Investigation of Mechanical Properties of Al- TiO$_2$-Graphite Hybrid Composite Fabricated Using Squeeze Casting Process

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Abstract: In this study TiO$_2$ particles and Graphite particles reinforced with Al1100 to form a metal matrix composite, which is more commonly used in aerospace, marine, military and automotive applications. Al 1100 an variable weight fractions of 2, 4 % titanium dioxide and 1,3 % percentage of graphite were fabricated through stir casting. Subsequent analysis on wear and mechanical properties such as microhardness, tensile, corrosion tests were carried out. Results showed improved wear and improved mechanical characteristics for 2% of TiO$_2$ and 3 % of Graphite at reinforcement preheat temperature of 900 C.

Keywords: Squeeze casting, Al1100, Tensile test, Hardness test, Corrosion Test, Taguchi method.

I. INTRODUCTION

Aluminium is a ductile, silvery white colour material, hence these Al based Metal matrix composite are the area for the research which have emerged as major class of materials for various fields of engineering applications. On the other hand Al alloy matrix composites have better wear resistance, low density, higher toughness and corrosion resistance.

Various researches have been conducted by reinforcing Graphite, TiB$_2$, TiC, B$_4$C, Flyash on aluminium based metal matrix composites using different manufacturing processes. Nevertheless, the reinforcement of TiO$_2$ particles in Al1100 has got a greater importance because they possess higher hardness and good corrosion resistance properties.

Generally the incorporation of hard ceramic particles on the Aluminium matrix may improve the mechanical and tribological behaviour, but sometimes they may cause rapid wear on the surface and deteriorated machinability.

II. MATERIALS AND EXPERIMENTAL FABRICATION

A. Matrix Material

For this experimental investigation, Al1100 is used as the matrix material. The chemical composition of Al1100 is listed in table 1 below. Al1100 has excellent machinability. In Al1100 hot and cold forming can also be easily performed.

| Mg   | Cr        | Cu       | Fe | Mn | Si | Zn | Others |
|------|-----------|----------|----|----|----|----|--------|
| 0.05 % | 0.15 to 0.35 % | 0.05 to 0.20 % | 0.95 % | 0.1 % max | 0.95 % max | 0.1 % max | 0.15 % max |

B. Reinforcement Material

Titanium di Oxide is chosen as the reinforcement material, since it is easy to blend with al alloys for improving strength and hardness.
III. EXPERIMENTAL PROCEDURE

The experimental setup of squeeze casting essentially consists of an electric furnace and a mechanical stirrer. The electric furnace carries a crucible of capacity 2 Kg. The maximum operating temperature of the furnace is 1000°C. The current rating of furnace is single phase 230V AC, 50Hz. The squeeze casting machine set up at GCT, Coimbatore is shown in Fig. 1.

![Squeeze Casting Setup](image1.png)

A. Experimental Plan

The matrix material is aluminium alloy Al 1100. Samples are to be prepared using Al 1100 reinforced with Aluminium oxide TiO₂ (2%, 4%) and Graphite (1%, 3%) by volume at various melting temperatures of 750°C, 825°C and reinforcement pre-heat temperatures as 850°C and 900°C. Experiments were conducted using Taguchi L₄ orthogonal design of experiments is shown in table II shows the various constituent levels of reinforcements added.

| Sample No. | Al1100 (gm) | TiO₂ (gm) | Graphite (gm) |
|------------|-------------|-----------|---------------|
| 1          | 1290.1      | 26.6      | 13.3          |
| 2          | 1236.9      | 53.2      | 39.9          |
| 3          | 1263.5      | 53.2      | 13.3          |
| 4          | 1263.5      | 26.6      | 39.9          |

An table III shows the material required for the fabrication of each sample.

| Sample No | Melting temperature (°C) | Reinforcement preheat Temperature (°C) | Reinforcement (%) |
|-----------|--------------------------|----------------------------------------|-------------------|
|           |                          |                                        | TiO₂   | Graphite |
| 1         | 750                      | 850                                    | 2      | 1       |
| 2         | 750                      | 900                                    | 4      | 3       |
| 3         | 825                      | 850                                    | 4      | 1       |
| 4         | 825                      | 900                                    | 2      | 3       |
IV. MECHANICAL TESTS RESULTS

A. Tensile Test

The Casting were made according to the Parameters (squeeze pressure, melting temperature, squeeze time) selected in the Taguchi L4 orthogonal Array. Tensile testing, also known as tension testing is a test in which a sample is subjected to a tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under normal forces.

The Tensile test is carried out on the casting samples is shown in figure 2. The samples is loaded in the machine nd tensile load is given to test the specimens tensile strength. The unit of load measured is in N/mm$^2$. Figure 3 shows the specimen is after breaking of specimen by applied the tensile load on the specimen.

![Fig 2 Tensile Test Sample preparation](image1)

![Fig3 Tensile Tested Samples](image2)

The tensile test results are as shown in the table IV below.

| Sample No | Tensile Test | SNRA |
|-----------|-------------|------|
|           | $N/mm^2$    |      |
| 1         | 124.88      | 41.16|
| 2         | 117.63      | 40.90|
| 3         | 119.81      | 41.56|
| 4         | 121.81      | 41.82|
The optimization of process parameter of tensile test is carried with minitab software the optimal values was shown in figure 4.

![Optimized SN ratios of Tensile test](image)

**B. Hardness Test**

Micro hardness test at various locations was carried out to know the effect of reinforced particulates on the alloy matrix as given in Table V. Vickers hardness measurement has been carried out on the embedded reinforcement particles as well as in the locality of particles and matrix.

| Sample No | Trial 1 HV | Trial 2 HV | Average HV | SNRA  |
|-----------|------------|------------|------------|-------|
| 01        | 121.3      | 123.7      | 122.5      | 42.62 |
| 02        | 130.4      | 134        | 132.2      | 43.01 |
| 03        | 142.4      | 156        | 149.2      | 43.30 |
| 04        | 173.9      | 174.9      | 174.4      | 43.63 |

![Indentation marked](image)

**Fig 5** shows the indentation marked on the Vickers micro hardness tested samples, Vickers Microhardness tester and the machined samples on which the micro hardness tests were conducted.
C. Corrosion Test

Corrosion testing is a method used for evaluation of a material's ability to withstand specific environmental conditions. Corrosion in field conditions can be extremely slow, so different test methods have been followed to enable prediction of long-term corrosion behavior. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. Figure 8 shows the samples on which corrosion test were conducted.
The corrosion test is carried out on the casted and machined samples. The samples are machined, corrosion rate was calculated by weight loss method. The samples were weighted and immersed in 3.5% of NaCl solution for 10 days. After 10 days sample were collected and then weighted. The corrosion test results are shown in the table VI. The corrosion resistance rate is high in level third of sample 4 addition of reinforcement percentage, squeezing time.

| Run Order | Area cm² | Density g/cm² | Before weight gm | After weight gm | Weight Loss Gm | Corrosion Rate MPY |
|-----------|----------|---------------|------------------|-----------------|----------------|-------------------|
| 01        | 15.30    | 2.71          | 11.85            | 11.77           | 0.08           | 0.014             |
| 02        | 15.30    | 2.71          | 12.45            | 12.39           | 0.06           | 0.010             |
| 03        | 15.30    | 2.71          | 12.65            | 12.55           | 0.10           | 0.021             |
| 04        | 15.30    | 2.71          | 12.60            | 12.53           | 0.07           | 0.013             |

The optimized SN curve of ratio curve for corrosion test is as shown in figure 9.

Table VII shows the Response table for signal to noise ratios for corrosion tests.

| Level | TiO₂ (2%, 4%) | Graphite (1%, 3%) |
|-------|---------------|-------------------|
| 1     | 37.40         | 35.32             |
| 2     | 36.7          | 38.86             |
| Delta | 0.62          | 3.54              |
| Rank  | 2             | 1                 |
V. ANOVA ANALYSIS

The inferences made from the above said graphs can be arrived at mathematically with the help of ANOVA.

Table VIII Anova table for Tensile test

| Source   | Seq SS  | Contribution | Adj SS  | Adj MS  | F-Value | P-Value |
|----------|---------|--------------|---------|---------|---------|---------|
| TiO₂     | 0.00004 | 53.55%       | 0.00004 | 0.000040| 0.16    | 0.758   |
| Graphite | 0.00003 | 37.57%       | 0.00003 | 0.000030| 1.44    | 0.442   |
| Error    | 0.00002 | 8.08%        | 0.0000250| 0.0000250|         |         |
| Total    | 0.000650| 100.00%      |         |         |         |         |

The confidence limits are taken as 95% for all the factors. Factors with P-value less than 0.05 are considered to be significant. The table VIII shows the values obtained from tensile test ANOVA table. Table IX shows ANOVA table values for hardness test and Table X shows ANOVA table values for Corrosion test.

Table IX Anova table for hardness test

| Source | Seq SS  | Contribution | Adj SS  | F-Value | Adj MS  | P-Value |
|--------|---------|--------------|---------|---------|---------|---------|
| TiO₂   | 59      | 38.08%       | 59      | 0.05    | 59      | 0.860   |
| Graphite | 306    | 59.54%       | 306     | 0.26    | 306     | 0.700   |
| Error  | 1183    | 6.37%        | 1183    | 1183    |         |         |
| Total  | 1549    | 100.00%      |         |         |         |         |

Table X Anova table for Corrosion test

| Source | Seq SS | Contribution | Adj SS | F-Value | Adj MS | P-Value |
|--------|--------|--------------|--------|---------|--------|---------|
| TiO₂   | 24.86  | 64.52%       | 24.86  | 0.860   | 24.86  | 0.371   |
| Graphite | 149.84 | 25.67%       | 149.84 | 149.84  | 149.84 | 0.647   |
| Error  | 64.96  | 8.81%        | 64.96  | 64.96   | 64.96  | 0.371   |
| Total  | 239.67 | 100.00%      |        |         |        |         |

A. Conformation Experiments

The samples were prepared by optimum parametric setting. The optimized values of tensile, hardness, corrosion properties are shown in table XI, table XII, table XIII.

Table XI Optimized values for tensile test

| Sample No | Weight of TiO₂+Graphite | Melting temperature | Squeeze time | Tensile test |
|-----------|--------------------------|---------------------|--------------|--------------|
|           | gm                       | ºC                  | Minutes      | N/mm²        |
| 4         | 26.6+39.9                | 750                 | 10           | 121.89       |

Table XII Optimized values for hardness test

| Sample No | Weight of TiO₂+Graphite | Melting temperature | Squeeze time | Hardness test |
|-----------|--------------------------|---------------------|--------------|---------------|
|           | Gm                       | ºC                  | Minutes      | HV            |
| 4         | 26.6+39.9                | 750                 | 10           | 174.4         |
Table XIII Optimized value for Corrosion test

| Sample No | Weight of TiO₂+Graphite | Temperature °C | Squeeze time Min | Corrosion rate MPY |
|------------|--------------------------|----------------|------------------|-------------------|
| 4          | 26.6+39.9                | 750            | 5                | 0.013             |

VI. CONCLUSION

The hybrid composite samples of Al 1100, TiO₂ and graphite as reinforcements were produced using squeeze casting process. The mechanical properties such as tensile strength, hardness and corrosion rate were investigated from the produced samples.

A. Composite having 2% TiO₂, 3% graphite, squeeze time 10 mins and 95% Al- 1100 combination fabricated at melting temperature 825 °C and reinforcement pre-heat temperature 900°C has higher tensile strength 121.89 N/mm² and hardness 174.4 HV compared to other combinations.

B. The minimum Corrosion rate for Al 1100 composite is 0.013 Mpy in combination of 2% TiO₂, 3% graphite and squeeze time 5 mins. Whereas for others, the corrosion rate is maximum.

This hybrid composite can be explored for use in applications where higher strength and corrosion resistance is required.

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