Influence of process parameters on tensile strength and hardness of AA 2024 / TiC / E-Glass

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Abstract: The aerospace industry's demand for engineering materials is growing by the day. Specific applications for AA 2024 alloy with titanium carbide particles and E-Glass fibre include aircraft structure, window panel, seats, aircraft fittings, and wheels. As a result, in this study, Al 2024 alloy was chosen as the matrix, with titanium carbide particles and E-Glass fibre as reinforcement. Titanium carbide particles with an average size of 40 micrometres, E-Glass fibre were chosen and incorporated in varying weight percentages into the Al 2024 matrix via the stir casting process. To validate the experimental values, Taguchi's Technique was used to evaluate optimization, the influence of process parameters, and the regression equation. Tensile strength and hardness were found to enhance as the weight percentage of titanium carbide particles and E-Glass in the Al 2024 alloy increased. SEM images reveal that titanium carbide particles E-Glass are uniformly distributed in the Al 2024 alloy, and dimple structures form at the tensile fracture surface.

Key words: Titanium carbide particles, E-Glass, Al 2024 alloy composite, tensile strength and hardness.

I. INTRODUCTION

Extensive materials research has resulted in a plethora of new scientific innovations aimed at synthesising special materials with increased efficiency and low manufacturing costs in order to meet the engineering sector's long-standing demands. A novel material system containing hard particulates embedded in a metal matrix demonstrated superior operating performance and enhanced tribological properties[1], [2].

Among MMCs, aluminium alloy-based composites demonstrated significant improvements in mechanical, thermal, electrical, and wear properties to meet industry demands. Due to their superior machining, joining, and processability, aluminium alloys are referred to as versatile materials that can be used in a wide variety of engineering applications. Additionally, Al alloys' low cost, increased strength-to-weight ratio, and other environmentally friendly properties make them a preferred material for engineering applications [3], [4].

Among the aluminium alloys, Al-Si is a well-known casting alloy due to its high wear resistance, low thermal expansion coefficient, excellent corrosion resistance, and improved mechanical properties over a wide temperature range. The grain refiner elements convert the coarse Si morphology to lamellar (fine) Si, thereby improving the mechanical properties [5].

Diverse researchers developed a variety of composite materials by varying the matrix, reinforcement size, shape, and volume, as well as the processing technique, to meet the requirements and applications. To optimise the properties of the metal matrix composite, the second phase's distribution within the matrix alloy must be uniform, and the wettability or bonding between these substances must be optimised. [6].

II. PROPOSED METHODOLOGY

2.1 Die Casting:

Is a method of metal casting that involves forcing molten metal into a mould cavity under high pressure[7]. The majority of die castings are made of non-ferrous metals, most notably zinc, copper, aluminium, magnesium, lead, pewter, and tin alloys. Lubricant is sprayed into the cavity of the dies to prepare them. Lubricant assists in regulating the die's temperature and also aids in the casting's removal. The dies are then sealed and molten metal is injected into them at high pressures ranging from 10 to 175 MPa (1,500 and 25,400 psi). After filling the mould cavity, pressure is maintained until the casting solidifies.

2.2 Machining:

Because the casted specimens will not have the required dimensions[8], they are further machined into the desired shape using a lathe in the machine shop. The specimen's centre portion diameter should be consistent with the standard before it is tested on the machine.

2.3 Design of Experiments:

Design of Experiments (DoE) is used to know the response of an output variable with the effect of input factors at the same time. Determining changes are made in the input factor for the series of experimental runs. The information has been gathered for each run. Standard experiment layout having 2 factors with 4 levels each, for L16 (2^4) Orthogonal Array (OA) was adopted by using Taguchi's Technique. Table 1 shows the L16 (2^4) Taguchi orthogonal array table.The experimental values of tensile strength and hardness of the formed composites under various parameters are tabulated in Table 2.

Table 1 Taguchi Orthogonal Array Table

Taguchi P = 2, L = 4			
Run #	**TiC (Weight percent)**	**E-Glass (Weight percent)**	**X**
1	0	0	X_1
2	0	1	X_2
3	0	3	X_3
4	0	5	X_1
5	2	0	X_5
6	2	1	X_6
7	2	3	X_7
8	2	5	X_8
9	4	0	X_9
10	4	1	X_{10}
11	4	3	X_{11}
12	4	5	X_{12}
13	6	0	X_{13}
14	6	1	X_{14}
15	6	3	X_{15}
16	6	5	X_{16}

Table 2

Taguchi P = 2, L = 4				
Run #	**TiC (Weight percent)**	**E-Glass (Weight percent)**	**Ultimate Tensile Strength (MPa)**	**Hardness (BHN)**
1	0	0	153.384	46.2
2	0	1	160.839	48.3
3	0	3	171.169	49.9
4	0	5	188.832	56.2
5	2	0	164.868	49.2
6	2	1	183.245	54.7
7	2	3	188.576	56.8
8	2	5	191.719	60.1
9	4	0	181.937	55.3
10	4	1	209.824	63.2
11	4	3	216.805	65.5
12	4	5	231.485	69.1
13	6	0	187.708	57.4
14	6	1	216.132	65.1

15	6	3	233.686	70.6
16	6	5	240.759	72.3

III. RESULTS AND DISCUSSION

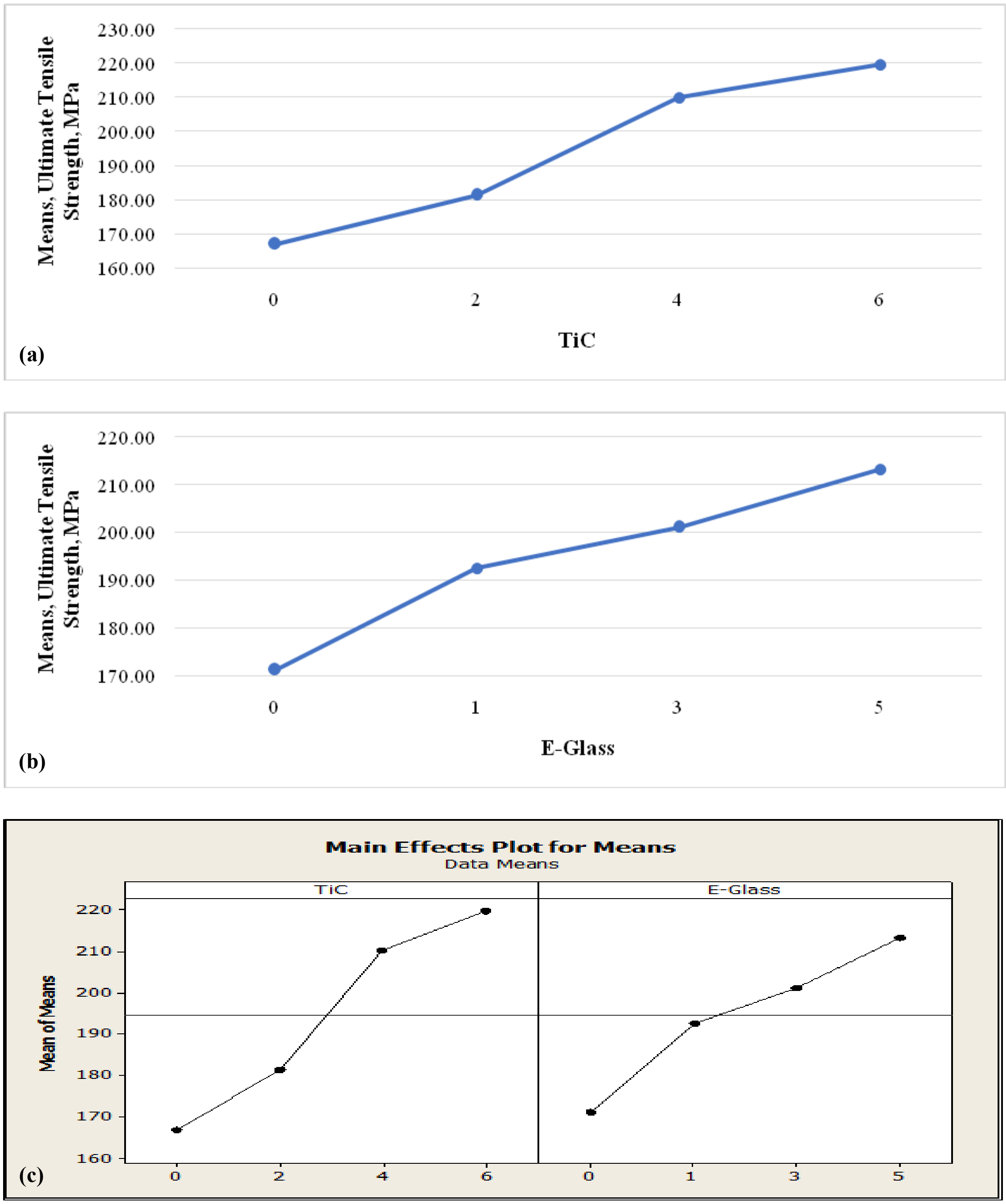
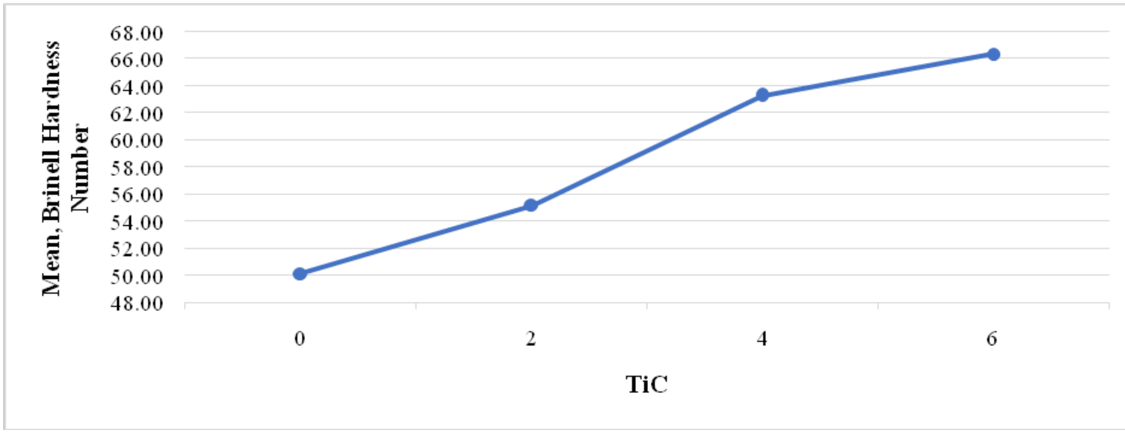
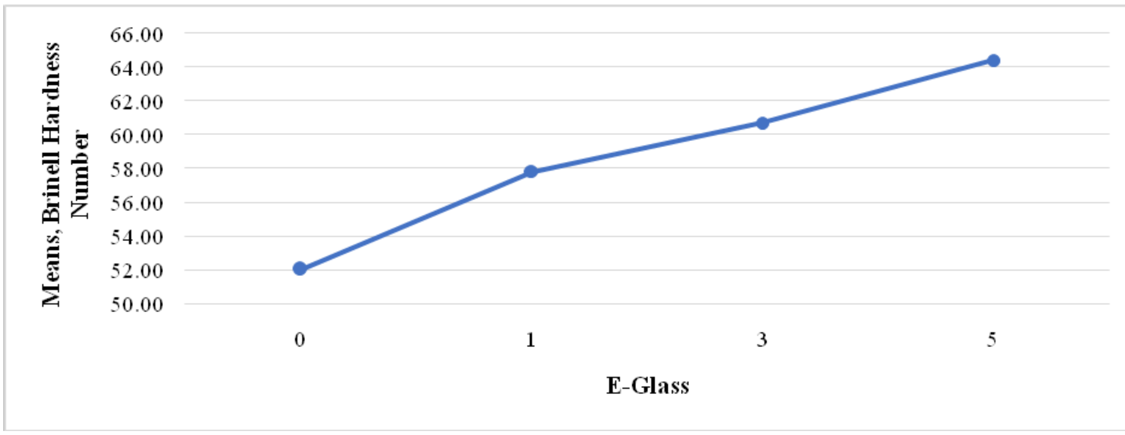


Figure 1Effect of individual parameters on ultimate tensile strength value of Al 2024 / TiC / E-Glass (a) TiC, (b) E-Glass, and (c) graph obtained from mini stab statistical tool.





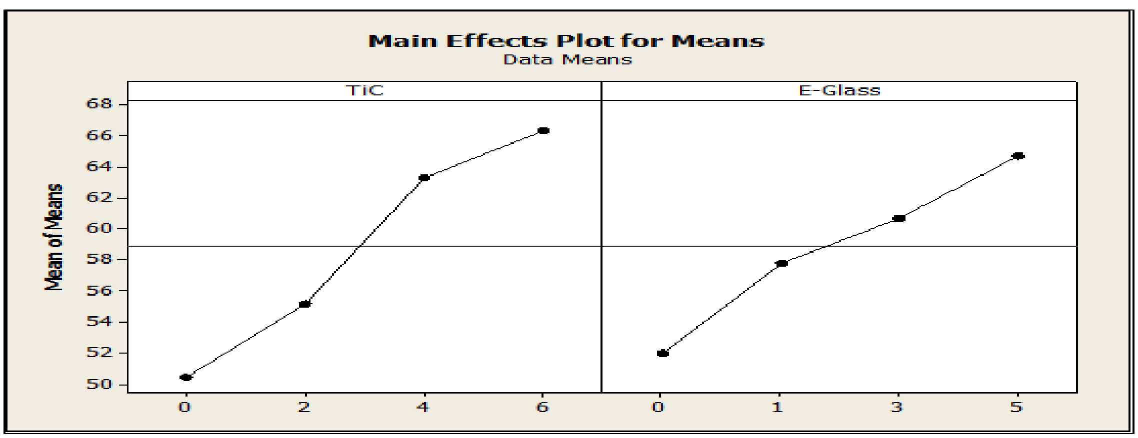


Figure 2Effect of individual parameters on Brinell hardness number value of Al 2024 / TiC / E-Glass (a) TiC, (b) E-Glass, and (c) graph obtained from mini stab statistical tool.

Table 3 Response table - ultimate tensile strength of Al 2024 / TiC / E-Glass for Means

Level	TiC	E-Glass
1	167.1	171.2
2	181.4	192.5
3	210.0	201.1
4	219.6	213.2
Delta	52.5	42
Rank	1	2

Table 4Response table –Brinell Hardness of Al 2024 / TiC / E-Glass for Means

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Table 5Results of ANOVA on ultimate tensile strength of Al 2024 / TiC / E-Glass obtained from mini tab statistical tool

Source	TiC	E-Glass	Error	Total
DF	3	3	9	15
Seq SS	7181	3753.5	463.4	11397.9
Adj SS	7181	3753.5	463.4	
Adj MS	2393.7	1251.2	51.5	
F-Value	46.49	24.3		
P-Value	0	0		
% of Contribution	63.00%	32.93%	4.07%	
Rank	1	2		

Table 6Results of ANOVA on Brinell hardness number of Al 2024 / TiC / E-Glass obtained from mini tab statistical tool

Source	TiC	E-Glass	Error	Total
DF	3	3	9	15
Seq SS	638.84	342.26	29.47	1010.56
Adj SS	638.84	342.26	29.47	
Adj MS	212.95	114.09	3.27	
F-Value	65.04	34.85		
P-Value	0	0		
% of Contribution	63.22%	33.87%	2.92%	
DF	3	3	9	15

Table 7 Comparison of experimental results - ultimate tensile strength, Brinell hardness number v/s regression equation of Al 2024 / TiC / E-Glass

Run #	Tensile Strength (MPa)		Error	Brinell Hardness Number		Error
	Experimental	Reg. Eq. 1	%	Experimental	Reg. Eq. 1	%
1	153.384	149.605	2.46%	46.200	45.238	2.08%
2	160.839	157.144	2.30%	48.300	47.556	1.54%
3	171.169	172.222	0.62%	49.900	52.191	4.59%
4	188.832	187.300	0.81%	56.200	56.825	1.11%
5	164.868	168.226	2.04%	49.200	50.816	3.28%
6	183.245	175.765	4.08%	54.700	53.133	2.86%
7	188.576	190.842	1.20%	56.800	57.768	1.70%
8	191.719	205.920	7.41%	60.100	62.403	3.83%
9	181.937	186.846	2.70%	55.300	56.393	1.98%
10	209.824	194.385	7.36%	63.200	58.711	7.10%
11	216.805	209.463	3.39%	65.500	63.346	3.29%
12	231.485	224.541	3.00%	69.100	67.980	1.62%
13	187.708	205.467	9.46%	57.400	61.971	7.96%
14	216.132	213.006	1.45%	65.100	64.288	1.25%
15	233.686	228.084	2.40%	70.600	68.923	2.38%
16	240.759	243.161	1.00%	72.300	73.558	1.74%

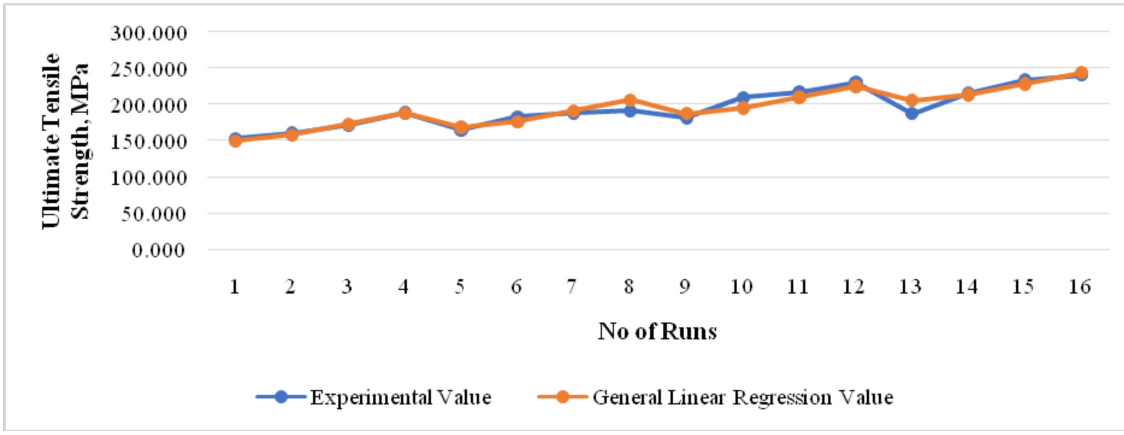

Figure 3ultimate tensile strength experimental value v/s general linear regression value of Al 2024 / TiC / E-Glass

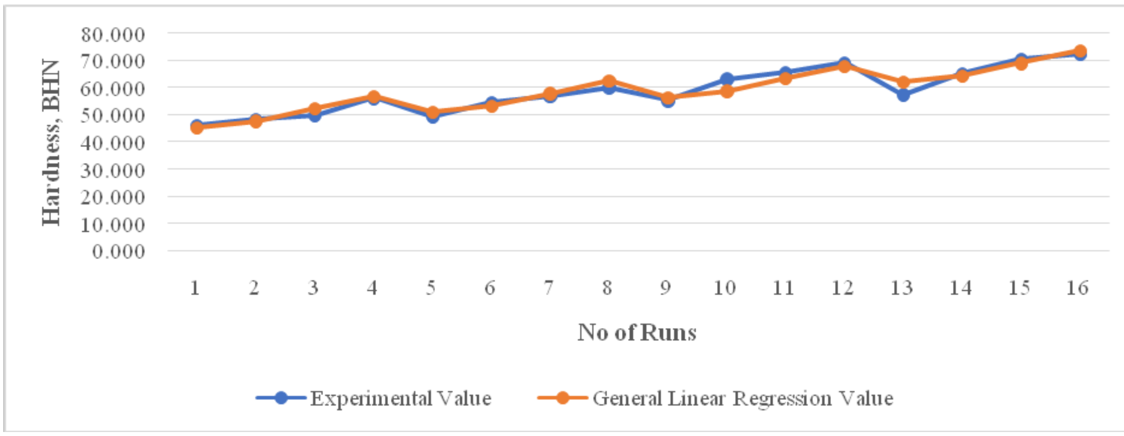

Figure 4Brinell hardness number experimental value v/s general linear regression value of Al 2024 / TiC / E-Glass

Table 8Summary of the Model for Ultimate Tensile Strength - Al 2024 / TiC / E-Glass

S	R-Sq	R-Sq(adj)
7.17542	95.93%	93.22%

Table 9Summary of the Model for Brinell Hardness Number - Al 2024 / TiC / E-Glass

S	R-Sq	R-Sq(adj)
1.80941	97.08%	95.14%

Figure 1 and 2 (a-c) shows the influence of TiC and E-Glass on Al 2024 related to ultimate tensile strength and hardness for theAl 2024 / TiC / E-Glass composite. It is noticed that for the factors 6 weight percent TiC and 5 weight percent of E-Glass have a better significantvalue on both ultimate tensile strength and hardness.

Tables 3 and 4 shows the response table for ultimate tensilestrength and hardness for means for the factor (weight percent of TiC and E-Glass on Al 2024alloy.

With the help of ANOVA analysis (ref table 5 and 6), the effect of process parameterson ultimate tensile strength and hardness on Al 2024 alloy are also discussed.Expected values for tensile strength and hardness werecalculated using regression equations and tabulated in table 7. Within the factors, theregression equation is used to project the ultimate tensile strength andhardness.

The regression equations for tensile strength and hardness are:

Ultimate Tensile Strength =149.605 + 9.31033 * TiC + 7.5389 * E-Glass (Eqn 1)

BHN=45.2384 + 2.78875 * TiC + 2.31737 * E-Glass (Eqn 2)

Figure 3 and 4 reveals the confirmation of the experimentalvalues with the expected values. The stable experimentations havebeen conducted at confidence intervals of 95% and the comparisonof experimental values Vs. expected values have been observedwith two factors at four levels each. Experimental values areslight variations with the expected values for both the ultimate tensilestrength and hardness of the composite material and hence theexperimental values are validated.

The summary of the model for tensile strength and hardness on Al 2024 alloy by ANOVA technique is shown in Tables 5 and 6.

Table 5 and 6 it is revealed that the percentage contributionfor ultimate tensile strength is highest for the TiCparticles is 63.00 %whereas E-Glass is 32.93 %, hence TiC has a more significant impact on ultimate tensile strength whencompared to the other factor. While percentage contributionfor hardness is highest for the TiC is 66.00 % whereas E-Glass is 33.87 %, hence TiC has a more significant impact on hardness when comparedto the other factor.

IV. CONCLUSIONS

Al 2024 / TiC / E-Glass composite can be successfully synthesizedthrough the stir casting technique. The optimum parameter is 6 weight percent TiC and 5 weight percent E-Glass found to be enhanced by 56.96 percent ultimate tensile strength and hardness by 56.49 percent.

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