across liquid metal, swirling didn't stop too soon. Movement through molten aluminum kept going just long enough to blend everything well.
Start with heat levels just right, also keep mixing steady - this helps spread particles evenly through the material while lowering flaws. A smooth blend shows up when conditions stay stable throughout production runs. Too fast or too hot messes things up, yet balance supportscleaner results every time.



*SiC content remains consistent (CONSTANT) across all test mixes, while B_4C content changes (VARIES).

Fig. 4: Stir Casting Process Steps

Fig. 5: Stir Casting Setup

3.4 Casting of Composite Material

Once the particles mixed evenly, liquid metal moved into warm molds. Because molds were heated ahead of time, temperature differences stayed low. Fast cooling avoided that way keeps cracks from forming. Shrink holes also less likely when changes happen slowly.

Slowly, the hot liquid metal began to harden into solid chunks when cooled with care. Only when it sets just right does the inside turn out smooth and even. A rushed stop can leave hidden flaws deep within.

Once hardened, out came the cast pieces from their molds, left sitting until they matched the air around them.

Fig. 6: Casting of Composite Material

3.5 Reheating Process

Midway through stirring, tiny pockets of air sometimes stay stuck in the hot metal, creating small gaps once cooled. Because of that, each piece was warmed up again after hardening to reduce empty spaces inside.

Out comes the gas when heat returns, thanks to loosened bonds inside. Pressure built while cooling fades once warmth flows back through. Denser buildup follows, piece by piece filling gaps left before. Strength climbs as layers settle into tighter alignment. Better performance shows up in how it holds force now.

3.6 Composition of Composite Samples

One way to check how added materials change strength was by making four mixtures. Each used a different amount of Silicon Carbide along with Boron Carbide. These blends were built step by step in the lab. Their responses under pressure became clear during testing. What mattered most was how much of each hard substance was included.

- Pure Al7178 Without Reinforcement
- Al7178 with 2 percent SiC and 2 percent B4C
- Al7178 with 4 percent SiC and 2 percent B4C
- Al7178 with 6 percent SiC and 2 percent B4C

Starting at different levels of reinforcement shows how it influences the material's resistance to stretching along with its firmness. What changes is how much stronger or stiffer the mix becomes when more filler is added. Depending on the amount used, results shift noticeably across tests. Each step up alters both stretch limit and surface toughness. Strength climbs a bit here, while stiffness shifts there. How far it goes ties directly to how much reinforcement is mixed in.

Fig. 7: Composition of Hybrid Composite Samples

Table 4: Composition of Composite Samples

Sample	Al7178 (%)	SiC (%)	B_4C (%)	Total Weight
Sample 1	100	0	0	800 g
Sample 2	96	2	2	800 g
Sample 3	94	4	2	800 g
Sample 4	92	6	2	800 g

3.7 Specimen Preparation

Out of the workshop came oddly shaped chunks, later trimmed by a spinning lathe until they fit what the test needed. A good shape matters - sloppy prep leads straight to shaky numbers when strength gets checked.
Out of standard sizes came the test pieces, shaped for pull and firmness checks. Smoothness mattered, so each got filed down just right, keeping shape accurate to dodge mistakes later. Before any machine touched them, someone looked closely - cracks or tiny holes meant they would not pass. Only clean ones moved forward.

Table 5: Specimen Dimensions for Mechanical Testing

Test Type	Shape	Dimension
Tensile Test	Cylindrical	Gauge Length ≈ 50 mm
Hardness Test	Flat Surface	Thickness ≈ 10 mm

Fig. 8: Machining of Composite Specimens

3.8 Mechanical Testing

The fabricated composite specimens were subjected to mechanical testing to evaluate their performance.

- **Tensile Test:** Conducted using a Universal Testing Machine (UTM) to determine tensile strength and deformation behavior.
- **Hardness Test:** Conducted using the Vickers microhardness method to measure resistance to indentation.
- **Microstructural Analysis:** Performed using an optical microscope to study particle distribution and bonding.

These tests help in understanding the influence of reinforcement particles on the mechanical properties of the composite.

Fig. 9: Vickers Hardness Testing Machine

Fig. 10: Universal Testing Machine

4. RESULTS AND DISCUSSION

Among tested specimens, those blended with SiC and B_4C showed shifts in strength when pulled apart. One after another, each variant underwent scrutiny under a hardness indenter. Weight per volume emerged differently across the set. Up close, their internal layouts revealed how grains settled among particles. Rather than uniform mixes, certain batches carried more filler. Performance trends appeared once comparisons unfolded. What changed most often was resistance to denting. Through layered inspection, patterns took shape without assumption.

4.1 Tensile Test Results

A pull-test on materials shows how they stretch and break when pulled straight. One moment it sits still; next, slow pulling begins till the sample splits apart. From this comes numbers like max load limit before breaking, point where permanent bending starts, also how much it stretches.

Watching this unfold gives clues about real-world performance under stress.

Table -6: Tensile Test Results

Sample	Composition	Ultimate Load (kN)	Tensile Strength (MPa)
S1	Pure Al7748	8.740	111.281
S2	2% SiC + 2% B_4C	10.500	134.845
S3	4% SiC + 2% B_4C	12.200	155.335
S4	6% SiC + 2% B_4C	12.420	156.40

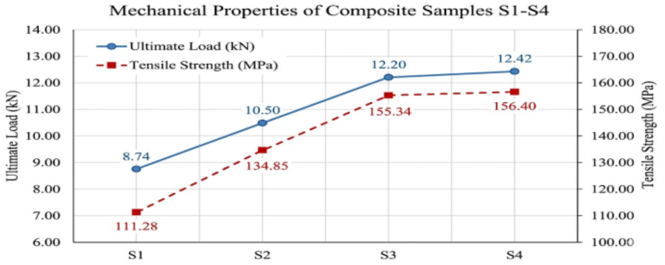


Chart -1: Tensile Test

Discussion

- **Sample 1 (Pure Al7178)**: The base alloy exhibits the lowest tensile strength (111.281 MPa) due to the absence of reinforcement particles. The material undergoes higher plastic deformation under tensile loading.
- **Sample 2 (2% SiC + 2% B_4C)**: A noticeable improvement in tensile strength (134.845 MPa) is observed. The addition of ceramic particles enhances load transfer and reduces deformation.
- **Sample 3 (4% SiC + 2% B_4C)**: Tensile strength further increases to 155.335 MPa, indicating improved reinforcement efficiency. Increased particle content restricts dislocation motion more effectively.
- **Sample 4 (6% SiC + 2% B_4C)**: The highest tensile strength (156.40 MPa) is achieved. The high reinforcement content significantly enhances strength due to strong interfacial bonding and resistance to deformation.

4.2 Hardness Test Results

Table -7: Vickers Hardness Results

Sample	Composition	Hardness (HV)
S1	Pure Al7178	78
S2	2% SiC + 2% B_4C	92
S3	4% SiC + 2% B_4C	108
S4	6% SiC + 2% B_4C	126

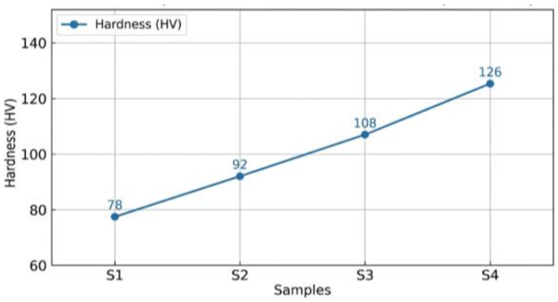


Chart -2: Hardness Test

Discussion

- **Sample1:** Exhibits the lowest hardness 78 HV due to the absence of hard reinforcement particles.
- **Sample 2:** Hardness increases to 92 HV, indicating initial strengthening effect of SiC and B_4C particles.
- **Sample 3:** Further improvement to 108 HV is observed due to increased particle concentration and resistance to indentation.
- **Sample 4:** Maximum hardness 126 HV is achieved due to high reinforcement content, which significantly restricts plastic deformation.

4.4 Microstructural Analysis

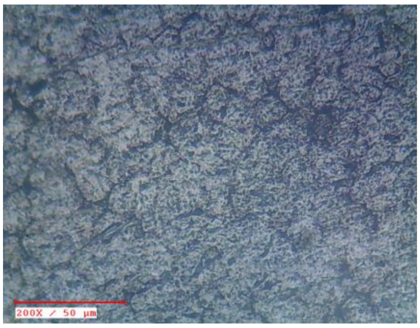


Fig. 11: Microstructure of Pure Al7178 Alloy at 200× Magnification

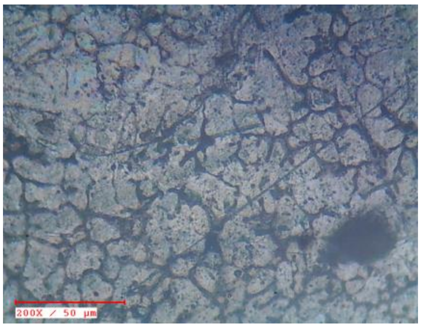


Fig. 12: Microstructure of Al7178 + 2% SiC + 2% B_4C at 200× Magnification

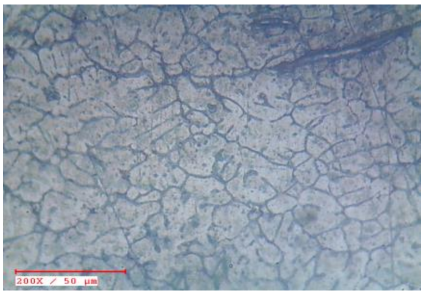


Fig. 13: Microstructure of Al7178 + 4% SiC + 2% B_4C at 200× Magnification

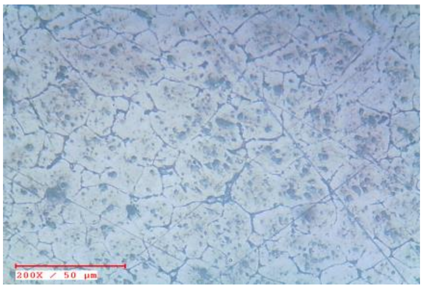


Fig. 14: Microstructure of Al7178 + 6% SiC + 2% B_4C at 200× Magnification

Discussion

- **Sample 1:** Uniform aluminium matrix with no reinforcement particles.
- **Sample 2:** Initial distribution of reinforcement particles observed with minor clustering.
- **Sample 3:** Improved uniformity of particle distribution with better bonding.
- **Sample 4:** Highly uniform distribution with strong matrix-reinforcement interface and minimal porosity.

4.5 Overall Discussion

The experimental results clearly demonstrate that the addition of hybrid reinforcement significantly enhances the mechanical properties of Aluminium Alloy 7178.

Key Improvements:

- Tensile strength increased from **111.281 MPa → 156.40 MPa**
- Hardness increased from **78 HV → 126 HV**

Reasons for Improvement:

- Effective load transfer between matrix and reinforcement
- Restriction of dislocation movement
- Strong interfacial bonding
- Uniform particle distribution

The results confirm that hybrid reinforcement using SiC and B_4C provides better performance compared to unreinforced alloy, making the material suitable for advanced engineering applications.

5. CONCLUSIONS

One look at how Al7178 aluminum alloy behaves when mixed with silicon carbide and boron carbide shows shifts in strength depending on amounts added. Instead of standard lab-only guesses, real tests measured changes through stirring methods used to blend materials together. Each mix varied slightly - more grit here, less there - to see what sticks, what breaks. Because structure shapes performance, tiny hard particles were stirred into molten metal just to watch how things held up afterward. While some blends stiffened under pressure, others gave way sooner than expected. Testing followed every shift, step after change, tracking each version like footprints across sand.

Tests show the mix of two reinforcements boosts how well aluminum holds up under stress. Not just stronger, it handles stretching much better than before. From a starting point of **111.281 MPa**, pull strength jumped to **156.40 MPa** when adding 6% SiC along with 2% B_4C. This jump means the material resists breaking more effectively. Hardness also rose sharply - measured at **78 HV** initially, now reaching **126 HV**. Tiny stiff bits inside make it tougher to dent or bend permanently. With these particles spread through, the metal pushes back harder against shape changes.

A bit less dense the composite became as more reinforcement was added - helpful when lightness matters. Scattered throughout the aluminum, the reinforcing bits spread out fairly evenly, sticking well to the base stuff while leaving almost no gaps, making the material stronger overall.

One thing stands out - mixing SiC with B_4C into Aluminium Alloy 7178 boosts both strength and hardness without adding weight. This blend holds promise, especially in areas like planes, cars, and load-bearing structures. Wherever light yet tough materials matter most, this combo might just fit. Performance stays sharp even under demanding needs.

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