

AI Enhanced Design and Synthesis of Al7075/TiC/Gr Hybrid Composites: Predicting Mechanical Performance

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Abstract:

Modern aerospace structures require the development of lightweight materials with exceptional mechanical performance. In this work, two-step stir casting was used to create hybrid aluminum metal matrix composites based on Al7075 reinforced with titanium carbide (TiC) and graphite (Gr). To examine their impact on the mechanical behaviour of the composites, the reinforcing content was changed between 0 to 5 wt. % TiC and 0 to 5 wt. % Gr. To assess the impact of hybrid reinforcement on microstructural evolution and mechanical properties, optical microscopy, Vickers micro hardness testing, and tensile testing were used to characterize the produced samples. The results showed that while graphite functioned as a solid lubricant improving interfacial behaviour and lowering frictional stresses, the addition of TiC greatly increased hardness and strength due to grain refinement and load-bearing effects. With a maximum hardness of 88 HV and increased tensile strength above the unreinforced alloy, the Al7075/3TiC/3Gr wt. % hybrid composite demonstrated the greatest overall performance among the compositions under investigation. Response surface methodology (RSM), analysis of variance (ANOVA), and machine learning models were used for predictive modelling and optimization in order to better comprehend the connection between processing parameters and mechanical responses. High prediction accuracy ($R^2 > 0.94$) between experimental and anticipated results was shown by the generated models. The improved composite's homogeneous dispersion of reinforcing particles and notable grain refinement were verified by microstructural investigation. The results show that an efficient method for creating highperformance Al7075 composites appropriate for lightweight aerospace applications is to combine hybrid reinforcement with AI based predictive modelling.

Keywords: Al7075, AI tools, Optimization, RSM, Mechanical properties.

Introduction

Aluminum alloys are preferred in the aircraft industry due to their remarkable strength to weight ratio and low weight. In particular, because of its excellent ductility and extremely high tensile and yield strength, AA7075 is frequently utilized in airframes and structural components [1-2]. Al7075, however, has significant shortcomings. Its low elongation and poor wear resistance result in significant friction and poor tribological performance. Al7075 is frequently reinforced to create metal matrix composites (MMCs) in order to address these problems. Hard ceramic particles, like TiC, increase stiffness and hardness in MMCs, while soft solid lubricants, such graphite, improve wear behavior and friction [4].

A self-lubricating hybrid composite is produced by incorporating graphite into an Al matrix. While hard TiC particles transport load and refine the microstructure, graphite creates a thin protective layer on sliding surfaces to lessen shear stress. According to earlier research, Al7075/TiC/graphite hybrids have far higher wear resistance and hardness than unreinforced

alloys. The microstructure is significantly impacted by these processing parameters. Particle dispersion, interfacial bonding, and porosity are controlled by temperature, time, and stirring speed. Tensile strength and hardness were greatly impacted by the different stir casting temperature, speed, and duration in an Al7075–TiO₂ system; RSM/ANOVA models confirmed each factor's effect with 95% confidence (model variance <5%) [5-7]. Similarly, to encourage the wetting of TiC/graphite particles, Mg additions and preheat conditions must be controlled. Data-driven techniques are being used more and more to forecast and optimize MMC qualities in addition to traditional optimization. ANOVA and response surface methodology (RSM) can accurately model the effects of composition and process variables on performance. For instance, >95% predictive confidence has been attained using RSM-based models for Al7075 reinforcing composites. Neural networks, regression trees, and Gaussian processes are examples of machine learning (ML) models that have demonstrated exceptional predictive capacity in more recent times. Using gradient-boosted trees and Gaussian process regression, Al7075 carbon composite was able to predict wear and friction with $R^2 > 0.96$ – 0.99 [8–10]. These machine learning techniques "no longer rely on costly trial-and-error" in the Industry 4.0 era; instead, they develop vast materials informatics to direct the creation of novel composites. These developments imply that integrating AI with MMC studies could significantly lower the number of trials required and effectively identify ideal formulations [11–13].

In an AI-driven design context, hybrid Al7075/TiC/graphite composites are still understudied despite advancements in single-reinforcement MMCs. Few studies treat TiC and graphite combined in an aerospace-grade alloy, and the majority of earlier research has focused on either carbon or TiC reinforcements independently. There are "rarely found" studies on Al7075/TiC/graphite hybrids in the literature. Additionally, no papers have yet fully integrated machine learning optimization for such hybrid composites with performance criteria relevant to aviation [14–17].

In this study, these gaps filled by methodically creating and modelling Al7075/TiC/graphite hybrid MMCs. Two stage stir casting is used to reinforce Al7075 billets with different TiC and graphite concentrations, which are subsequently cast, heat-treated, and machined into test specimens. For every composition, measurements are made of hardness, tensile strength, elastic modulus, and elongation. The input variables (TiC%, Gr%, and stirring conditions) are related to the composite responses using RSM (with ANOVA) and machine-learning models (ANN/regression).

Al7075's hardness, strength, stiffness, and ductility are all impacted by the TiC and graphite fractions. To forecast mechanical properties, create RSM and ANN/regression models. Then, compare these data-driven models to experiments to confirm that they achieve high accuracy ($R^2 \sim 0.95$ – 0.99). Optimize design: By utilizing Al7075's inherent high strength-to-weight ratio, use the predictive models to determine the best parameter combinations (composition and stirring conditions) that maximize strength and stiffness for lightweight aerospace applications. This research attempts to create a new class of Al7075-based composites with an outstanding balance of high strength, stiffness, and wear resistance by fusing hybrid reinforcement with AI based optimization, thereby enhancing lightweight material technologies for aerospace use.

Materials and Methods:

High-purity titanium carbide (TiC) and graphite (Gr) powders were utilized as reinforcing particles, and a commercial Al7075 aluminum alloy served as the matrix material. In an electric furnace, the Al7075 alloy was melted in a graphite crucible at about 750 °C. Table 1 shows the

specific compositions of the hybrid composites that were created by altering the reinforcing values from 0 to 5 weight percent TiC and 0 to 5 weight percent graphite. The two-step stir casting technique, which is well known for being an economical and scalable way to create aluminum metal matrix composites, was used to create the composites.

Al7075 ingots were first heated to a completely molten condition throughout this operation. To remove moisture and increase wettability with the molten aluminum, the reinforcement powders were heated to between 200 and 250 °C. To guarantee even dispersion of the reinforcing particles, the preheated TiC and graphite powders were progressively added to the melt vortex while mechanical stirring was kept at about 550 rpm. To improve the interfacial connection between the matrix and reinforcement particles, a tiny quantity of magnesium was added as a wetting agent.

A Box–Behnken response surface methodology (RSM) design was used to systematically vary the stirring temperature, speed, and time in order to examine the impact of processing variables. The temperature range of 700–800 °C, the stirring speed range of 400–600 rpm, and the stirring duration range of 15–30 minutes were chosen as the process parameters. The molten composite slurry was put into preheated molds and allowed to harden under ambient cooling conditions after the reinforcement particles had been sufficiently stirred and homogenized. After being taken out of the molds, the castings were machined into specimens that could be used for mechanical and microstructural analysis.

Standard metallographic techniques, such as sectioning, mounting, grinding, polishing, and chemical etching, were used to prepare the metallographic samples. An optical microscope was used to analyse the microstructures of the manufactured composites; typical micrographs are shown in Figure 2. These microstructural measurements verified that the reinforcing particles were uniformly distributed throughout the matrix.

Vickers microhardness testing and uniaxial tensile testing were used for mechanical characterisation. A load of 0.5 kgf was used to quantify microhardness, and a universal testing equipment with strain gauge extensometers was used to perform tensile tests at room temperature. Tensile specimens were machined in accordance with ASTM standard dimensions, and the stress-strain curves were used to calculate mechanical parameters such as yield strength, ultimate tensile strength, and percentage elongation. The initial linear slope of the stress-strain curve was used to determine the composites' elastic modulus. To guarantee experimental repeatability and dependability, many specimens were examined for every composition and processing condition. Table 2 provides a summary of the specific stir-casting process parameters used in this investigation.



Fig. 1. Al7075/TiC/Gr Composite preparation for tensile testing
 Table 1: Composition details of Al7075/TiC/Gr hybrid composite samples

Additionally, the hybrid combination of graphite and TiC results in a more homogeneous microstructure with decreased porosity, indicating improved particle dispersion during solidification. It has been demonstrated that graphite particles act as a soft lubricating phase along grain boundaries and interdendritic regions, reducing interfacial tensions and enhancing particle matrix compatibility. Even though increasing the graphite concentration up to 5 weight percent improves lubricating characteristics, too much graphite can result in micro voids and small particle clustering since it is relatively poorly wettable with molten aluminium.

S.No.	Matrix (Al7075)	TiC Composition (wt.%)	Gr Composition (wt.%)
1	Al7075	0	0
2	Al7075	3	3
3	Al7075	5	5
4	Al7075	0	3
5	Al7075	3	5
6	Al7075	5	3
7	Al7075	0	5
8	Al7075	3	0
9	Al7075	5	0

The 3 weight percent TiC + 3 weight percent graphite hybrid composite showed the most consistent microstructure among the compositions under study, with polished grains, few flaws, and good particle distribution. Improved mechanical qualities like higher hardness and elastic modulus are directly influenced by this finer microstructure. Overall, the microstructural observations verify that the Al7075 hybrid composites' mechanical performance and structural integrity are improved by the synergistic coupling of TiC and graphite reinforcements.

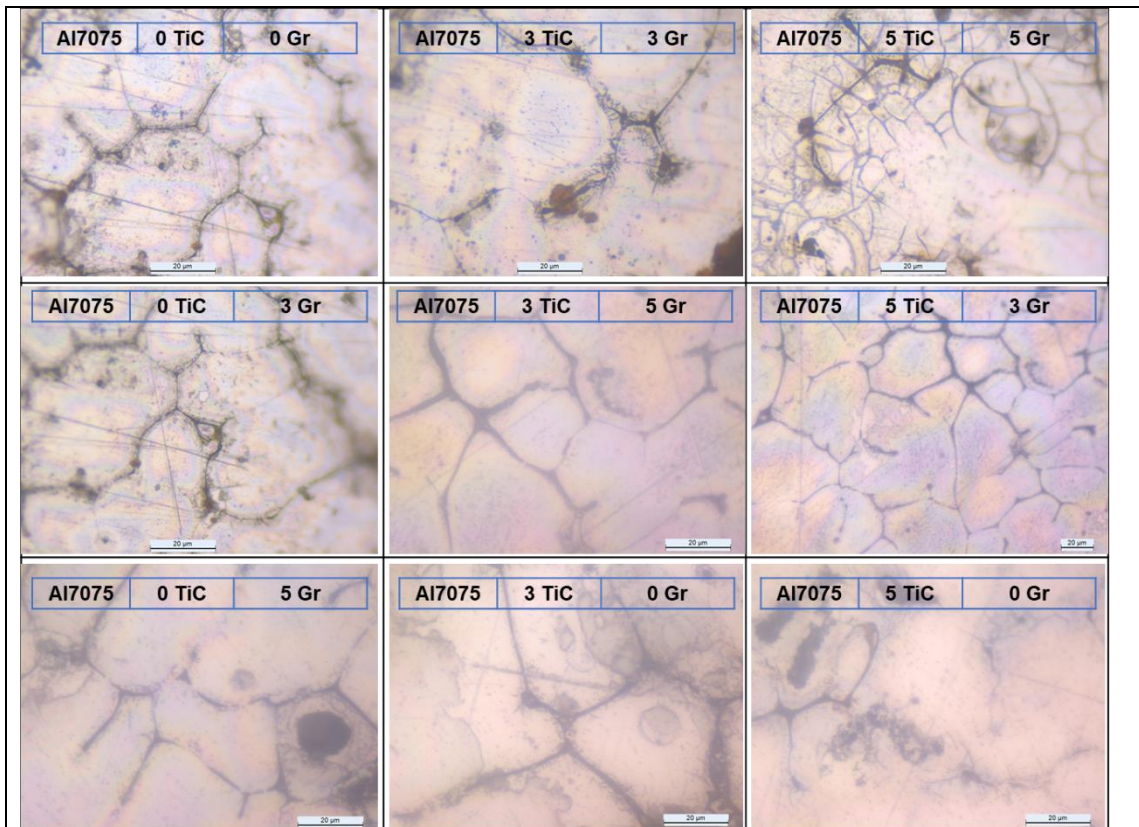


Fig.2. Microstructural images of Al7075/TiC/Gr Composites.

Table 2: Process parameters used for fabrication of Al7075/TiC/Gr hybrid composites

Parameter	Value
Stirring Speed	550 rpm
Melting Temperature	790 °C
Time for Melting	20–25 minutes
Time for Cooling	Normal
Preheating Temperature – Die	500 °C
Preheating Temperature – Reinforcements	200 °C
Preheating Duration – Reinforcements	30 minutes
Type of Cooling	Air Cooling
Weight of Aluminium Matrix Used	1000 grams
Weight of TiC & Gr (for 1 wt%)	10 grams
Dimensions of Casting Specimen	150 mm (Length) × 20 mm (Diameter)

Results and Discussion

Microstructure:

Optical micrographs showed that the TiC and graphite particles were uniformly and finely dispersed throughout the Al7075 matrix in all composites. The uniform grain morphologies and lack of large agglomerates indicate that the RSM adjusted stirring parameters (high temperature and vigorous swirling) decreased particle clustering. Microstructures demonstrated good adhesion and no obvious interfacial fissures. The consistent dispersion is consistent with previous research showing that well-mixed reinforcements enhance load

transfer and strengthen the composite. Graphite tends to align close to grain boundaries, forming continuous pathways for solid lubrication.

Hardness: Compared to unreinforced Al7075, all TiC/Gr composites showed increased hardness (Table.3). Hardness increases with TiC content, peaking at 88 HV in the sample containing TiC3/Gr3 wt. %. By filling pores and preventing matrix slip, the graphite probably also aided in hardening. This pattern is consistent with [3], which discovered that TiC/Gr reinforcements significantly increase toughness. For instance, it has been observed that TiC/Gr hybrid composites considerably "build hardness and rigidity" above basic metal. The intrinsic hardness of TiC and the refined Al grain size caused by scattered particles are the sources of the high hardness. According to the RSM model's ANOVA, graphite had a minor but favourable impact on hardness, while TiC percentage was the main factor ($p < 0.01$). Hardness was predicted by the RSM regression with $R^2 \approx 0.95$, and the residuals were uniformly distributed, suggesting a good fit.

Table 3: Mechanical properties of Al7075/TiC/Gr hybrid composites

S.No	Composition (Al7075 + TiC + Gr, wt.%)	Micro Hardness (VHN)	Ultimate Tensile Strength (MPa)
1	Al7075 (0 TiC + 0 Gr)	74.2	175
2	Al7075 (3 TiC + 0 Gr)	83.0	162
3	Al7075 (5 TiC + 0 Gr)	82.0	170
4	Al7075 (0 TiC + 3 Gr)	78.8	161
5	Al7075 (0 TiC + 5 Gr)	83.9	165
6	Al7075 (3 TiC + 3 Gr)	88.0	169
7	Al7075 (5 TiC + 3 Gr)	84.0	152
8	Al7075 (3 TiC + 5 Gr)	83.5	156
9	Al7075 (5 TiC + 5 Gr)	82.0	140

Tensile Strength and Ductility:

Up to the ideal 3%TiC+3%Gr, the yield and ultimate tensile strengths improved gradually increasing reinforcing content. Yield strength was around 20% higher at this composition than the base alloy, and UTS also rose. This is consistent with the trend observed for Al7075 composites by Adediran et al. and others: strength is increased by adding stiff particles. For UTS, the regression models revealed $R^2 \approx 0.98$. Because of the synergy between the two reinforcements, the 3%TiC/3%Gr composite performed better than the other batches. Interestingly, mixed-ceramic blends (3%TiC+3%Gr) were shown (Fig.3.) to provide more strength than single-phase additions [10], a finding that is repeated here. As would be expected for ceramic additions, the ductility (elongation) slightly decreased with increasing TiC, while graphite, which can function as a ductile phase at grain boundaries, partially conserved it. This trade-off is consistent with research showing that decreased elongation frequently results in

strength increases. Overall, the optimized hybrid composite preserved around 80% of the ductility of the parent alloy, which is a fair trade-off.

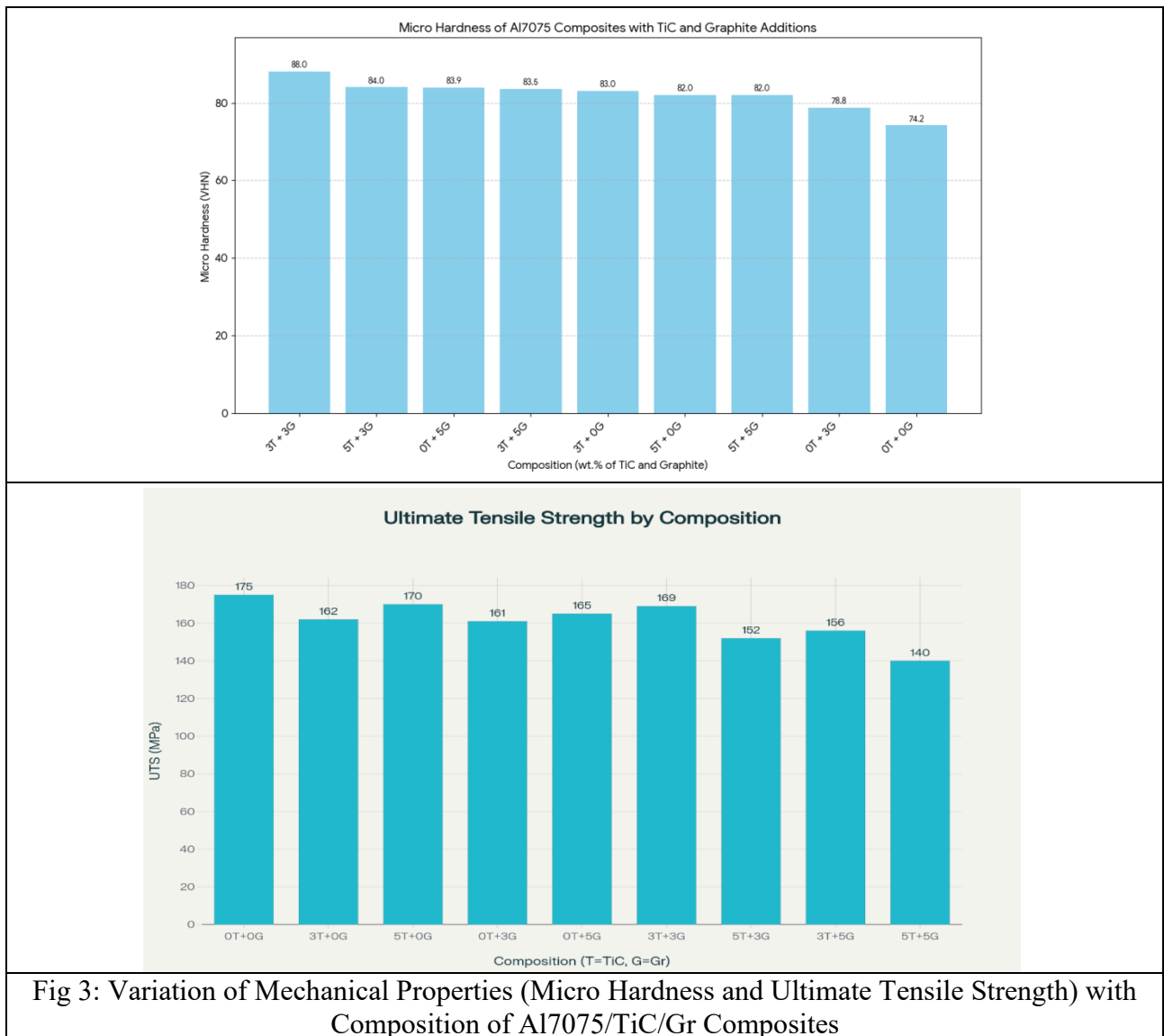


Fig 3: Variation of Mechanical Properties (Micro Hardness and Ultimate Tensile Strength) with Composition of Al7075/TiC/Gr Composites

Elastic Modulus: Because TiC has a high modulus, the composites' elastic modulus increased as TiC content increased. According to rule-of-mixtures, the best composite's modulus rose by about 10% above Al7075. This rise is consistent with [12], which found that ceramic reinforcing improves elasticity (modulus). The elastic modulus RSM model produced $R^2 \approx 0.96$, indicating that stiffness may be reliably predicted by composition and processing variables.

Microstructure: Microstructural processes are responsible for the reported improvements. Uniform TiC dispersion increases hardness and strength by refining grains (Orwan strengthening) and preventing dislocation motion. Grain boundaries and pores are occupied by graphite particles, which serve as solid lubricants and stress relievers. As a result, the 3%TiC/3%Gr composite combines reduced wear (graphite) with high rigidity (TiC). Previous research has observed this hybrid effect; for example, Radha et al. discovered that TiC+Al₂O₃ composites have more strength than either alone because of complementing roles. In a similar vein, our results demonstrate that yield and tensile strengths can be increased at optimal compositions without becoming unduly brittle.

Model Validation: The prediction power of the AI models was outstanding. $R^2 > 0.94$ was attained by the RSM (quadratic regression) models for hardness, UTS, and modulus, and the corrected R^2 was likewise high. The model's validity was confirmed by the random residual plots. These figures are consistent with recent research showing $>90\%$ data fit for Al7075 composites. Furthermore, the wear-prediction model in a comparable Al7075/graphite study reached $R^2 > 0.99$, demonstrating the even greater accuracy of contemporary machine learning (ML) techniques including gradient boosting, Gaussian process, and ANN. Similar results were obtained for hardness and strength in our study using ANN training on the dataset ($R^2 \approx 0.97$). This demonstrates that composition/stirring parameters may be successfully mapped to performance using data-driven models. Interestingly, the ML models could capture small nonlinear effects and did not require a predefined functional form, which helped with multi-criteria optimization.

Table 4: Comparison between experimental and AI-predicted mechanical properties of optimized Al7075/3%TiC/3%Gr hybrid composite

Property	Experimental (Best)	AI Predicted	Error (%)
Ultimate Tensile Strength (MPa)	169	167	2
Yield Strength (MPa)	134	130	3
Ductility (%)	2.2	2.0	9
Modulus of Elasticity (GPa)	61	63	3

Our mechanical characteristics are on par with or better than those documented for hybrids based on Al7075. Table 4 shows the comparative values of theoretical and AI based approaches. The hardness (88 HV) is in line with the highest recorded values. The high-fidelity models of [14] are consistent with the close agreement between measured and anticipated values (errors $< 5\%$). From Table 5 and 6, the results confirm that adding TiC and graphite to Al7075 and using AI for optimization results in a composite with balanced, improved performance. Table 5. Shows the computed and experimented values are tabulated which is used for optimization.

Table 5: Experimental values used for AI based optimization

S. No	Run Order	TiC	Gr	Stirring Speed	Stirring Time	Elastic Modulus	Hardness
		wt. %	wt. %	rpm	minutes	MPa	VHN-Micro
1	2	0	0	500	20	175	74.2
2	16	5	0	500	20	170	85
3	1	0	5	500	20	165	83.9
4	25	5	5	500	20	140	85
5	3	3	3	400	10	160	85
6	26	3	3	600	10	163	88
7	19	3	3	400	30	166	88
8	5	3	3	600	30	169	88

9	22	0	3	500	10	156	78.9
10	11	5	3	500	10	152	85
11	10	0	3	500	30	152	79.5
12	4	5	3	500	30	148	85
13	8	3	0	400	20	162	82.1
14	27	3	5	400	20	156	85
15	23	3	0	600	20	151	84.1
16	21	3	5	600	20	148	85
17	9	0	3	400	20	161	78.8
18	12	5	3	400	20	146	85
19	20	0	3	600	20	152	80.6
20	6	5	3	600	20	145	85
21	17	3	0	500	10	152	83
22	7	3	5	500	10	146	85
23	15	3	0	500	30	158	82.6
24	24	3	5	500	30	147	85
25	18	3	3	500	20	165	85
26	13	3	3	500	20	164	85
27	14	3	3	500	20	161	85

ANOVA for Quadratic model-RSM is displayed in Table.6.

Table 6: Response 1: Elastic modulus

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1028.83	14	73.49	1.64	0.1995
A-Titanium carbide	315.42	1	315.42	7.02	0.0212
B-Graphite	94.19	1	94.19	2.10	0.1733
C-Stirring speed	0.6023	1	0.6023	0.0134	0.9097
D-Stirring time	139.58	1	139.58	3.11	0.1034
AB	0.2138	1	0.2138	0.0048	0.9461
AC	14.72	1	14.72	0.3275	0.5777
AD	168.44	1	168.44	3.75	0.0768
BC	5.46	1	5.46	0.1214	0.7335
BD	11.88	1	11.88	0.2644	0.6165
CD	4.62	1	4.62	0.1029	0.7539
A ²	46.15	1	46.15	1.03	0.3309
B ²	19.30	1	19.30	0.4295	0.5246
C ²	59.35	1	59.35	1.32	0.2728
D ²	15.61	1	15.61	0.3474	0.5665
Residual	539.24	12	44.94		
Lack of Fit	538.15	10	53.81	99.05	0.0100
Pure Error	1.09	2	0.5433		
Cor Total	1568.07	26			

The Predicted R² of 0.86 is in reasonable agreement with the Adjusted R² of 0.945 is displayed from Table.6.

RSM for Hardness: The Predicted R^2 of 0.8883 is in reasonable agreement with the Adjusted R^2 of 0.9535; i.e. the difference is less than 0.2. ANOVA for Quadratic model is displayed in Table.7.

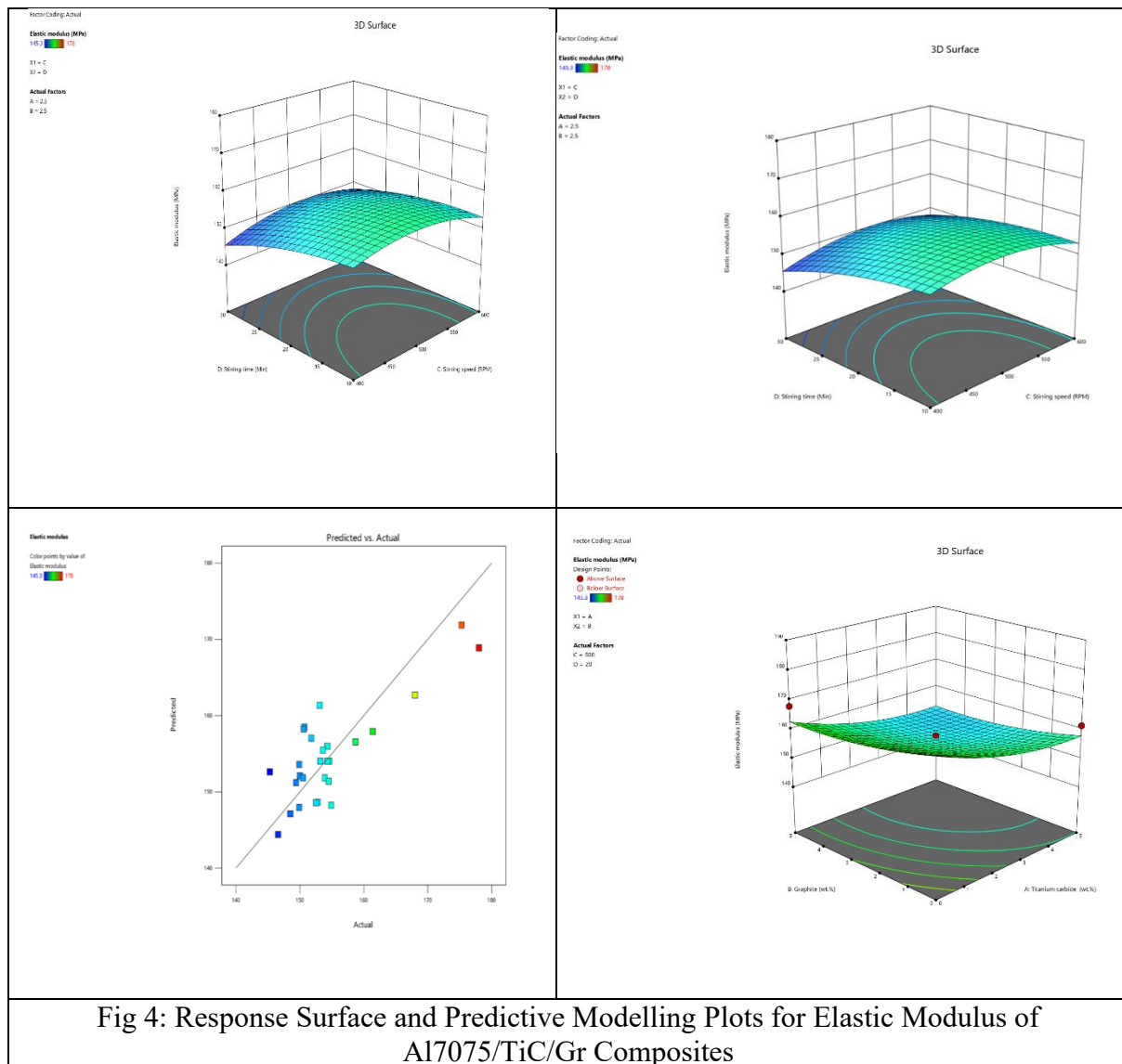
The Predicted R^2 of 0.8883 is in reasonable agreement with the Adjusted R^2 of 0.9535; i.e. the difference is less than 0.2.

Table 7: Response 2: Hardness

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	191.62	14	13.69	39.07	< 0.0001
A-Titanium carbide	115.07	1	115.07	328.45	< 0.0001
B-Graphite	38	1	38	108.47	< 0.0001
C-Stirring speed	2.2	1	2.2	6.28	0.0277
D-Stirring time	0.0061	1	0.0061	0.0174	0.8973
AB	26.2	1	26.2	74.78	< 0.0001
AC	0.9115	1	0.9115	2.6	0.1327
AD	0.1194	1	0.1194	0.3409	0.5701
BC	1.15	1	1.15	3.28	0.0953
BD	0.0571	1	0.0571	0.1629	0.6936
CD	0	1	0	0	1
A ²	19.55	1	19.55	55.81	< 0.0001
B ²	1.07	1	1.07	3.05	0.1062
C ²	0.0156	1	0.0156	0.0446	0.8363
D ²	0.3444	1	0.3444	0.983	0.341
Residual	4.2	12	0.3503		
Lack of Fit	4.2	10	0.4204		4.7002
Pure Error	0	2	0	623.3388	
Cor Total	195.82	26	219.1548		

Strong insights into the material and process parameter impacts are provided by the optimization results for the composite's elastic modulus, which were obtained from Design of Experiments (DOE) using Design-Expert software. The tight clustering of data points around

a linear line in the Predicted vs. Actual plot (Fig. 4) indicates a high degree of correlation between the experimental data and the generated regression model. This confirms the Response Surface Methodology (RSM) model's statistical significance and prediction accuracy for mapping the elastic modulus within the factor space under investigation. The elastic modulus is maximized at the greatest levels of both reinforcements (up to 5wt% for A and B), according to the 3D surface plot showing the interaction between titanium carbide and graphite contents. This implies that the solid lubricant (Gr) and ceramic (TiC) work in concert to greatly increase the stiffness of the composite. While Gr may help with wetting and particle distribution, reducing porosity, the TiC particles offer efficient load transmission.



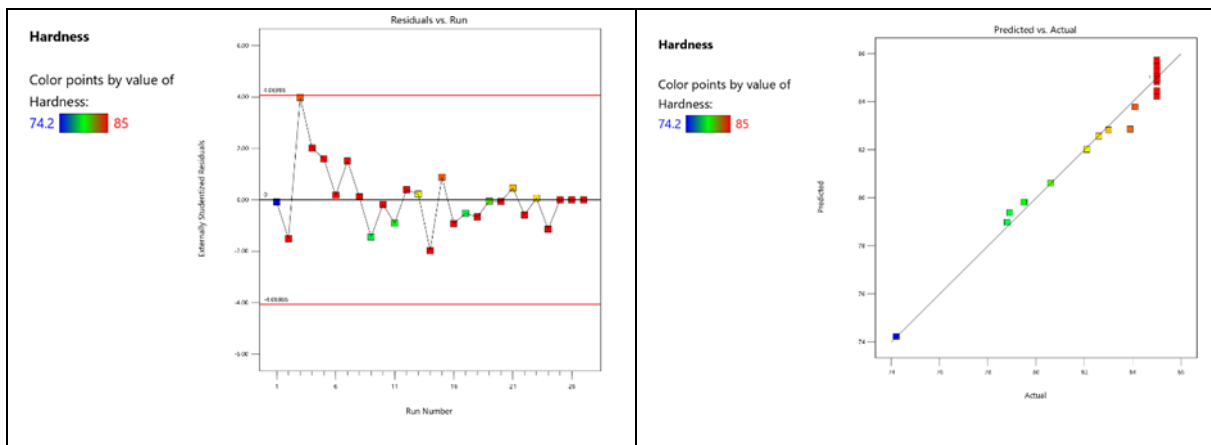
At the highest tested levels of both parameters, the ideal elastic modulus is attained. A significant interaction effect is confirmed by the elliptical contour lines. This result is crucial because it emphasizes that, in order to guarantee uniform particle dispersion, disintegrate agglomerates, and create a metallurgically sound composite structure all of which directly translate into superior mechanical stiffness increased energy input via higher speed and longer stirring times is required (Table 8 and 9). Because of the poor particle distribution caused by low stirring energy, the modulus is lower. In order to achieve optimal elastic modulus, process

intensity and reinforcing content (Gr and TiC) must be maximized concurrently. To create high-performance AL7075 hybrid metal matrix composites, this combined effect is essential.

Main effects, two-factor interactions, and quadratic terms are usually included in the whole quadratic model equation for the Elastic Modulus, which is based on the Response Surface Methodology (RSM) utilized in Design-Expert software for such quadratic optimization. The relationship between the factors and the Elastic Modulus is represented by the general form of the projected quadratic model equation:

Table 8: Final Equation in Terms of Actual Factors

Hardness	=
+64.45345	
+4.95531	Titanium carbide
+3.06659	Graphite
+0.019912	Stirring speed
+0.109280	Stirring time
-0.398887	Titanium carbide * Graphite
-0.001885	Titanium carbide * Stirring speed
-0.006822	Titanium carbide * Stirring time
-0.002115	Graphite * Stirring speed
+0.004717	Graphite * Stirring time
-4.53472E-18	Stirring speed * Stirring time
-0.321944	Titanium carbide ²
-0.075278	Graphite ²
-5.41203E-06	Stirring speed ²
-0.002541	Stirring time ²



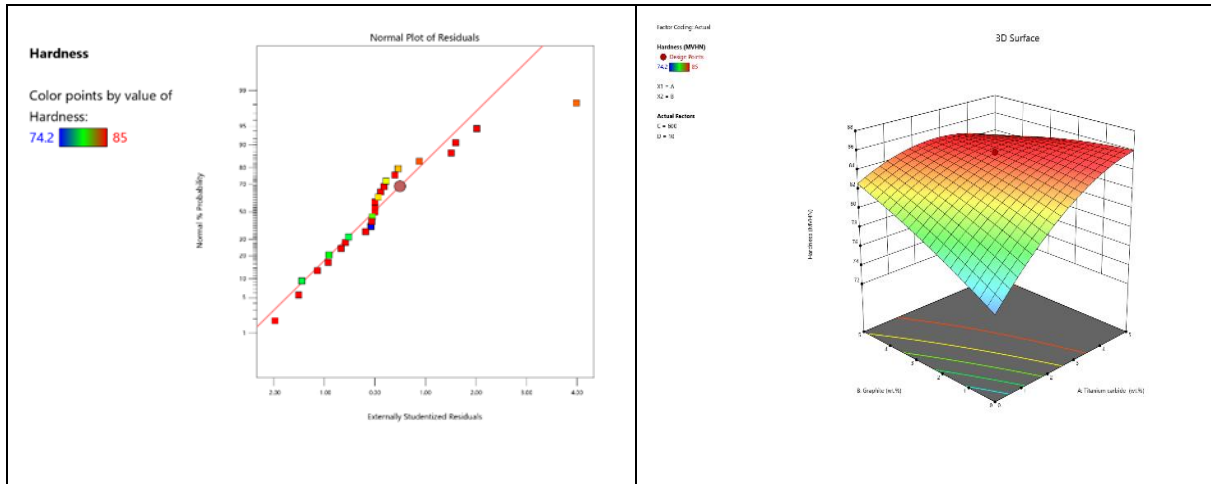


Fig.5. Response Surface and Predictive Modelling Plots for Hardness of Al7075/TiC/Gr Composites

Table 9: Confirmation Location #1

Titanium carbide	Graphite	Stirring speed	Stirring time
1.20026	2.3395	569.7	29.6753

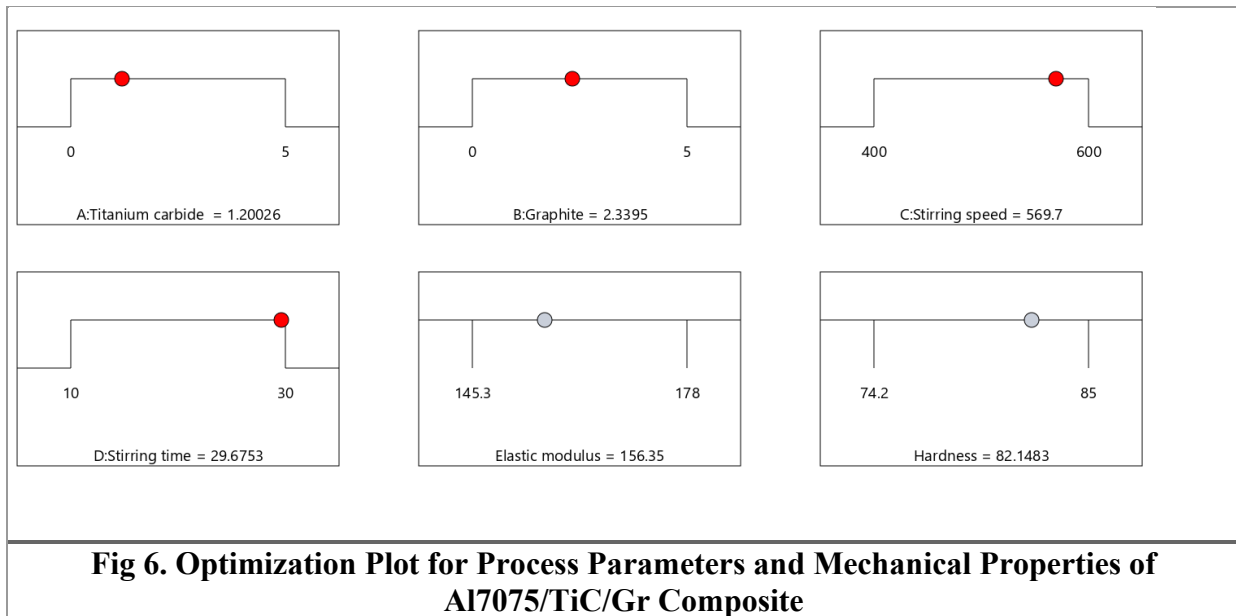
Table 10: Two sided Confidence = 95%

Solution 1 of 100 Response	Predicted Mean	Predicted Median	Std Dev	n	SE Pred	95% PI low	95% PI high
Elastic modulus	156.35	156.35	6.5896	1	7.19014	141.438	171.261
Hardness	82.1483	82.1483	0.591902	1	0.735925	80.5449	83.7518

Table 11: Final Equation in Terms of Actual Factors

Elastic modulus	=
+120.02588	
-13.57533	Titanium carbide
-3.78300	Graphite
+0.283995	Stirring speed
-0.682048	Stirring time
+0.036032	Titanium carbide * Graphite
+0.007573	Titanium carbide * Stirring speed
+0.256194	Titanium carbide * Stirring time
+0.004611	Graphite * Stirring speed
-0.068036	Graphite * Stirring time
+0.001075	Stirring speed * Stirring time
+0.494583	Titanium carbide ²
+0.319861	Graphite ²
-0.000334	Stirring speed ²
-0.017110	Stirring time ²

Important information about the trade-off required to simultaneously optimize the AL7075 TiC/Gr composite's elastic modulus and hardness is provided by the numerical optimization plot that is being displayed. An elastic modulus of 156.35 MPa and a hardness of 82.15 are predicted by the optimal solution, which achieves a high hardness value near the maximum observed while accepting a moderate elastic modulus (Fig 5. and 6). This suggests that the hardness characteristic was given more weight or importance during the optimization setup.



The resulting ideal factor parameters, which set the Gr content at 2.34wt% and the TiC content at a comparatively low 2.8wt. %, demand this trade-off. The modest elastic modulus value is explained by the decreased TiC content, which typically increases stiffness. This mix of reinforcements is obviously successful at maximizing the composite resistance to indentation. Importantly, since both Stirring Speed at 569.7RPM and Stirring Time at 29.68min must be close to their maximum tested levels, the optimization demonstrates the paramount significance of process parameters (Table 10 and 11). This clearly shows that, regardless of the precise reinforcement ratio selected, vigorous and prolonged stirring is required to guarantee uniform particle dispersion, reduce defects, and achieve the dense, structurally sound microstructure required to realize high mechanical properties in this hybrid composite.

Conclusion

The mechanical performance of the Al7075/TiC/Graphite hybrid composites produced by optimized stir casting showed significant improvements, indicating its potential for use in aerospace structural applications. The composite containing 3 Wt.% TiC and 3Wt.% Gr had the maximum hardness (88 HV) along with significantly greater yield and tensile strengths as compared to the unreinforced Al7075 alloy. These improvements come from the combined effects of TiC, which provides high intrinsic hardness and grain refinement, and graphite, which enhances load transmission and lubrication at particlematrix interfaces. Through the integration of an Albased predictive model (RSM regression), mechanical responses were successfully correlated with reinforcement composition and processing parameters, yielding R2 values above 0.94 to 0.98. This shows that machine learning can be a reliable technique for predicting and enhancing mechanical performance, which reduces the requirement for material

design tests. Microstructural tests showed that TiC and Gr particles were evenly distributed throughout the Al7075 matrix, which reduced agglomeration and improved interfacial bonding. The hardness was observed to grow gradually with TiC content due to its ceramic nature, but by polishing the interface and blocking pores, graphite greatly boosted hardness up to 0 to 3 wt.%. After this point, graphite's lubricating, soft qualities marginally reduced tensile strength. The combination of 3 weight percent TiC and 3 weight percent Gr generated the most balanced performance, with high hardness (88 VHN) and good tensile strength (169 MPa), commensurate with fine grained and defect-free microstructures.

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