GIET UNIVERSITY JOURNAL, Engineering, Science, Agriculture & Management 2024, SPECIAL ISSUE **“Sustainable Engineering, Technology and Management (NSETM-2024)”**

PP. – 23-31, Manuscript Received: 20th March 2024; Revised 28th June2024, Accepted: 30th July, 2024

# Synergistic Effect of Boron Carbide and Titanium Diboride on the Mechanical Properties of AA5083 Hybrid Composite

[1]Debasish Rout, Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Sambalpur 768018, India, contact.rdebasish@gmail.com

[2]Chitta Ranjan Deo*, Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Sambalpur 768018, India, crdeo_me@vssut.ac.in

[3]Deepak Kumar Mohapatra, Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Sambalpur 768018, India, dkmohapatra_phdme@vssut.ac.in

[4]Rabindra Behera, Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Sambalpur 768018, India, drrabindrabehera@gmail.com

(Corresponding Author email address: crdeo_me@vssut.ac.in)

**Abstract: The growing worldwide fascination with metal-matrix composites has spurred significant research and development initiatives. This investigation specifically focused on the effects of integrating Boron Carbide (B4C) and Titanium Diboride (TiB2) into an AA5083 matrix on manufacturing process as well as mechanical attributes. Three distinct combinations of hybrid reinforcements are deliberately selected to formulate the composite materials. A precise two-step stir-casting process is employed to produce the composite specimens. Various mechanical assessments, including tensile strength, impact strength, and hardness tests following ASTM standards, are conducted to evaluate the composite materials. Through experimentation, the most effective reinforcement proportions are identified, with the combination of 6 wt% B4C and 9 wt% TiB2 demonstrating superior mechanical strength.**

***Keywords*- AA5083, TiB2, B4C, hybrid composite, Two-step Stir casting process, Mechanical attributes**

## 1. Introduction

Metal Matrix Composites (MMCs) are innovative materials formed by combining matrix and reinforcement elements. This fusion empowers researchers to tailor the attributes of MMCs, enabling the fabrication of materials with precise characteristics. Commonly employed matrix materials include aluminum, magnesium, titanium, and copper. Among these, aluminum emerges as the preferred option due to its inherent features such as lightweight and exceptional resistance to corrosion. These inherent properties make the Aluminium Metal Matrix Composites (AMMCs) highly sought after. By introducing foreign particles into the aluminum matrix, characteristics such as density, specific modulus, thermal conductivity, and wear resistance can be effectively altered, allowing Advanced Metal Matrix Composites (AMMCs) to be applied across a wide range of industries including aeronautics, aviation, automotive, and marine sectors. To achieve enhanced mechanical properties, tough and inflexible ceramic particles such as SiC, TiB2, B4C, Al2O3, and others can be blended into the aluminum matrix, thereby boosting the overall performance and adaptability of these sophisticated composites.

The various research inquiries and analyses highlighted previously illuminate the substantial influence of different reinforcing components in Metal Matrix Composites (MMCs). The detailed analysis of these studies shows that adding different reinforcing elements to the matrix can greatly augment the mechanical attributes of MMCs. Moreover, the utilization of creative methods like hybridization, which involves integrating multiple types of reinforcement into one material matrix, has demonstrated the ability to customize the characteristics of metal matrix composites effectively. This strategy has played a crucial role in creating hybrid metal matrix composites (HMMCs), providing a flexible and adaptable platform to enhance the properties of these sophisticated materials through the strategic choice of appropriate reinforcing particles [3-5].

The two-step stir casting method has emerged as a suitable solution to address challenges such as the distribution of reinforcing particulates in the molten phase of the matrix and the wettability of particulates in the molten matrix. This method is well-regarded for its simplicity, economic feasibility, and effectiveness in addressing the complex manufacturing issues associated with metal matrix composites [6]. Additionally, the diverse findings from multiple research endeavors underline the pivotal role of careful selection and varied weight percentages of reinforcing elements in influencing the mechanical attributes of metal matrix composites. The studies reveal the nuanced effects of different weight proportions of reinforcing elements, including B4C, TiB2, Al2O3, SiC, mica, and more, on characteristics like tensile strength, hardness, wear resistance, friction, and sliding wear behavior, thereby contributing to a deeper understanding of the intricate relationships between reinforcement content and material performance [7-9].

Based on comprehensive insights and observations from previous studies, the present research aims to enhance performance of AA5083 hybrid metal matrix composites by reinforcing varying weight fractions of B4C and TiB2. The study also aimed to explore how varying reinforcement weight fractions affect the mechanical properties of hybrid composites. Further, integrating experimental results with existing knowledge, the potential applications of this fabricated composite across industrial and engineering sectors can be decided [10-13].

## 2. Materials and Methods

### 2.1 Materials Used

Aluminum alloy 5083 (AA5083) is an alloy with manganese and chromium traces. It is well known for its excellent performance in harsh environments such as seawater and industrial chemicals. It is widely used for the construction of ships, pressure vessels, car bodywork, and other applications. Due to its high resistance, corrosion resistance, welding, and mechanical strength, it has been chosen as a basis material for current research. AA 5083 aluminum alloy



ISSN NO – 2583-5955 (Online)

in billet form is purchased from Suresh Metals, Maharashtra, India. The reinforced particles, B4C and TiB2, are procured from Parshwamani Metals, Maharashtra, India.

## 2.2. Fabrication of Composite

In this investigation, AMMC is fabricated by utilizing a two-step stir-casting approach. A stir casting machine with a bottom pouring mechanism manufactured by Swam-Equip, illustrated in Figure 1, is used. As outlined in Table 1, a suitable quantity of AA5083 alloys along with reinforcement materials (B4C and TiB2) are taken to produce the targeted AMMCs. Initially, the required amount of AA5083 alloy billet is placed within a crucible and heated to a temperature of 750°C. 1% magnesium is incorporated into the melt to improve the adhesion amongst the matrix and reinforcement. Then, the temperature was allowed to decrease to 575°C to attain a semi-solid state. The appropriate amounts of B4C and TiB2, as specified in Table 3, are added to the melt. Before incorporation, the reinforcement particles underwent preheating at 400°C for an hour to eliminate any residual moisture. Subsequently, the mixture of matrix and reinforcement was stirred at a semi-solid consistency, utilizing a four-blade mechanical stirrer at a speed of 300 rpm, for a duration of 7-8 minutes. Then, the slurry temperature is elevated to 750°C to achieve a liquid state, ensuring thorough mixing of the matrix and reinforcement. Subsequently, the slurry is stirred at 300 rpm for an additional 10 minutes. Argon gas was introduced during this process to prevent oxidation, and thermocouples are utilized to regulate the temperatures. Following the stirring process, the resulting mixture is dispensed into a preheated cylindrical mould cavity measuring 140 mm in long and 13 mm diameter [15-17]. One of the primary advantages of employing this two-step stir-casting procedure instead of traditional stir casting is the uniform dispersion of particles, leading to a homogeneous scattering of the reinforcement [18]. The detailed composition of various composites fabricated, are presented in Table 1.

Table 1: Weight percentage of matrix and reinforcement material

| SL NO. | Wt.% of Matrix material (AA5083) | Wt.% of boron carbide ($B_4C$) | Wt.% of Titanium Diboride ($TiB_2$) |
|---|---|---|---|
| S1 | 100 | 0 | 0 |
| S2 | 85 | 4 | 11 |
| S3 | 85 | 6 | 9 |
| S4 | 85 | 8 | 7 |



ISSN NO – 2583-5955 (Online)

GIET UNIVERSITY JOURNAL, Engineering, Science, Agriculture & Management 2024, SPECIAL ISSUE **“Sustainable Engineering, Technology and Management (NSETM-2024)”**

PP. – 23-31, Manuscript Received: 20th March 2024; Revised 28th June2024, Accepted: 30th July, 2024


Figure 1: Stir casting setup

## 2.3. Mechanical Characterization

### 2.3.1. Tensile test

The tensile test was carried out by following the ASTM E8/E8M-09 standard using an INSTRON 3382 with load capacity of 100 KN. The test was conceded out at a crosshead speed of 2.3 mm/min. To ensure accuracy and reliability, five test samples for each category listed in Table 3 are prepared by cutting cylindrical rods using a CNC lathe. The ultimate tensile strength is determining the mean value from the outcomes of the five samples [19].

### 2.3.2. Impact testing

The Charpy impact test is employed to assess how much energy the material absorbs when it fractures, which indicates the material's notch toughness because it operates at high strain rates. This test is conducted in alignment with the ASTM E23-18 standard, involving impact specimens. Like the tensile test, five test samples of distinct combinations were examined, and the average value of their results is recorded.

### 2.3.3. Hardness Test

The Vickers-micro hardness test is a valuable technique for evaluating the hardness or resistance to deformation of materials. The testing procedures is conducted in full compliance with the ASTM E92 standard. Before the test, the workpiece underwent a polishing phase to ensure optimal testing conditions. The indentation is achieved using a diamond-shaped indenter for a duration of 30 seconds, utilizing a dead weight of 300 g. The final hardness value



ISSN NO – 2583-5955 (Online)

GIET UNIVERSITY JOURNAL, Engineering, Science, Agriculture & Management 2024, SPECIAL ISSUE **“Sustainable Engineering, Technology and Management (NSETM-2024)”**

PP. – 23-31, Manuscript Received: 20th March 2024; Revised 28th June2024, Accepted: 30th July, 2024

is evaluated by calculating the average value from the results of these five locations of each sample, ensuring a comprehensive and accurate assessment [20].

## 3. Result Analysis

### 3.1. Tensile strength

The tensile test outcomes of the composites are illustrated in Figure 2. From the experiment, the tensile strengths of the S1, S2, S3, and S4 samples are found to be 123.53, 142.17, 154.48, and 149.63 MPa, respectively. Notably, a notable increase in tensile strength is noticed with the incorporation of hybrid reinforcement using B4C and TiB2, as compared to the base material AA5083. Tensile strength consistently rises as the concentration of B4C is raised from 0 wt% to 6 wt%. The composite sample containing 6 wt% B4C and 9 wt% TiB2 exhibited an optimal tensile strength value, approximately 25% higher than pure AA5083. This indicates the enhanced mechanical properties achieved through the strategic incorporation of B4C and TiB2. The study observed a declining trend in tensile strength as the proportion of B4C increased beyond the optimal percentage. This finding indicates that the addition of B4C and TiB2 substantially enhanced the tensile strength up to a specific weight percentage combination, after which an excess amount of B4C led to degradation in tensile strength. Similar findings regarding the increasing trend in tensile properties were also reported by other researchers [5, 21, 22], affirming the significance of the observed results.

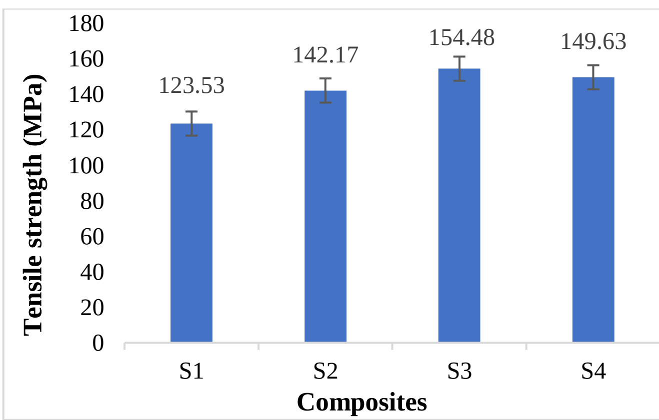


Figure 2: Tensile strength of composites

### 3.2. Impact Strength

Figure 3 demonstrates the impact strength of the AA5083 hybrid composite. At first, a reduction in impact strength was noticed upon incorporating 4 wt% B4C and 11 wt% TiB2 into AA5083. However, a subsequent increase of 43% in impact strength is observed with the incorporation of 6 wt% B4C and 9 wt% TiB2, showcasing the significant enhancement achieved through this hybridization process. The variability in impact strength as the B4C



ISSN NO – 2583-5955 (Online)

GIET UNIVERSITY JOURNAL, Engineering, Science, Agriculture & Management 2024, SPECIAL ISSUE **"Sustainable Engineering, Technology and Management (NSETM-2024)"**

PP. – 23-31, Manuscript Received: 20th March 2024; Revised 28th June2024, Accepted: 30th July, 2024

content changes is due to the unpredictable dispersion of reinforcing particles throughout the base matrix material, which leads to localized energy concentration effects. However, a higher value of the impact strength is noticed in the subsequent increase of B4C. Again, the impact strength is found to decrease with further increases in B4C content from 6 wt% to 8 wt%. It could have happened due to the agglomeration of reinforcing B4C at the preferred propagation sites. These findings align with earlier research by Hu et al. [2], which also highlighted similar trends in impact strength based on the varying composition of reinforcing materials in composites.

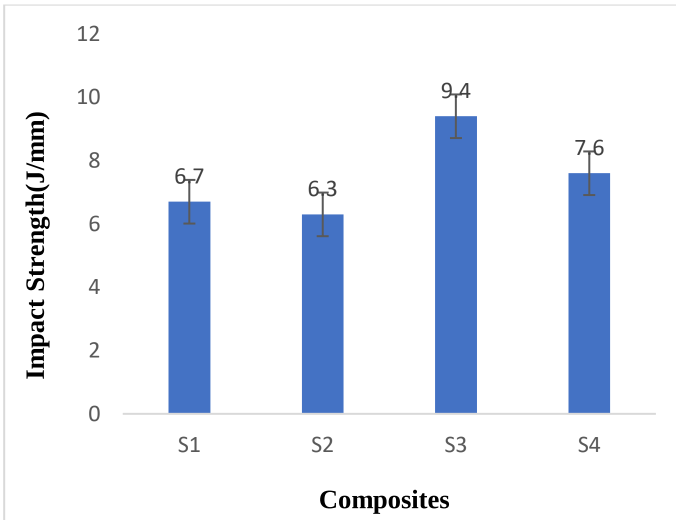


Figure 3: Impact strength of composites

### 3.3. Micro-Hardness

Figure 4 illustrates a distinct pattern in how hardness varies across the hybrid composite, as shown by the experimental results. The plot pattern reveals that the hardness increases with a higher reinforcement of B4C, coupled with a decrease in TiB2 content. This behaviour aligns with the theory of plastic deformation, as the increasing reinforcement leads to dislocation pile-up, contributing to the enhanced hardness. The increased hardness is due to the incorporation of tough reinforcements that integrate smoothly with the matrix, thereby boosting overall hardness. Additionally, the grains formed through in-situ creation add to the improved resistance against indentation. Given that B4C exhibits higher hardness and superior fusion with the AA5083 matrix compared to TiB2, an increase in B4C content directly correlates with an increase in composite hardness. The peak hardness value of 114.3 HV is attained with 8 wt% of B4C and 7 wt% of TiB2 reinforcement. These outcomes are in line with a similar study by Raja et al. [7], further emphasizing the significance of reinforcement composition on composite hardness.



ISSN NO – 2583-5955 (Online)

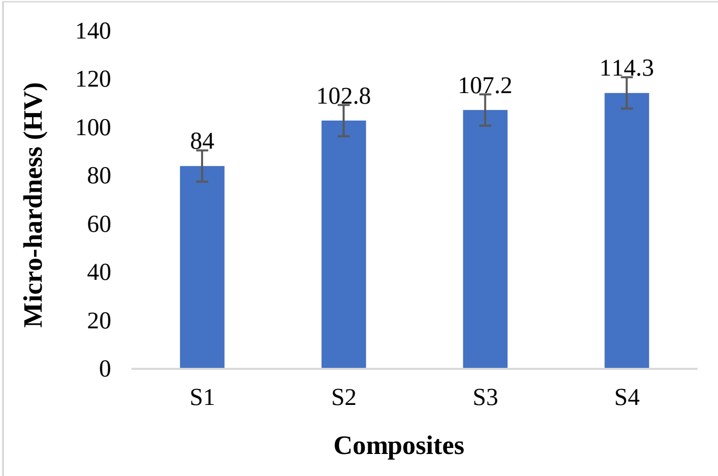


Figure 4: Micro-hardness of composites

## 4. Conclusion

Based on the investigations conducted in the current study on the hybrid composites prepared by incorporating $B_4C$ and $TiB_2$ into the AA5083 matrix using a two-step stir casting process, the following conclusions can be inferred:

1. Adding 6% B4C and 9% TiB2 increased the tensile strength of the test samples by 25% compared to the original AA5083 matrix. However, excessive amounts of B4C significantly decreased the strength, highlighting the critical need for optimal proportions of reinforcement materials.

2. The Impact strength decreased as the TiB2 content decreased, with the highest impact strength observed at 6 wt% B4C and 9 wt% TiB2.

3. In contrast, higher levels of B4C content lead to increased Vickers micro-hardness, which highlighting how the inclusion of foreign particles affects the mechanical characteristics of the composites.

These findings underscore how B4C and TiB2 enhance the mechanical attributes of hybrid composites, opening avenues for their application in various engineering fields requiring improved durability and performance.

## References

1. M. V. Raja and K. Manonmani, “Mechanical and Tribological Characteristics of Aluminium Hybrid Composites Reinforced With Boron Carbide and Titanium Diboride,” *Ceram. - Silikaty*, vol. 66, no. 3, pp. 396–406, 2022, doi: 10.13168/cs.2022.0035.

2. X. Hu, F. Jiang, F. Ai, and H. Yan, "Effects of rare earth Er additions on microstructure development and mechanical properties of die-cast ADC12 aluminum alloy," *J. Alloys Compd.*, vol. 538, pp. 21–27, 2012, doi: 10.1016/j.jallcom.2012.05.089.
3. D. S. Rao and T. S. Simhadri, "Improvements in mechanical properties of aluminium alloy-titanium di boride and boron carbide hybrid composite produced through friction stir processing route," *Mater. Today Proc.*, vol. 45, no. xxxx, pp. 5231–5236, 2021, doi: 10.1016/j.matpr.2021.01.774.
4. A. Bhowmik, D. Dey, and A. Biswas, "Comparative Study of Microstructure, Physical and Mechanical Characterization of SiC/TiB2 Reinforced Aluminium Matrix Composite," *Silicon*, vol. 13, no. 6, pp. 2003–2010, 2021, doi: 10.1007/s12633-020-00591-2.
5. P. Shanmughasundaram, R. Subramanian, and G. Prabhu, "Synthesis of Al-fly ash composites by modified two step stir casting method," *Adv. Mater. Res.*, vol. 488–489, no. March 2012, pp. 775–781, 2012, doi: 10.4028/www.scientific.net/AMR.488-489.775.
6. G. Singh and N. Sharma, "Evolution of physical and mechanical properties of Al5083/B4C Composites fabricated through Stir Casting," *Mater. Today Proc.*, vol. 21, pp. 1229–1233, 2020, doi: 10.1016/j.matpr.2020.01.074.
7. R. Raja, S. Jannet, S. Reji, and C. S. Glen Paul, "Analysis of mechanical and wear properties of Al2O3 + SiC + B4C/AA5083 hybrid metal matrix composite done by stir casting route," *Mater. Today Proc.*, vol. 26, no. xxxx, pp. 1626–1630, 2020, doi: 10.1016/j.matpr.2020.02.340.
8. M. Gupta, B. Gangil, and L. Ranakoti, "Mechanical and Tribological Characterizations of Al/TiB2 composites," *Ind. Eng. J.*, vol. 13, no. 4, 2020, doi: 10.26488/iej.13.4.1250.
9. K. Velavan, K. Palanikumar, and N. Senthilkumar, "Experimental investigation of sliding wear behaviour of boron carbide and mica reinforced aluminium alloy hybrid metal matrix composites using Box-Behnken design," *Mater. Today Proc.*, vol. 44, pp. 3803–3810, 2021, doi: 10.1016/j.matpr.2020.12.333.
10. S. Soni, S. Verma, "Double shear performance of the hybrid aluminium metal matrix composite Al6063-SiC/$Al_2O_3$ fabricated through electromagnetic stir casting process," *Mater. Today Proc.*, vol. 62, no. 10, 2022, pp 5942-5947, doi:10.1016/j.matpr.2022.04.639
11. M. Karthikeyan, A. Devaraju, R. Gopi, "Investigations on mechanical properties of aluminium alloy Al6061 hybrid metal matrix composite", Mater Today Proc.00:1-12,2022
12. M. S. Kumar, M. Vasumathi, S. R. Begum, S. M. Luminita, S. Vlase, and C. I. Pruncu, "Influence of B4C and industrial waste fly ash reinforcement particles on the micro structural characteristics and mechanical behavior of aluminium (Al–Mg–Si-T6) hybrid metal matrix composite," *J. Mater. Res. Technol.*, vol. 15, pp. 1201–1216, 2021, doi:10.1016/j.jmrt.2021.08.149.
13. S M, Sivaganesan DS, "Mechanical behaviour of aluminium based hybrid metal matrix composites (Al6061/B4C/ZrO2/SiC)", Mater Today Proc 56:507–513, 2022.
14. S. Venkatesan and M. Anthony Xavior, "Wear Property Evaluation of Aluminum Alloy (AA7050) Metal Matrix Composite Reinforced with Graphene Fabricated by Stir and Squeeze Cast Processes," *Mater. Today Proc.*, vol. 22, pp. 3330–3339, 2019, doi: 10.1016/j.matpr.2020.03.296.
15. T. Satyanarayana, P. S. Rao, and M. G. Krishna, "Influence of wear parameters on friction performance of A356 aluminum – graphite/ granite particles reinforced metal matrix hybrid composites," *Heliyon*, vol. 5, no. 6, p. e01770, 2019, doi: 10.1016/j.heliyon.2019.e01770.

16. P. Shanmughasundaram, R. Subramanian, and G. Prabhu, "Some studies on aluminium - Fly ash composites fabricated by two step stir casting method," *Eur. J. Sci. Res.*, vol. 63, no. 2, pp. 204–218, 2011.
17. K. K. Alaneme and M. O. Bodunrin, "6063 Metal Matrix Composites Developed By Two Step – Stir Casting Process," *Acta Tech. Corveniensis- Bull. Eng.*, vol. 6, no. 3, pp. 105–110, 2013.
18. M. Sambathkumar a, P. Navaneethakrishnan, and S. K. S. . Ponappa.K, "Mechanical and Corrosion Behavior of Al7075 ( Hybrid ) Metal Matrix Composites by Two Step Stir Casting Process," *Lat. Am. J. Solids Struct.*, vol. 7075, pp. 243–255, 2016.
19. A. Kumar, R. C. Singh, and R. Chaudhary, "Investigation of Nano-Al2O3 and Micro-coconut Shell Ash (CSA) Reinforced AA7075 Hybrid Metal–Matrix Composite Using Two-Stage Stir Casting," *Arab. J. Sci. Eng.*, vol. 47, no. 12, pp. 15559–15573, 2022, doi: 10.1007/s13369-022-06728-2.
20. A. D. Assi, H. A. Abdulhadi, and S. H. Omran, "Effect of adding SIC and TIO2 nanoparticles to AA6061 by stir casting technique on the mechanical properties of composites," *J. Mech. Eng. Res. Dev.*, vol. 43, no. 6, pp. 167–183, 2020.
21. M. Manoj, G. R. Jinu, J. S. Kumar, and V. Mugendiran, "Effect of TiB2 Particles on the Morphological, Mechanical and Corrosion Behaviour of Al7075 Metal Matrix Composite Produced Using Stir Casting Process," *Int. J. Met.*, vol. 16, no. 3, pp. 1517–1532, 2022, doi: 10.1007/s40962-021-00696-3.
22. A. J. Pirlari, M. Emamy, A. A. Amadeh, and M. Naghizadeh, "Elucidating the Effect of TiB2 Volume Percentage on the Mechanical Properties and Corrosion Behavior of Al5083-TiB2 Composites," *J. Mater. Eng. Perform.*, vol. 28, no. 11, pp. 6912–6920, 2019, doi: 10.1007/s11665-019-04403-6.