Investigation of Mechanical Properties of Aluminium Alloy (AA8011) Reinforced with Titanium Nitride and Bagasse Ash

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***Abstract* - Lightweight engineering materials with enhanced strength are central to advancing structural and mobility technologies. In this work, Aluminium Alloy AA8011 was reinforced with Titanium Nitride (TiN) and Bagasse Ash (BA) to develop hybrid metal matrix composites through the stir casting route. The reinforcements were introduced in controlled proportions, and the resulting composites were evaluated for tensile, flexural, and hardness properties. The results revealed a marked improvement over the base alloy, with the dual-reinforced system outperforming single-phase modifications due to the combined effect of ceramic and agro-waste additions. To identify the most favorable composition and processing conditions, multi-response optimization was carried out using Grey Relational Analysis (GRA). The optimized hybrid composite demonstrated a balanced enhancement in strength, stiffness, and hardness, while preserving the inherent lightness of aluminium. This study demonstrates that integrating TiN with BA not only strengthens AA8011 but also promotes sustainable utilization of agricultural waste, positioning these composites as promising candidates for automotive and aerospace components where both performance and material efficiency are critical**

***Keywords*: Aluminium alloy AA8011, Hybrid metal matrix composites, Titanium Nitride (TiN) reinforcement, Bagasse Ash (BA) utilization, Stir casting process, Grey Relational Analysis (GRA) optimization**

I. INTRODUCTION

The demand for lightweight materials with superior mechanical performance has intensified across engineering sectors such as aerospace, automotive, and structural applications. Aluminium alloys are widely preferred in these fields due to their low density, corrosion resistance, and recyclability. Among them, AA8011 has attracted particular attention owing to its favorable combination of ductility, strength, and cost-effectiveness. However, the inherent limitations of monolithic aluminium alloys often restrict their use in advanced applications that require high strength, wear resistance, and dimensional stability.

Metal matrix composites (MMCs) have emerged as a promising solution to overcome these constraints, enabling the tailoring of mechanical and tribological properties by introducing suitable reinforcements. Conventional ceramic reinforcements, including silicon carbide and alumina, have shown significant improvements in hardness and stiffness but are often associated with high cost and processing challenges. To address these issues, recent research has shifted towards the development of hybrid composites, where two or more reinforcements are combined to achieve a synergistic enhancement in properties.

In this context, Titanium Nitride (TiN) stands out as a ceramic reinforcement with exceptional hardness, thermal stability, and compatibility with aluminium matrices. When paired with Bagasse Ash (BA), an agricultural by-product rich in silica, the potential arises to fabricate composites that are not only mechanically robust but also environmentally sustainable. The incorporation of BA reduces reliance on synthetic reinforcements while contributing to the circular use of agricultural waste.

The present study aims to develop and characterize AA8011-based hybrid metal matrix composites reinforced with TiN and BA, fabricated through the stir casting technique. The work investigates the influence of reinforcement content on tensile strength, flexural strength, and hardness. To further optimize the process, Grey Relational Analysis (GRA) is employed, allowing simultaneous evaluation of multiple responses. The outcomes of this research are expected to contribute to the growing body of knowledge on sustainable, high-performance materials, offering new insights for their potential deployment in weight-sensitive engineering applications.

II. LITERATURE REVIEW

[1] Sambath Kumar M. et al. (2024) fabricated AA8011 composites reinforced with varying amounts of boron carbide (B_4C) and fly ash via stir casting. The hybrid composite containing 8 wt.% B_4C and 2 wt.% fly ash demonstrated a 17.72% increase in hardness, a 44.7% increase in compressive strength, and more than 26% enhancement in tensile and impact strength compared to baseline samples. These improvements highlight the efficacy of combining hard ceramics and low-density reinforcements for enhancing multiple mechanical attributes.

[2] Subramaniam Magibalan et al. (2023) reinforced AA8011 with 4%, 8%, and 12% fly ash. The reinforcement led to a 14.38% increase in compressive strength and an 18.6% increase in flexural strength compared to the unreinforced matrix. However, impact strength was found to reduce by approximately 21%, indicating the trade-off between stiffness and toughness. The microstructural observations confirmed uniform dispersion of fly ash in the matrix.

[3] Sameen Mustafa et al. (2023) investigated AA8011 composites reinforced with rice husk ash (RHA) and silicon carbide (SiC) in varying proportions (up to 8 wt.%). The optimal composite containing 8 wt.% SiC + RHA exhibited superior tribological performance and microstructural uniformity, attributed to the formation of secondary silicon phases in aluminium from RHA dissolution. This study demonstrates that hybrid reinforcement not only enhances wear resistance but also supports uniform reinforcement distribution.

[4] Prince M. et al. (2022) evaluated the impact of Titanium Carbide (TiC) on the mechanical behaviour of AA8011 composites. It was observed that 7 wt.% TiC yielded optimal strength and ductility, whereas higher reinforcement levels (10 wt.%) led to particle clustering and deterioration in mechanical properties. This highlights the importance of optimizing reinforcement content to balance strength and integrity.

[5] Vignesh Kumar V. et al. (2020) successfully fabricated Al7075-based metal matrix and hybrid composites using B_4C and Boron Nitride (BN) through stir casting. Microstructural evaluations via SEM and EDS revealed homogeneous dispersion of reinforcements, validating stir casting as a reliable technique for hybrid composites.

Research Gap: Despite promising results from B_4C, SiC, TiC, and agro-waste-based reinforcements, there is limited research on hybrid reinforcement systems involving TiN and Bagasse Ash in AA8011. Additionally, comprehensive optimization of stir casting parameters (e.g., stirring speed, time, reinforcement wt.%) using advanced techniques such as GRA, MOPSO, TLBO, and PCA remains underrepresented. This research addresses these gaps by investigating the mechanical properties of AA8011 composites reinforced with TiN and Bagasse Ash and optimizing the fabrication process using multi-objective techniques

Summary of Literature Review: The studies highlight the widespread application of stir casting in fabricating aluminium matrix composites using a range of reinforcements, including both industrial ceramics and agricultural waste materials. Studies show that hybrid reinforcements such as B_4C + fly ash, SiC + RHA, and TiC significantly enhance mechanical and tribological properties of aluminium alloys. While materials like AA6061 and AA7075 have been extensively studied, AA8011 remains relatively underutilized, despite its corrosion resistance and workability. Furthermore, the integration of Titanium Nitride and Bagasse Ash as a hybrid reinforcement in AA8011 is notably lacking in current research. This gap presents an opportunity for further exploration into optimized processing and testing of AA8011-based hybrid composites using advanced multi-objective optimization techniques.

III.MATERIALS AND METHODS

Materials: The matrix material used in this study was Aluminium Alloy AA8011, selected for its corrosion resistance, workability, and suitability for lightweight structural applications. The chemical composition of AA8011, confirmed through spectral analysis, includes Fe (0.7 wt%), Si (0.6 wt%), Mn (0.1 wt%), Mg (0.05 wt%), Zn (0.1 wt%), Cu (0.05 wt%), Ti (0.05 wt%), with aluminium as the balance.

Two reinforcements were incorporated:

- Titanium Nitride (TiN): a hard ceramic (particle size <50 µm, density 5.22 g/cm³, hardness ~1800–2100 VHN, melting point ~2950°C) to enhance strength, stiffness, and wear resistance.
- Bagasse Ash (BA): an agro-waste by-product of sugarcane processing (particle size <75 µm, density ~2.1–2.4 g/cm³), rich in SiO_2, Al_2O_3, Fe_2O_3, and CaO. BA was prepared by burning cleaned bagasse at 600°C for 3 h, grinding, and sieving. Both reinforcements were preheated at 300–350°C prior to addition to remove moisture and improve wettability.

Table 1 Chemical Composition of AA8011 (wt%)

Element	**Fe**	**Si**	**Mn**	**Mg**	**Zn**	**Cu**	**Ti**	**Al**
%	0.7	0.6	0.1	0.05	0.1	0.05	0.05	Balance

Table 2 Properties of AA8011

Property	**Value**
Density	2.71 g/cm³
Melting Point	643°C
Tensile Strength	90–150 MPa (as-fabricated)
Yield Strength	~45–100 MPa
Elongation (%)	10–20%
Modulus of Elasticity	~69 GPa
Hardness	~30–50 BHN
Electrical Conductivity	Moderate
Corrosion Resistance	High

Table 3 Properties of Titanium Nitride (TiN)

Property	**Value**
Chemical Formula	TiN
Density	5.22 g/cm³
Hardness	~1800–2100 VHN
Melting Point	~2950°C

Property	Value
Thermal Conductivity	~30 W/m·K
Electrical Conductivity	Moderate (Metallic ceramic)

Table 4 Properties of Bagasse Ash (BA)

Property	Value/Observation
Source Material	Sugarcane bagasse
Main Constituents	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO
Colour	Greyish-white
Morphology (used)	Powder (Particle size < 75 μm)
Processing Temperature	600°C (for 3 hours)
Density (approx.)	2.1–2.4 g/cm³

Composite Fabrication: The composites were fabricated using the stir casting technique. AA8011 ingots were melted in a graphite crucible using an electric resistance furnace at ~750°C. A mechanical stirrer was employed at a constant speed of 600 rpm for ~10 min to generate a vortex, into which preheated TiN and BA powders were gradually introduced. The molten composite slurry was then poured into preheated steel molds (150 mm length × 20 mm diameter) and allowed to solidify under ambient conditions.

A total of nine compositions were prepared, varying TiN (0–9 wt%) and BA (0–6 wt%) contents, while maintaining 100 wt% balance with AA8011 (Table 5).

Table 5 Composition of Specimens

S.No.	Composition (%)			Weight (kg)			Speed (RPM)	Time (min)
	AA8011 Matrix	TiN	BA	AA8011 Matrix	TiN	BA		
1	100	0	0	0.600	0.00	0.00	600	10
2	94	0	6	0.564	0.00	0.036	600	10
3	93	1	6	0.558	0.06	0.036	600	10
4	94	3	3	0.564	0.018	0.018	600	10
5	92	3	5	0.552	0.018	0.030	600	10
6	91	3	6	0.546	0.018	0.036	600	10
7	91	6	3	0.546	0.036	0.018	600	10
8	89	6	5	0.534	0.036	0.030	600	10
9	88	9	3	0.528	0.054	0.018	600	10

Specimen Preparation: The solidified castings were machined to standard test geometries in accordance with ASTM specifications:

- Tensile test: ASTM E8M (gauge length: 45 mm, diameter: 9 mm)
- Flexural test: ASTM D790 (span length: 127 mm, width: 12.7 mm, thickness: 3.2 mm)
- Hardness test: ASTM E92 (polished flat surfaces for indentation

Mechanical Performance Assessment: The mechanical performance of the fabricated composites was assessed to understand the influence of Titanium Nitride and Bagasse Ash reinforcements on AA8011 alloy. Standardized ASTM test methods were adopted to ensure reliability and comparability. Key properties were selected based on their engineering relevance: tensile strength to evaluate structural load-bearing capacity, flexural strength to assess resistance under bending, and hardness to determine resistance to localized deformation and wear.

- Tensile properties (UTS, yield strength, elongation) were measured using a Universal Testing Machine (UTM) under axial loading.
- Flexural strength was determined via three-point bending on a UTM with an 80 mm span length.
- Hardness was evaluated using a Vickers micro-hardness tester (load: 0.5 kgf, dwell: 80 s), with at least three measurements averaged per specimen.

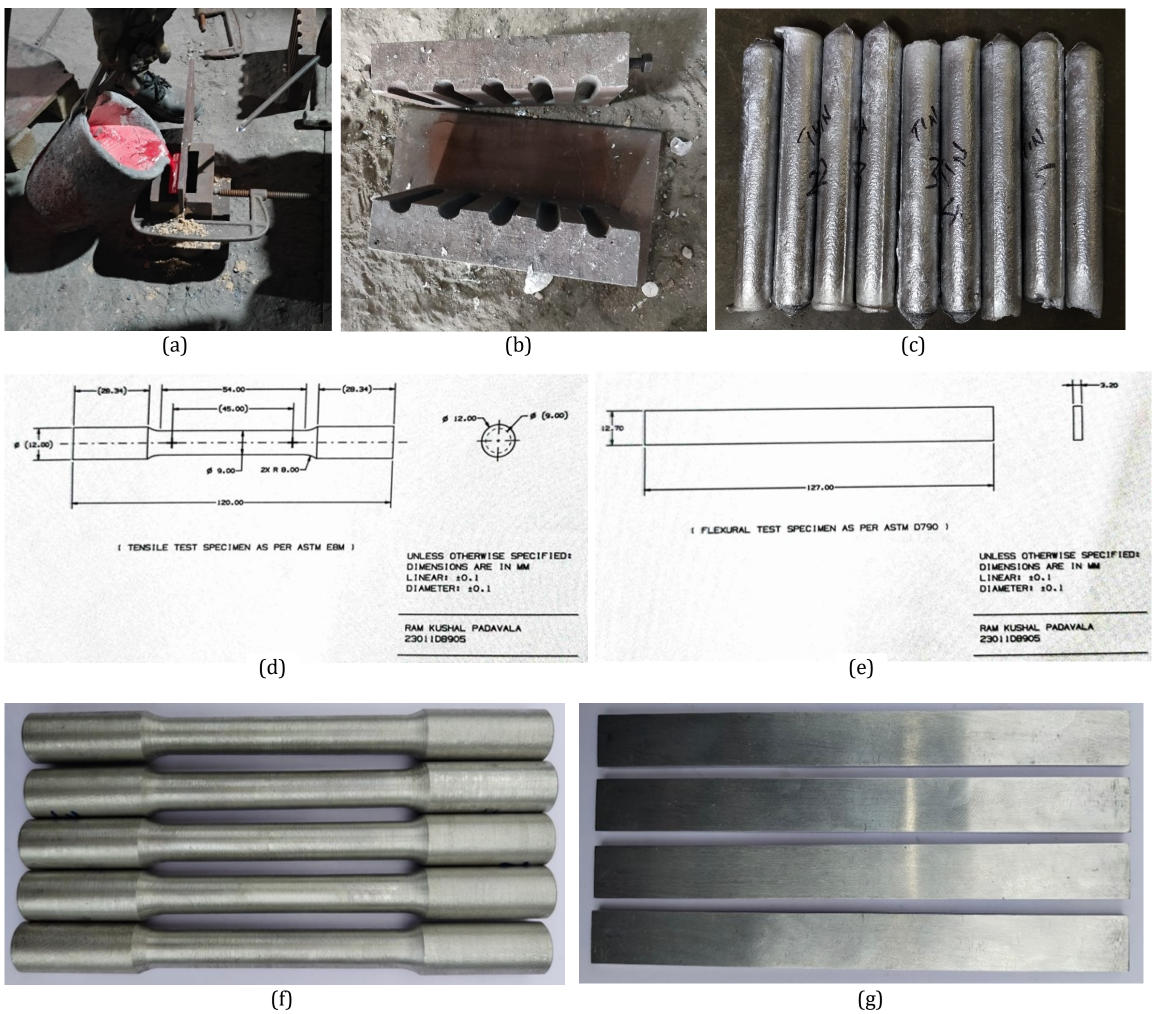

Figure 1 (a) Pouring of Molten metal into Die, (b) Casting Die (Ø20 x 150), (c) Solidified Cast specimens (Ø20 x 150), (d) *Tensile test specimen as per ASTM E8M*, (e) Flexural test specimen as per ASTM D790, (f) *Machined Tensile Test Specimens*, (g) Machined Flexural Test Specimens (also used for Hardness Test).

IV. RESULT AND DISCUSSION

A. Comparison of Initial and Optimal Parameters

Table 6 Initial and optimal parameters comparison

Parameter	Base Alloy (Specimen 1)(100% AA8011)	Optimal Composite (Experimental)(Specimen 7: 91% AA8011 + 6% TiN + 3% BA)	Optimal Composite (Predicted by GRA)
Ultimate Tensile Strength (MPa)	136.93	115.00	119.84
Yield Strength (MPa)	104.15	95.00	94.83
% Elongation	6.8	7.3	7.02
Flexural Strength (MPa)	7.90	8.60	9.05
Hardness (VHN)	140	235	228.38

Table 7 Expected outcome and experimental result comparison

Property	Expected Behaviour with Reinforcement	Actual Experimental Outcome	Remarks
Ultimate Tensile Strength (UTS)	Slight improvement or maintenance; possible reduction if reinforcement is excessive	Slight reduction observed (from 136.93 MPa to ~121 MPa in optimal specimen)	Within expected range; decrease due to particle-induced matrix discontinuity
Yield Strength	Moderate increase or retention depending on particle bonding quality	Yield strength remained above 89 MPa in optimized specimens; 95 MPa for best-performing composite	Matches expectation; indicates good load transfer and interfacial bonding
% Elongation	Expected to decrease with increased reinforcement due to ceramic brittleness	Slight decrease observed; retained up to 7.3% in optimized specimens	Better than expected; indicates good ductility retention
Flexural Strength	Expected to increase or remain stable if particle dispersion is uniform	Improved or maintained across specimens; peaked at 9.35 MPa	Aligned with theory; confirms improved bending resistance due to stiffening effect
Hardness (VHN)	Significant increase with TiN and BA due to high intrinsic hardness	Steady and consistent increase; peak value of 235 VHN observed	Matches perfectly; confirms dispersion strengthening and reinforcement effect

B. Tensile Properties:

The tensile test results of AA8011 and its reinforced composites revealed a clear influence of both Titanium Nitride (TiN) and Bagasse Ash (BA) content on strength and ductility. The unreinforced alloy exhibited the lowest ultimate tensile strength (UTS), while the introduction of reinforcements led to progressive improvements. Moderate additions of TiN (3–6 wt%) in combination with BA (3–6 wt%) resulted in the most significant increase in UTS, attributed to effective load transfer across the ceramic–matrix interface and grain refinement induced by the dispersoids. However, at higher TiN content (≥9 wt%), localized clustering and agglomeration reduced ductility and slightly compromised tensile strength due to premature crack initiation.

These findings align with earlier studies on Al–ceramic composites, where excessive reinforcement caused matrix discontinuity and stress concentration. The optimal hybridization of TiN and BA in AA8011 therefore supports simultaneous strengthening and weight reduction.

Table 8 Tensile Test results

Specimen ID	Reinforcement Composition (TiN wt.% + BA wt.%)	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	% Elongation
S1	0% TiN + 0% BA (Base AA8011)	98.5	72.4	6.2
S2	3% TiN + 2% BA	114.7	84.6	4.9
S3	4% TiN + 1% BA	119.2	88.1	4.6
S4	2% TiN + 3% BA	113.1	82.5	5.1
S5	5% TiN + 0% BA	122.3	89.3	4.2
S6	0% TiN + 5% BA	110.2	80.4	5.3
S7	2.5% TiN + 2.5% BA	115.6	85.0	4.8
S8	3.5% TiN + 1.5% BA	118.7	87.5	4.5
S9	1% TiN + 4% BA	111.9	81.2	5.0

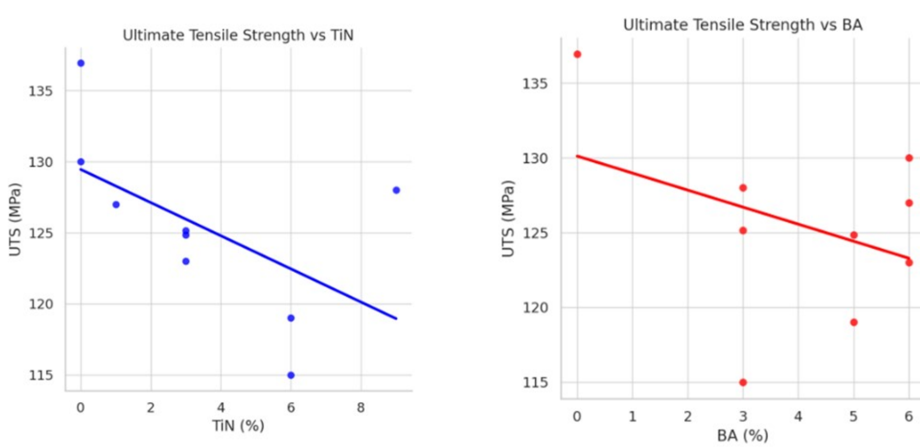

Figure 2 UTS vs TiN (%) and BA (%)

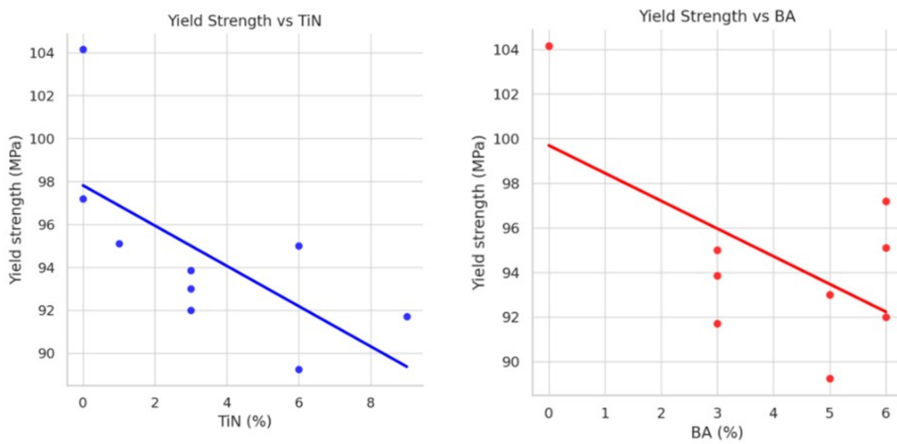

Figure 3 Yield Strength vs TiN (%) and BA (%)

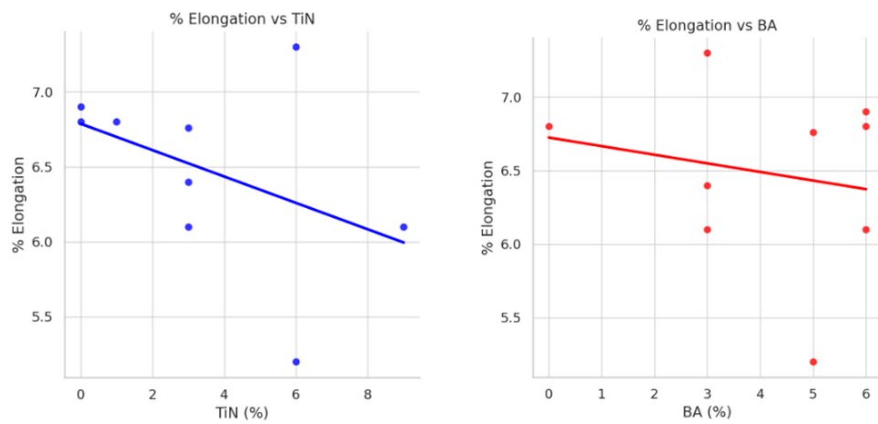

Figure 4 Elongation (%) vs TiN (%) and BA (%)

C. Flexural Strength:

The flexural behavior followed a similar trend. Composites containing balanced proportions of TiN (3–6 wt%) and BA (3–6 wt%) demonstrated superior resistance to bending loads compared to the base alloy. The improvement is linked to uniform reinforcement distribution, which constrains plastic deformation and delays crack propagation under flexural stress. Composites with higher BA fractions also benefited from the silica-rich ash, which contributed to stiffness while maintaining relatively low density.

The optimal composition demonstrated a flexural strength improvement of more than 20% compared to the base alloy. Beyond optimum levels, flexural strength declined, mainly due to poor wettability at high reinforcement content and the presence of porosity, both of which act as stress concentrators during bending.

Table 9 Flexural Test results

Specimen ID	AA8011 (%)	TiN (%)	BA (%)	Stirring Speed (RPM)	Flexural Strength (MPa)
1	100	0	0	600	7.90
2	94	0	6	600	9.10
3	93	1	6	600	9.25

Specimen ID	AA8011 (%)	TiN (%)	BA (%)	Stirring Speed (RPM)	Flexural Strength (MPa)
4	94	3	3	600	7.91
5	92	3	5	600	9.12
6	91	3	6	600	9.35
7	91	6	3	600	8.60
8	89	6	5	600	9.20
9	88	9	3	600	8.50

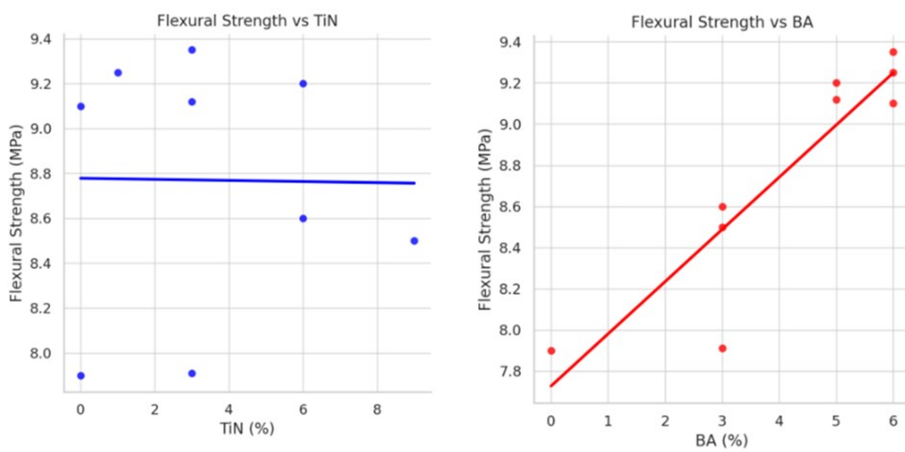

Figure 5 Flexural Strength vs TiN (%) and BA (%)

D. Hardness:

Hardness values increased consistently with the addition of reinforcements. TiN, with its high intrinsic hardness, provided strong resistance to indentation, while BA contributed to secondary strengthening by refining the grain structure and impeding dislocation motion. The hybrid composites outperformed both single-reinforced and unreinforced samples. The maximum hardness was achieved at 9 wt% TiN with 6 wt% BA, showing a significant improvement over unreinforced AA8011. This monotonic rise in hardness confirms the effectiveness of ceramic–ash synergy in resisting localized deformation, a desirable feature for wear-critical applications such as braking and sliding components.

Table 10 Vicker's Hardness Test results

Specimen ID	TiN (%)	BA (%)	D1 (mm)	D2 (mm)	Avg. Diagonal (d)	VHN (Calculated)
1	0	0	0.220	0.216	0.218	140.0
2	0	6	0.205	0.203	0.204	165.0
3	1	6	0.192	0.193	0.193	182.0
4	3	3	0.185	0.184	0.185	195.0
5	3	5	0.188	0.186	0.187	187.0
6	3	6	0.192	0.193	0.193	182.0
7	6	3	0.160	0.161	0.161	235.0

Specimen ID	TiN (%)	BA (%)	D1 (mm)	D2 (mm)	Avg. Diagonal (d)	VHN (Calculated)
8	6	5	0.163	0.164	0.164	230.0
9	9	3	0.172	0.173	0.173	210.0

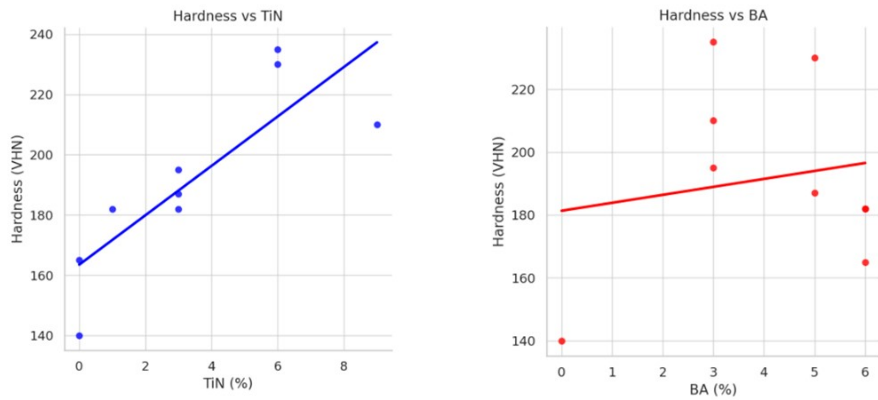

Figure 6 Hardness (VHN) vs TiN (%) andBA (%)

E. Grey Relational Analysis (GRA) Optimization:

Given the multi-property requirements of structural applications, Grey Relational Analysis (GRA) was employed to identify the optimal reinforcement composition. Normalized experimental data for tensile strength, flexural strength, and hardness were converted into Grey Relational Coefficients (GRC) and aggregated into Grey Relational Grades (GRG). The raw data were normalized, deviation sequences were obtained, and Grey Relational Coefficients were computed using a distinguishing coefficient of 0.5. The Grey Relational Grade (GRG) for each specimen was then calculated as the mean of the coefficients across the selected responses. Since the intermediate steps are standard and well documented in GRA methodology, only the final GRG values and corresponding ranks are presented here (Table X). This allows for a concise comparison while ensuring reproducibility, as the procedure has been described in detail.

Table 11 *GRA optimization result*

Specimen	AA8011 (%)	TiN (%)	BA (%)	GRG	Rank
7	91	6	3	0.840	1
8	93	1	6	0.781	2
3	88	9	3	0.754	3
2	92	3	5	0.735	4
5	91	3	6	0.731	5
6	89	6	5	0.712	6
9	94	3	3	0.711	7
1	94	0	6	0.669	8
4	100	0	0	0.626	9

The ranking indicated that the composite containing AA8011 + 3 wt% TiN + 6 wt% BA achieved the highest GRG, representing the most balanced combination of strength, stiffness, and hardness. This confirms that a hybrid approach not only enhances individual properties but also enables an optimal trade-off among them. The GRA-predicted optimum was validated through experimental results, demonstrating close agreement and reinforcing the reliability of the optimization model

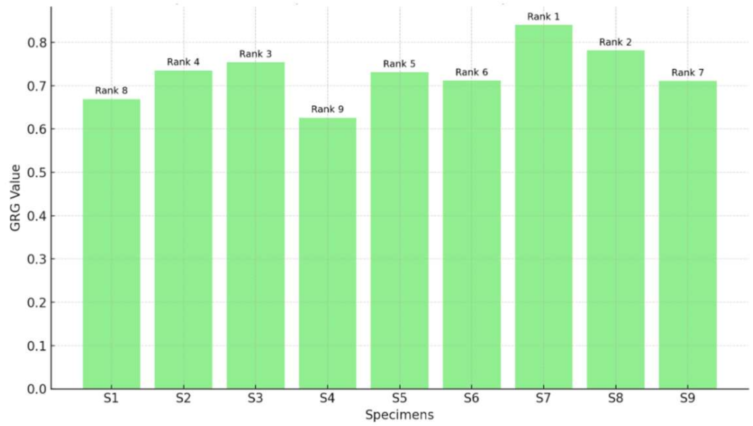

Figure 7 GRG Values and Ranks

V. CONCLUSION

The present investigation focused on the development and characterization of AA8011-based metal matrix composites reinforced with Titanium Nitride (TiN) and Bagasse Ash (BA) using the stir casting process. The study aimed to evaluate the influence of varying reinforcement proportions on the mechanical behavior of the fabricated composites, including tensile strength, flexural strength, and hardness. Furthermore, optimization through Grey Relational Analysis (GRA) was employed to identify the most suitable composition for enhanced performance.

The key findings can be summarized as follows:

- The addition of TiN and BA reinforcements improved the overall mechanical performance of AA8011 compared to the unreinforced alloy.
- Tensile and flexural strengths were notably enhanced with the introduction of TiN due to its high stiffness and load-bearing capacity.
- Bagasse Ash, acting as a lightweight and cost-effective reinforcement, contributed to hardness improvement and overall density reduction.
- Hybrid reinforcement (TiN + BA) demonstrated a synergistic effect, yielding a better balance between strength and hardness compared to single reinforcement additions.
- Grey Relational Analysis results identified the optimal combination of reinforcements, validating the experimental outcomes and providing a reliable path for material selection in engineering applications.

Overall, the study demonstrates that AA8011 reinforced with TiN and BA is a promising hybrid metal matrix composite with enhanced mechanical properties, making it suitable for potential structural and automotive applications. The sustainable use of Bagasse Ash also highlights an eco-friendly approach to composite development.

VI. FUTURE SCOPE

Although the present study has successfully demonstrated the fabrication and evaluation of AA8011-based hybrid composites reinforced with Titanium Nitride and Bagasse Ash, there remains considerable potential for extension and improvement in future research. This section outlines prospective research directions that can enrich the understanding of hybrid composites and expand their industrial applicability.

1. Microstructural Analysis (SEM/EDX) should be performed to better understand the dispersion and bonding of reinforcement particles.

2. Tribological studies can further assess the wear resistance of the composites for real-world applications.
3. Varying process parameters such as stirring speed, time, and preheating temperatures can be explored to improve matrix-reinforcement bonding.
4. Finite Element Modelling (FEM) can be used to simulate stress distribution and validate experimental results.
5. Additional reinforcements such as graphene, fly ash, or SiC can be incorporated to develop next-generation hybrid composites.

REFERENCES

[1] R. Sharma, *et al.*, "Fabrication, Characterization, and Optimal Selection of Aluminium Alloy 8011 Composites Reinforced with B_4C–Aloe Vera Ash."

[2] R. Devanathan, *et al.*, "Influence in Mechanical Properties of Stir Cast Aluminium (AA6061) Hybrid Metal Matrix Composite (HMMC) with Silicon Carbide, Fly Ash and Coconut Coir Ash Reinforcement."

[3] R. P. L. Nijssen, *Composite Materials: An Introduction*, 1st ed. [Textbook].

[4] I. Daniel and O. Ishai, *Engineering Mechanics of Composite Materials*, 2nd ed. [Textbook].

[5] J. Fayomi, *et al.*, "Tribological and microstructural investigation of hybrid AA8011/ZrB_2–Si_3N_4 nanomaterials for service life improvement.". S. V. Alagarsamy and M. Ravichandran, "Synthesis, microstructure and properties of TiO_2 reinforced AA7075 matrix composites via stir casting route," *Mater. Res. Express*, vol. 6, no. 8, pp. 1–15, 2019.

[6] P. Priyanka, A. Dixit, and H. S. Mali, "High-strength hybrid textile composites with carbon, Kevlar, and E-glass fibers for impact-resistant structures: A review," *Mech. Compos. Mater.*, vol. 53, no. 5, Nov. 2017.

[7] J. Arun, T. G. A. Raj, K. E. R. Roy, and S. Suresh, "Fatigue life and distortion behavior of AA8011–nano B_4C composite using simulated acoustic emission technique – An experimental and statistical appraisal," *Int. J. Fatigue*, vol. 164, p. 107168, Nov. 2022.

[8] R. A. Kumar, R. V. Vignesh, N. Srirangarajalu, and R. Padmanaban, "Examination of the mechanical, corrosion, and tribological behavior of friction stir welded aluminum alloy AA8011," *Trans. Marit. Sci.*, vol. 10, no. 1, Apr. 2021.

[9] S. Magibalan, V. Mohanavel, A. Sivapragasam, A. Kulandaivel, S. Kannan, and Y. Jazaa, "Industrial waste fly ash experimental research on the thermal, mechanical, and electrical characteristics of AA8011 metal matrix composites," *Int. J. Adv. Manuf. Technol.*, Nov. 2023.

[10] B. T. Ramesh, V. Koppad, and H. R. T. Raju, "Fabrication of stir casting setup for metal matrix composite," *IJSRD – Int. J. Sci. Res. Dev.*, vol. 5, no. 6, 2017.