



REGULAR ARTICLE

Structural and Physical Property Enhancement in Al 7075–Boron Carbide–Zirconium Dioxide Hybrid Nano Composites

R. Vijaya Prakash^{1,*}, Prakash Babu Kanakavalli², Jogi Krishna³, DVSSSV Prasad⁴,
R.L. Krupakaran⁵, Nageswara Rao Medikundu^{6,†}

¹ Department of Mechanical Engineering, Acharya Nagarjuna University, 52510, Andhra Pradesh, India

² Department of Mechanical Engineering, V.R. Siddhartha School of Engineering, Siddhartha Academy of Higher Education, Deemed to be University, 520007 Kanuru, A.P., India

³ Department of Mechanical Engineering, RISE Krishna Sai Prakasam Group of Institutions, 523272 Ongole, India

⁴ Department of Mechanical Engineering, Aditya University Surampalem, 533437 Andhra Pradesh, India

⁵ Department of Mechanical Engineering, Mohan Babu University, Sree Sainath Nagar, 517102 Tirupati, Andhra Pradesh, India

⁶ Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, 522302 Vaddeswaram, Andhra Pradesh, India

(Received 25 January 2026; revised manuscript received 17 April 2026; published online 29 April 2026)

The Aluminum Metal Matrix Composites (AMMCs) continue to attract substantial research interest for high-performance locomotive, aerospace, and defense structures due to their superior specific strength, stiffness, and tribological behavior. The present investigation aims to enhance the mechanical response of Al 7075 by hybrid augmentation with ceramic particulates. Boron carbide (B_4C), known for its high hardness and modulus, was incorporated at a constant weight fraction, while zirconium dioxide (ZrO_2), a toughening ceramic with high thermal stability, was introduced in varying weight percentages to evaluate its incremental contribution to composite performance. Hybrid composites were synthesized via the Stir Casting Method (SCM), selected for its capability to disperse ceramic reinforcements uniformly in the molten matrix through controlled vortex formation. Process parameters such as stirring temperature, stirring speed, and holding time were systematically regulated to minimize particle clustering, interfacial porosity, and wetting inconsistencies. Mechanical characterization comprised tensile testing, compression testing, and Brinell hardness evaluation in accordance with ASTM standards. Results indicated that hybrid reinforcement significantly enhances load-bearing capability and resistance to deformation. The composite containing Al 7075 + 3 wt. % B_4C + 15 wt. % ZrO_2 achieved the highest tensile strength of 192 MPa, compared to 137 MPa for the monolithic alloy, demonstrating a 40 % improvement. Similar trends were observed in compressive strength and hardness, attributed to particle-matrix interfacial strengthening, Orowan looping, dislocation pile-up at reinforcement boundaries, and microstructural refinement induced by ceramic additions. To identify the most influential processing parameters and optimize the mechanical response, the Taguchi L9 orthogonal array was employed. Signal-to-noise analysis confirmed that reinforcement ratio and stirring temperature were the dominant factors affecting property enhancement. The optimized parameter set yielded composites with superior mechanical performance and reduced variability. Overall, the findings establish that B_4C - ZrO_2 hybrid-reinforced Al 7075 composites fabricated via SCM are promising candidates for next-generation light-weight structural components demanding high strength, reliability, and thermal resilience.

Keywords: Aluminum metal matrix composites, Al 7075, Boron carbide, Zirconium dioxide, Stir casting method, Taguchi method, Tensile strength, Mechanical properties.

DOI: [10.21272/jnep.18\(2\).02017](https://doi.org/10.21272/jnep.18(2).02017)

PACS number(s): 78.67.Sc, 81.05.Ni

1. INTRODUCTION

Aluminum-based AMMCs have found applications in the automotive and aerospace sectors due to high mechanical properties, SiC, Al_2O_3 , and B_4C ceramic is included AMMCs to enhance aluminum matrix properties. [1]. The primary elements that comprise the material, the Augmentation used in the aluminum matrix affects the material's strength and durability [2]. The unique

properties of MMC, such as low friction, damping property, fatigue strength, electrical and thermal conductivity, wear resistance, appropriate expansion coefficient, etc., cannot be produced in any monolithic metal or alloy and are instead made possible by matrix combination, Augmentation, and controlling procedures [3, 4]. Augmentation is applied in the MMC to use the unique advantage and to suppress the limitations of each constituent [5]. Boron carbide, often known as B_4C , is a hard

* Correspondence e-mail: vijayaprakash353@gmail.com

† medikundu2025@gmail.com



reinforcing material that is ideal for many technical applications because of its exceptional mechanical, hardness, and corrosion [6]. New particle Augmentation groups, such ZrO_2 , ZrB_2 , etc., have been utilized recently with promising outcomes [7]. Zirconium addition strengthens materials, according to research [8]. Before casting and solidification process are mechanically evenly distributed throughout [9]. Matrix particles must be distributed uniformly for high stiffness with improved strength [10]. ZrO_2 and B_4C hybrid Augmentation is applied to Al 7075. The B_4C is kept constant at 3 % and ZrO_2 is varied in the material. It demonstrates that hybrid composition is stronger than Al 7075. Key contributions from the study to include in the introduction:

1. B_4C and ZrO_2 addition improved strength, hardness, impact, and wear properties of Al7075.
2. Taguchi optimization identified the most effective reinforcement levels.
3. At 15 % ZrO_2 , tensile strength, hardness, and impact increased, while wear rate dropped.
4. The hybrid composite is suitable for high-stress aerospace and locomotive uses.
5. Further studies should evaluate higher ZrO_2 , environmental effects, and fatigue life.

The work is structured as follows: Section 2 surveys aluminum MMC; Section 3 discusses methodology and materials; Section 4 presents the hybrid composition experiment results; and Section 5 concludes The novelty of this work lies in the development of a hybrid Al 7075 nanocomposite reinforced with Boron Carbide (B_4C) and Zirconium Dioxide (ZrO_2) nanoparticles, exploiting their synergistic strengthening effects. Unlike single-reinforcement systems, the proposed hybrid approach achieves improved structural uniformity, reduced porosity, and enhanced physical properties, offering a balanced performance improvement for advanced lightweight applications.

2. LITERATURE SURVEY

Aluminium is widely preferred in aircraft components and automobile manufacturing due to its low cost and favorable mechanical properties. Recent research focuses on enhancing these properties through hybrid metal matrix composites. Kuldeep et al. [11] reinforced Al7075 with 3 % boron nitride and 6 % zirconium dioxide using stir casting, achieving improved hardness, wear resistance, and tensile strength, while recommending alternative fabrication techniques for further enhancement. Zhang et al. [12] increased zirconium content in Al-Cu-Mg alloys using selective laser melting, reducing hot-cracking and improving strength; adding 2 wt.% Zr significantly decreased cracking during fabrication. Jamdani and Daei-Sorkhabi [13] used blended powder semisolid formation and high-energy ball milling to incorporate boron carbide into Al7075, analyzing compaction pressure and augmentation fraction. Although reinforcement dispersion improved with smaller particles, cracking and agglomeration reduced durability. Karpasand et al. [14] reinforced Al7075 with B_4C and TiB_2 using friction stir processing; hybrid reinforcement showed higher hardness and wear resistance than

mono compositions, though cracking and uneven dispersion were observed. Liu et al. [15] applied stir casting with varying B_4C content, reporting uniform distribution and enhanced mechanical properties. However, research gaps remain concerning strength-to-weight optimization, long-term durability, fatigue behavior, and performance under real environmental conditions, particularly for aerospace and automotive applications.

3. METHODS AND MATERIALS

This study produced and characterized aluminium metal matrix composites (AMMCs) using Stir Casting. Aluminium alloy Al7075 was melted, and boron carbide (B_4C) and zirconium dioxide (ZrO_2) were added as reinforcements. Continuous stirring promoted uniform particle dispersion, improving mechanical properties. Stir Casting is simple, cost-effective, and suitable for large-scale composite fabrication. The method aims to enhance strength, hardness, and wear resistance. Al7075-0 served as the matrix; Table 1 presents its composition, along with reinforcement densities respectively.

Table 1 – Al 7075 constitutes

Component	Wt.%
Zn	5.5
Mg	2.3
Cu	1.6
Cr	0.23
Fe	0.2
Mn	0.2
Ti	0.12
Si	0.1
Al	Remaining

Table 2 – Materials composition

Composition Code	Composition
Al	Al 7075
M1	Al 7075 + 3 % B_4C + 5 % ZrO_2
M2	Al 7075 + 3 % B_4C + 10 % ZrO_2
M3	Al 7075 + 3 % B_4C + 15 % ZrO_2

The Al7075 composition with hybrid augmentation is shown in Table 2. Stir casting was used to fabricate the hybrid composite using an electric furnace. Al7075 ingots were cut and melted at 760 °C, and C2Cl6 tablets were added for degassing. Wettability is critical for reinforcement dispersion; therefore, small alloy additions were used to reduce the contact angle. Magnesium (1.5-2%) and 1 % Coverall were added to improve wettability and reduce surface tension. The permanent mold and augmentations, each 250 mm long and 25 mm in diameter, were preheated to 450 °C for 20 minutes to remove moisture. Zirconia was coated on the stirrer blades, arranged antiparallel and twisted 45° to ensure proper melt flow. The stirrer was positioned with 30 % melt below and operated at 400 RPM while augmentation was added slowly, followed by 10 minutes stirring. The melt was heated to 800 °C, poured in the mould, and solidified completely for 12 hours.

4. EXPERIMENTAL RESULTS

The experimental results include tensile strength, hardness, impact, morphological, density, and porosity tests. Tensile and hardness tests show enhanced strength and deformation resistance, while impact testing highlights durability. Morphological analysis reveals uniform particle dispersion, and density and porosity tests confirm the composite’s structural integrity, impacting overall mechanical performance.

4.1 Tensile Strength

Aluminum metal matrix composites (AMMCs), particularly Al 7075, are widely used in transportation due to their strong mechanical properties. By adding ceramic particles like boron carbide (B₄C) and zirconium dioxide (ZrO₂) through the Stir Casting Method (SCM), these composites achieve significant strength improvements. The hybrid composite of Al 7075 + 3 % B₄C + 15% ZrO₂ reaches a tensile strength of 192 MPa, surpassing the standard Al 7075’s 137 MPa. The Taguchi method further refines processing, optimizing mechanical performance, making it ideal for demanding applications in locomotives and aircraft. Table 3 illustrates the mechanical properties of four Al 7075 samples with varying compositions of B₄C and ZrO₂

Table 3 – Tensile strength of various combinations of MMC

S.No	Material	TS (MPa)	CS (MPa)	Hardness	Application Suitability
S1	Al	137	Moderate	Moderate	Structural
S2	M1	155	Higher	Higher	Moderate performance
S3	M2	175	High	High	Structural and Aerospace
S4	M3	192	Very High	Very High	Locomotive & Aerospace

In Table 3, as the ZrO₂ content increases, tensile strength, compression strength, and hardness show significant improvement, enhancing suitability for demanding applications.

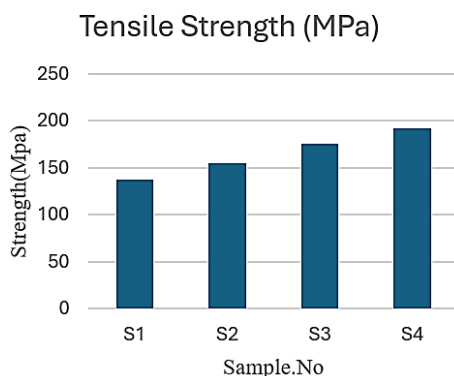


Fig. 5 – Various composites UTS

Figure 6 shows that increasing ZrO₂ content in Al 7075 composites significantly enhances tensile strength. Starting from 137 MPa in pure Al 7075, the strength rises to 155 MPa with 5 % ZrO₂, 175 MPa with 10 %

ZrO₂, and reaches 192 MPa with 15 % ZrO₂, highlighting its suitability for demanding applications.

4.2 Hardness Test

Brinell hardness of Al7075 composites increases with ZrO₂ addition. Pure Al7075 shows baseline BHN, which improves with 3 % B₄C. Hardness rises progressively with 5 % and 10 % ZrO₂, reaching maximum in the 15 % ZrO₂ composite. This enhanced hardness indicates superior deformation resistance, suitable for high-durability applications.

Table 4 – Hardness of various combinations of MMC

Material	Hardness (BHN)
Al	95
M1	105
M2	113
M3	120

Table 4. shows the progressive increase in BHN with ZrO₂ content, confirming enhanced hardness across the composites and these values are illustrated in below Figure 6.

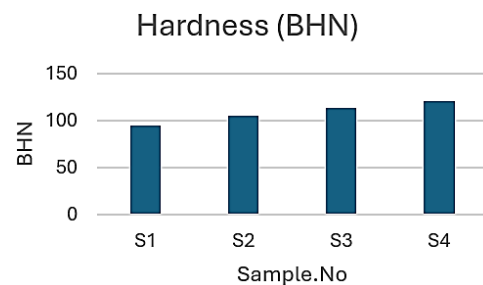


Fig. 6 – Hardness of MMC

Al7075 composite hardness rises with ZrO₂ addition: 95 BHN for base, 105 with 5 % ZrO₂, 113 with 10 %, and 120 with 15 %, showing enhanced deformation resistance, wear durability, and high-strength suitability.

4.3 Morphological Testing

Morphological analysis of Al7075 composites shows that increasing ZrO₂ content leads to uniform, dense dispersion of B₄C and ZrO₂ particles. This enhances particle–matrix bonding, reduces porosity, and improves load transfer, resulting in higher tensile strength, hardness, and stability under high-stress conditions due to a more refined microstructure.

Table 5 – Microstructural characteristic through SEM analysis

Material	Particle Distribution	Porosity	Microstructure
Al	Minimal particle distribution	Higher porosity	Coarse, low particle reinforcement
M1	Moderate, even distribution	Moderate	Finer, enhanced particle dispersion
M2	Dense, uniform distribution	Low	Improved particle integration
M3	Very dense, uniform distribution	Very low	Refined, highly reinforced structure

The table shows improved particle distribution, reduced porosity, and refined microstructure in Al7075 composites (C1–C3) with increasing ZrO₂ content, confirmed by morphological testing and SEM images shown in Figure 7.

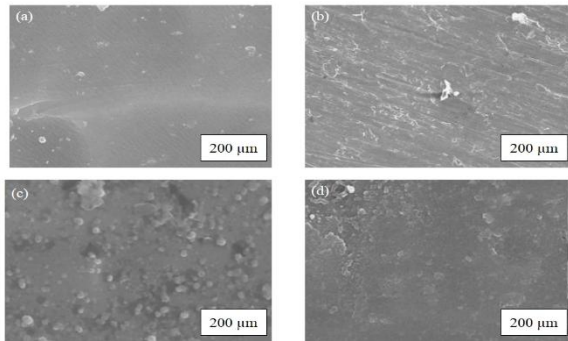


Fig. 7 – SEM image of (a) Al 7071, (b) Composite C1, (c) Composite C2, and (d) Composite C3

The SEM images provide visual confirmation of these findings, showing a progressively denser and more uniform dispersion of reinforcement particles within the matrix as ZrO₂ content rises. This refined microstructure, evident in Figure 7, contributes directly to the composite's improved mechanical properties, offering greater durability and stability under load.

4.4 Impact Test

Impact resistance of Al7075 composites improves with added ZrO₂ and 3 % B4C. Pure Al7075 shows baseline strength, while increasing ZrO₂ from 5 % to 15 % significantly enhances energy absorption, toughness, and durability. These hybrid composites are thus suitable for applications requiring resistance to sudden or heavy loads.

Table 6 – Impact Strength of various combinations of MMC

Material	Impact Strength (J)
Al	8
M1	11
M2	14
M3	17

This table indicates a progressive increase in impact strength, with the Al 7075 + 3 % B4C + 15 % ZrO₂ composite achieving the highest impact resistance at 17 J, showcasing its superior toughness.

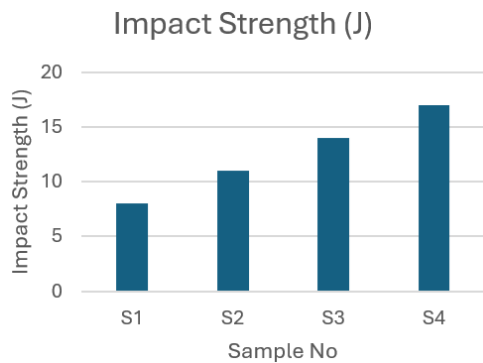


Fig. 8 – Various components impact strength

These results highlight the composite's suitability for applications requiring high resilience to impact forces. All values are illustrated in Figure 8, which visually confirms the trend of increasing impact strength as ZrO₂ content rises, emphasizing the material's enhanced durability and energy absorption capacity.

4.5 Density and Porosity

The density and porosity testing of Al 7075 composites with varying ZrO₂ content reveals notable trends in structural integrity. As ZrO₂ content increases, the density of the composites rises slightly due to the higher density of ZrO₂ particles compared to the aluminium matrix. Meanwhile, porosity decreases with increased ZrO₂ content, indicating better particle distribution and reduced voids within the material. This reduction in porosity enhances mechanical properties, as a denser, more compact structure improves both strength and durability, making the composite suitable for high-performance applications.

Table 8 – Density and porosity of MMC

Material	Density (g/cm ³)	Porosity (%)
Al	2.81	4.2
M1	2.85	3.6
M2	2.88	2.9
M3	2.91	2.4

This table (Table 8) demonstrates a gradual increase in density and a decrease in porosity as ZrO₂ content rises. The Al 7075 + 3 % B4C + 15 % ZrO₂ composite achieves the highest density and the lowest porosity, confirming its enhanced compactness and suitability for applications requiring robust structural integrity. These findings are illustrated in Figure 9, which visually represents the correlation between density, porosity, and ZrO₂ content in the composites.

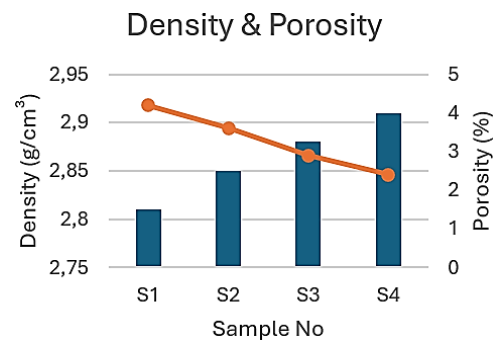


Fig. 9 – Density and porosity results for MMC

The density and porosity results for Al 7075 composites reveal significant trends with increasing ZrO₂ content. Pure Al 7075 has a density of 2.81 g/cm³ and a porosity of 4.2 %. With the addition of 3 % B4C and 5 % ZrO₂, the density increases to 2.85 g/cm³, and porosity decreases to 3.6 %. As the ZrO₂ content rises to 10 %, density further increases to 2.88 g/cm³ with porosity dropping to 2.9 %. Finally, the composite with 15 % ZrO₂ achieves the highest density of 2.91 g/cm³ and the lowest porosity at 2.4 %, highlighting improved structural integrity and compactness.

4.6 Material Characteristics

Adding B₄C and ZrO₂ significantly improves Al7075 composites. Tensile strength rises from 137 to 192 MPa, hardness from 95 to 120 BHN, and impact strength from 8 to 17 J. Density slightly increases to 2.91 g/cm³, while porosity drops to 2.4 %, yielding a stronger, more compact composite.

Table 9 – Material characteristics

Material	Tensile Strength (MPa)	Hardness (BHN)	Impact Strength (J)	Density (g/cm ³)	Porosity (%)
Al	137	95	8	2.81	4.2
M1	155	105	11	2.85	3.6
M2	175	113	14	2.88	2.9
M3	192	120	17	2.91	2.4

The table summarizes the key material characteristics of Al 7075 composites, showing significant improvements with the addition of B₄C and varying ZrO₂ content. Tensile strength rises from 137 MPa in pure Al 7075 to 192 MPa with 15 % ZrO₂, indicating enhanced mechanical performance. Hardness increases from 95 BHN to 120 BHN, and impact strength improves from 8 J to 17 J, showcasing greater toughness. Additionally, density reaches 2.91 g/cm³ while porosity decreases to 2.4 %, resulting in a more compact and robust structure suitable for demanding applications.

4.7 Wear Rate

The wear rate testing of Al 7075 composites demonstrates a reduction in material wear as the ZrO₂ content increases. The incorporation of B₄C and ZrO₂ significantly enhances the wear resistance of the composites, making them more suitable for applications where abrasion is a concern. As ZrO₂ content increases, the wear rate decreases, indicating improved performance and longevity of the materials are shown in below Table 10.

Table 10 – MMC wear rate

Material	Load (N)	Wear Rate (mm ³ /Nm)
Al	10	0.36
	20	0.42
	30	0.5
M1	10	0.28
	20	0.32
	30	0.39
M2	10	0.22
	20	0.27
	30	0.34
M3	10	0.18
	20	0.24
	30	0.3

This table presents the wear rate results for Al 7075 composites under three different load conditions. As the load increases, the wear rate generally increases for all samples, demonstrating that higher loads lead to

greater wear. Notably, the addition of B₄C and ZrO₂ significantly reduces the wear rate, with the composite containing 15 % ZrO₂ exhibiting the lowest wear rate of 0.18 mm³/Nm at a 10 N load, confirming its superior wear resistance compared to pure Al 7075.

5. DESIGN OF EXPERIMENTS

The Design of Experiments (DOE) is a systematic method for identifying how different factors influence process outcomes. By varying parameters and observing responses, DOE determines critical variables and interactions. Techniques like Taguchi help optimize processes and mechanical properties while reducing resources in engineering and materials applications.

5.1 Taguchi Method

The Taguchi Method is a statistical approach within DOE developed by Genichi Taguchi to reduce variability and enhance quality in process and product design. It uses orthogonal arrays to evaluate multiple parameters with fewer experiments. By employing signal-to-noise ratios, it identifies optimal settings that resist external variations. This method is widely used in engineering and materials science for improving reliability and performance while lowering cost. In this study, tensile strength, hardness, impact strength, and wear rate of Al7075 composites are optimized using an L9 orthogonal array with ZrO₂ content, load, and process temperature selected as key influencing factors.

Table 11 – Material properties through taguchi method

Experiment (Run)	ZrO ₂ Content (%)	Process Temp (°C)	Tensile Strength (MPa)	Hardness (BHN)
1	5	500	155	105
2	5	550	148	102
3	5	600	140	100
4	10	550	170	110
5	10	600	160	108
6	10	500	165	112
7	15	600	192	120
8	15	500	180	115
9	15	550	175	118

Table 12 – Material properties through taguchi method

Experiment (Run)	Load (N)	Process Temp (°C)	Impact Strength (J)	Wear Rate (mm ³ /Nm)
1	10	500	11	0.28
2	20	550	10	0.32
3	30	600	9	0.35
4	10	550	13	0.25
5	20	600	12	0.3
6	30	500	14	0.27
7	10	600	17	0.18
8	20	500	16	0.22
9	30	550	15	0.24

Table 11 and 12 shows an example setup for using the Taguchi Method in optimizing the properties of Al 7075 composites. Each row represents an experimental

run with unique parameter settings. After conducting the experiments, the results are analyzed using signal-to-noise (S/N) ratios to identify optimal conditions for maximum tensile strength, hardness, and impact strength while minimizing wear rate, ensuring a balance of enhanced mechanical properties.

5.2 Signal to Noise Ration

Signal-to-Noise (S/N) ratio response table for four samples of Al 7075 composites with different ZrO₂ content levels (Level 1, Level 2, and Level 3). This table includes the delta (difference between the highest and lowest S/N ratios for each property) and rank (indicating the influence of each factor on the response, where Rank 1 has the highest delta).

Table 13 – Response table for signal-to-noise ratio (Larger is better)

Mechanical Property	L1 (5% ZrO ₂)	L2 (10% ZrO ₂)	L3 (15% ZrO ₂)	Delta	Rank
Tensile Strength	43.38	44.34	45.21	1.83	2
Hardness	40.21	40.83	41.42	1.21	3
Impact Strength	20	22.28	24.08	4.08	1
Wear Rate	- 9.89	- 11.37	- 13.55	3.66	2

Table 13 ranks each property based on the delta value, which measures the effect of ZrO₂ levels on the S/N ratio for each property. Impact Strength ranks highest, with the largest delta (4.08), indicating it is the most sensitive to changes in ZrO₂ levels. Tensile Strength and Wear Rate follow, showing moderate sensitivity, while Hardness is least affected by ZrO₂ content changes, as indicated by the smallest delta (1.21).

5.3 Mean

Mean response table for the four samples of Al 7075 composites with varying ZrO₂ content levels (Level 1, Level 2, and Level 3). This table includes the delta (difference between the highest and lowest mean values for each property) and rank (indicating the influence of each factor on the response, where Rank 1 has the highest delta).

REFERENCES

- R. Harichandran, N. Selvakumar, *Archiv. Civ. Mech. Eng.* **16**, 147 (2016) <https://doi.org/10.1016/j.acme.2015.07.001>.
- V.K. Sharma, R.C. Singh, R. Chaudhary, *Eng. Sci. Technol. Int. J.* **20**, 1318 (2017) <https://doi.org/10.1016/j.jestech.2017.08.004>.
- S. Poria, P. Sahoo, G. Sutradhar, *Silicon* **8**, 591 (2016) <https://doi.org/10.1007/s12633-016-9437-5>.
- E. Omrani, A.D. Moghadam, P.L. Menezes, P.K. Rohatgi, *Int. J. Adv. Manuf. Technol.* **83**, 325 (2016) <https://doi.org/10.1007/s00170-015-7528-x>.
- K. Shirvanimoghaddam et al., *Compos. A Appl. Sci. Manuf.* **92**, 70 (2017) <https://doi.org/10.1016/j.compositesa.2016.10.032>.
- Ş. Karabulut, H. Karakoç, R. Çıtak, *Compos. B Eng.* **101**, 87 (2016) <https://doi.org/10.1016/j.compositesb.2016.07.006>.
- S.D. Kumar, M. Ravichandran, M. Meignanamoorthy, *Material. Today Proc.* **5**, 19844 (2018) <https://doi.org/10.1016/j.matpr.2018.06.348>.
- J. Long et al., *J. Manuf. Process.* **49**, 373 (2020) <https://doi.org/10.1016/j.jmapro.2019.12.004>.
- Devaganesh, P.D. Kumar, N. Venkatesh, R. Balaji, *J. Mater. Res. Technol.* **9**, 3759 (2020) <https://doi.org/10.1016/j.jmrt.2020.02.002>.

Table 14 – Response table for mean

Mechanical Property	L1 (5% ZrO ₂)	L2 (10% ZrO ₂)	L3 (15% ZrO ₂)	Delta	Rank
Tensile Strength (MPa)	147.7	165	182.3	34.6	1
Hardness (BHN)	102.3	110	117.7	15.4	3
Impact Strength (J)	10	13	16	6	4
Wear Rate (mm ³ /Nm)	0.32	0.27	0.21	0.11	2


Table 14 ranks each property based on the delta value, representing the effect of ZrO₂ levels on each property. Tensile Strength ranks highest with a delta of 34.6, indicating that it is the most sensitive to changes in ZrO₂ levels. Wear Rate is also significantly affected, ranking second. Hardness and Impact Strength follow, showing less sensitivity to changes in ZrO₂ levels.

6. CONCLUSION

The study demonstrates that incorporating B4C and varying amounts of ZrO₂ into Al 7075 composites significantly enhances mechanical properties, including tensile strength, hardness, impact strength, and wear resistance. As ZrO₂ content increases, we observe substantial improvements: tensile strength rises from 147.7 MPa in pure Al 7075 to 182.3 MPa in the composite with 15 % ZrO₂, hardness improves from 102.3 BHN to 117.7 BHN, impact strength increases from 10 J to 16 J, and wear rate reduces from 0.32 mm³/Nm to 0.21 mm³/Nm. This optimized performance indicates that the hybrid composite is suitable for high-stress applications like those in the locomotive and aerospace industries. Through the application of the Taguchi Method, an efficient experimental setup was achieved, identifying optimal parameter levels for each property and ranking their sensitivities. The results indicate that impact strength and wear resistance are most influenced by the ZrO₂ content, suggesting that future work could further explore ZrO₂ levels beyond 15 % to assess limits in durability and toughness. Further studies could also consider real-world environmental conditions, fatigue tests, and cost-benefit analyses for large-scale applications. These insights contribute to advancements in high-performance materials with tailored properties, promising broader applications in industries that demand materials with high strength, toughness, and wear resistance.

10. K.K. Singh, S. Singh, A.K. Shrivastava, *Mater. Today Proc.* **4**, 8960 (2017) <https://doi.org/10.1016/j.matpr.2017.07.248>.
11. B. Kuldeep, K.P. Ravikumar, S. Pradeep, K.R. Gopi, *Mater. Res. Exp.* **6**, 036509 (2018) <https://doi.org/10.1088/2053-1591/aaf36b>.
12. H. Zhang et al., *Scripta Mater.* **134**, 6 (2017) <https://doi.org/10.1016/j.scriptamat.2017.02.036>.
13. A. Javdani, A.H. Daei-Sorkhabi, *Trans. Nonferrous Met. Soc. China* **28**, 1298 (2018) [https://doi.org/10.1016/S1003-6326\(18\)64767-3](https://doi.org/10.1016/S1003-6326(18)64767-3).
14. F. Karpasand, A. Abbasi, M. Ardestani, *Surf. Coat. Technol.* **390**, 125680 (2020) <https://doi.org/10.1016/j.surfcoat.2020.125680>.
15. S. Liu, Y. Wang, T. Muthuramalingam, G. Anbuhezhiyan, *Composites Part B: Eng.* **176**, 107329 (2019) <https://doi.org/10.1016/j.compositesb.2019.107329>.

Покращення структурних та фізичних властивостей гібридних нанокompозитів Al 7075–карбід бору–діоксид цирконію

R. Vijaya Prakash¹, Prakash Babu Kanakavalli², Jogi Krishna³, DVSSSV Prasad⁴,
R.L. Krupakaran⁵, Nageswara Rao Medikundu⁶ 

¹ Department of Mechanical Engineering, Acharya Nagarjuna University, 52510, Andhra Pradesh, India

² Department of Mechanical Engineering, V.R. Siddhartha School of Engineering, Siddhartha Academy of Higher Education, Deemed to be University, 520007 Kanuru, A.P., India

³ Department of Mechanical Engineering, RISE Krishna Sai Prakasam Group of Institutions, 523272 Ongole, India

⁴ Department of Mechanical Engineering, Aditya University Surampalem, 533437 Andhra Pradesh, India

⁵ Department of Mechanical Engineering, Mohan Babu University, Sree Sainath Nagar, 517102 Tirupati, Andhra Pradesh, India

⁶ Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, 522302 Vaddeswaram, Andhra Pradesh, India

Алюмінієво-металоматричні композити (АММК) продовжують привертати значний дослідницький інтерес для високопродуктивних конструкцій локомотивів, аерокосмічної та оборонної промисловості завдяки своїй високій питомій міцності, жорсткості та трибологічним характеристикам. Метою цього дослідження є покращення механічної реакції Al 7075 шляхом гібридного додавання керамічних частинок. Карбід бору (В₄С), відомий своєю високою твердістю та модулем пружності, був введений у постійній ваговій частці, тоді як діоксид цирконію (ZrO₂), зміцнювальна кераміка з високою термічною стабільністю, був введений у різних вагових відсотках для оцінки його додаткового внеску в характеристики композиту. Гібридні композити були синтезовані методом лиття з перемішуванням (SCM), обраним за його здатність рівномірно розподіляти керамічне армування в розплавленій матриці шляхом контрольованого утворення вихрів. Параметри процесу, такі як температура перемішування, швидкість перемішування та час витримки, систематично регулювалися для мінімізації кластеризації частинок, міжфазної пористості та невідповідностей змочування. Механічна характеристика включала випробування на розтяг, випробування на стиск та оцінку твердості за Брінеллем відповідно до стандартів ASTM. Результати показали, що гібридне армування значно підвищує несучу здатність та стійкість до деформації. Композит, що містить Al 7075 + 3 мас.% В₄С + 15 мас. % ZrO₂, досяг найвищої міцності на розтяг 192 МПа порівняно зі 137 МПа для монолітного сплаву, що демонструє покращення на 40 %. Подібні тенденції спостерігалися в міцності на стиск та твердості, що пояснюється зміцненням на межі розділу частинок-матриця, утворенням петель Орована, накопиченням дислокацій на межах армування та мікроструктурним подрібненням, викликаним додаванням кераміки. Для визначення найбільш впливових параметрів обробки та оптимізації механічної реакції було використано ортогональний масив Taguchi L9. Аналіз сигнал/шум підтвердив, що коефіцієнт армування та температура перемішування були домінуючими факторами, що впливають на покращення властивостей. Оптимізований набір параметрів дозволив отримати композити з чудовими механічними характеристиками та зменшеною мінливістю. Загалом, отримані результати встановлюють, що гібридно-армовані композити Al 7075 В₄С-ZrO₂, виготовлені за допомогою SCM, є перспективними кандидатами на легкі конструкційні компоненти наступного покоління, що вимагають високої міцності, надійності та термостійкості.

Ключові слова: Алюмінієво-металоматричні композити, Al 7075, Карбід бору, Діоксид цирконію, Метод лиття з перемішуванням, Метод Тагучі, Міцність на розтяг, Механічні властивості.