In situ Fabrication of Aluminium Titanium Diboride Composite

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ABSTRACT

In metal matrix composites, a metal is often combined with another, a non-metallic, phase to produce a novel material possessing attractive engineering attributes of its own. A subject of research in the 1980s and 1990s, this class of materials has, in the past ten years, increased significantly in variety. Aluminium matrix composites (AMCs) refer to the group of light weight, high performance, aluminium centric material systems.

This project emphasises on casting a Al-TiB₂ metal-matrix composites fabricated using an exothermic reaction process using K₂TiF₆ and KBF₄ salts. The possibility of developing simple, cost effective and efficient processing routes for the production of metal matrix composites was used. These insitu prepared composites were characterized using scanning electron microscope. The dry sliding wear behaviour of the prepared composite was compared. Also, the study at room temperature was carried out for comparison purpose. The results indicate that the wear rate decreases with the increase in the weight percentage of TiB₂, while it increases with the increase in the applied load.

KEY WORDS: Aluminum Titanium Diboride, Insitu.

1. INTRODUCTION

A metal matrix composite (MMC) is a composite material with at least two constituent parts, one necessarily being a metal, the other material may be a different metal or another material, such as a ceramic or organic compound. MMCs have emerged as an important category of materials for structural, wear, thermal, transportation and electrical applications because of their ability to exhibit superior strength-to-weight and strength-to-cost ratios when compared to equivalent monolithic commercial alloys. The possibility of developing simple, cost effective and efficient processing routes for the production of metal matrix composites is currently being explored by materials researchers from most developing countries. The reinforcement in AMCs, the class of light weight high performance aluminium centric material systems could be in the form of continuous or discontinuous fibres or particulates, in volume fractions ranging from a few percent to 70%.

The current project work is an effort to study the mechanical behaviour of Aluminium and TiB₂ composites produced using stir casting process. Both alloy and composites were prepared using the in situ fabrication technique. In situ fabrication of MMC is a process, in which dispersed reinforcing phase is formed in the matrix as a result of precipitation from the melt during its cooling and solidification. This contrasts with ex-situ composites where the reinforcing phase is synthesized separately and then inserted into the matrix during a secondary process.

2. EXPERIMENTAL PROCEDURES

The complete experimental procedure comprises of two casting processes-

- To form the Aluminium Matrix alloy consisting of 0.75% Magnesium and 7.0% Silicon.
- To reinforce the Aluminium Matrix with Insitu TiB₂, produced as a reaction product of salts K₂TiF₆ and KBF₄.

To cast the Aluminium based alloy 1000 gm of pure Aluminium was carefully weighted and placed inside a clay-graphite crucible kept inside the furnace core which is maintained at 850°C. After about 40 minutes, Aluminium melts and 70 gm Silicon and 7.5 gm Magnesium is then added in the melt. Take note that Magnesium is perfectly submerged inside melt otherwise Magnesium at that temperature reacts with oxygen very fast and starts burning. The melt is then stirred rapidly for some time, keeping in notice that the Magnesium is perfectly submerged inside the melt. Before pouring the molten alloy for casting, the oxidised top layer in the melt is removed using a graphite rod because graphite does not react with the melt and has a very high melting point. The molten alloy is carefully poured into the mould.

The TiB₂ reinforcement was synthesised using two types of salt Potassium Hexafluorotitanate (K₂TiF₆) and Potassium Tetrafluoroborate (KBF₄). The exothermic reaction between the salts yield in situ formed TiB₂ particulates in the alloy. The salts such as K₂TiF₆ and KBF₄ were carefully measured and preheated at 150°C for two hours remove any moisture residue from the salts. A 1000 gms of the Aluminium alloy was then melted in a pure graphite crucible at 800°C. The preheated mixture of powder salts K₂TiF₆ and KBF₄ is then packed into small pouches of aluminium foil. The pouches are then carefully added to the alloy melt and stirred well in order to distribute the salt in the melt uniformly. The exothermic reaction between the salts yield insitu formed TiB₂ particulates in the alloy. Stir the mixture rapidly for 30 seconds after each 5-minute interval for 1 hour. This is done because the reaction process of the salts and the alloy melt yields potassium fluoride as by-product which is highly injurious and oxidation

make the slag volume increase. After removing slag, the melt is carefully poured into the preheated moulds for Gravity casting.

3. RESULT AND DISCUSSION

Characterization Test: Table.1, shows the chemical composition of the aluminium alloy along with the aluminium alloy reinforced with 6% and 2% TiB₂.

The table value shows the percentage of various elements present in the alloy before and after reinforcement with titanium diboride. The amount of magnesium in the alloy shows a decrease in amount than the theoretically calculated value which is due to evaporation of magnesium during melting in the furnace. We can also observe the presence of titanium particles in the alloy after reinforcing it with titanium diboride. The loss in the amount of magnesium does not affect the hardness and wear properties of the alloy as the major contributor of hardness to the alloy is the presence of titanium diboride particles present in the aluminium matrix.

Table.1. Chemical composition of Alloy and Composite

Element (wt.%)	Mg	Si	Fe	Cu	Mn	Zn	Ti	Cr	Al
0% TiB ₂	0.696	0.700	0.100	0.014	0.100	0.090	0.000	0.000	Bal.
6% TiB ₂	0.159	8.010	0.181	0.014	0.090	0.094	7.880	0.003	Bal.
2% TiB ₂	0.133	7.905	0.192	0.015	0.090	0.093	3.550	0.004	Bal.

Micro hardness test:

Aluminium alloy:

Table.2. shows the hardness values of aluminium alloy.

Wt.% TiB ₂	Hv _(0.2)	Hv _(0.5)	Hv _(1.0)
0%	63	62	59
	66	61	58
	69	60	56

The hardness test is carried out on three different samples of the alloy with varying loads of 0.2, 0.5 and 1.0 kg. Figure.1, indicates a decrease in the value of hardness with the increase in the load applied.

Figure.1. Hardness value test on aluminium alloy for varying loads

Aluminium Alloy Reinforced With 2% TiB₂: Table.3, shows the hardness values of 2% composite. The hardness test is carried out on three different samples of the 2% TiB₂ with varying loads of 0.2, 0.5 and 1.0 kg. Figure.2, indicates a decrease in the value of hardness with the increase in the load applied.

Table.3. Hardness test values on 2% composite

Wt.% TiB ₂	Hv _(0.2)	Hv _(0.5)	Hv _(1.0)
2%	83	79	72
	85	77	70
	81	75	71

Figure.2. Hardness value test on 2% composite for varying loads

Aluminium Alloy Reinforced With 6% TiB₂: Table.4, shows the hardness values of 6% composite. The hardness test is carried out on three different samples of the 6% TiB₂ sample with varying loads of 0.2, 0.5 and 1.0 kg. Figure.3, indicates a decrease in the value of hardness with the increase in the load applied.

Table.4. Hardness test values on 6% composite

Wt. % TiB ₂	Hv _(0.2)	Hv _(0.5)	Hv _(1.0)
6%	89	78	75
	87	79	73
	88	77	71

Figure.3. Hardness value test on 6% composite for varying loads

Hardness Comparison among Aluminium Alloy and 2%, 6% Composite: Figure.4, shows the hardness comparison among aluminium alloy and 2%, 6% composite. Figure.4, shows a marked improvement in the hardness value of the composite as compared to that of the aluminium alloy.

Figure.4. Hardness comparison among aluminium alloy and 2%, 6% composite

The hardness value also decreases for all the samples with an increase in the load applied. The 6% TiB₂ sample shows the highest hardness value among the three samples followed by the 2% TiB₂ sample and the aluminium alloy. The hardness values decreases steeply for the reinforced samples when the load applied increases from 0.2 kg to 0.5 kg and thereafter the decrease is gradual. This indicates that the composite has high hardness values for lower loads and the value decreases as the amount of load applied is increased.

Wear Load Test: The wear rate is compared between the normal alloy (unreinforced) and the reinforced composites in this section. It is found from Figure that the wear rate of both matrix alloy and composite specimens increased with increase in applied load. However, a lower wear rate was obtained for the MMC alloy when compared with matrix alloy. Also, the wear rate decreased with an increase in TiB₂ content in the Al/TiB₂ MMC specimens.

Aluminium Alloy: Table.5, shows the result of wear load test conducted on aluminium alloy.

Table.5. Wear load test values on aluminium alloy

Load Applied	Initial Weight (gm)	Final Weight (gm)	Abrasion Loss (gm)	Loss %
1 Kg	1.6762	1.4215	0.2547	15.19
2 Kg	1.3589	1.0174	0.3415	25.13
3 Kg	1.1400	0.6710	0.4690	41.14

Figure.5. Wear test in aluminium alloy as a function of weight loss

Figure.5, shows that the abrasion loss increases with the load applied for the aluminium alloy. The loss is minimum at the starting when the load applied is 1kg and increases thereafter with the load applied.

The results indicate that at lower loads, relatively low wear rates exist, indicating the regime of mild wear in which the composites demonstrate significant wear-resistance than the alloy counterpart. At higher loads, the materials show a quick increase in wear rate. At loads greater than transition load, severe wear occurs leading to seizure of the materials

Aluminium Alloy Reinforced with 2% TiB₂: Table.6, shows the result of wear load test conducted on 2% composite.

Table.6. Wear load test values on 2% composite

Load Applied	Initial Weight (gm)	Final Weight (gm)	Abrasion Loss (gm)	Loss %
1 Kg	1.5954	1.3807	0.2147	13.46
2 Kg	1.3807	1.0877	0.2930	21.22
3 Kg	1.0877	0.6866	0.4011	36.88

Figure.6. Wear test in 2% composite as a function of weight loss

Figure.6, shows that the abrasion loss increases with the load applied for the 2% TiB₂ sample. The loss is minimum at the starting when the load applied is 1kg and increases thereafter with the load applied.

Aluminium Alloy Reinforced With 6% TiB₂: Table.7, shows the result of wear load test conducted on 6% composite.

Table.7. Wear load test values on 6% composite

Load Applied	Initial Weight (gm)	Final Weight (gm)	Abrasion Loss (gm)	Loss %
1 Kg	1.6118	1.4165	0.1953	12.12
2 Kg	1.4165	1.1400	0.2765	19.52
3 Kg	1.1400	0.7241	0.4159	36.48

Figure.7. Wear test in 6% composite as a function of weight loss

Figure.7, shows the abrasion loss increases with the load applied for the 6% TiB₂ sample. The loss is minimum at the starting when the load applied is 1kg and increases thereafter with the load applied.

Abrasion Loss Comparision among Aluminium Alloy And 2%, 6% Composite:

Figure.8. Abrasion loss% among aluminium alloy and 2%,6% composite with varying loads

Figure.8, shows that abrasion loss is minimum for the 6%TiB₂ sample and is minimum for the aluminium alloy. The 2% TiB₂ sample has an intermediate abrasion loss as should be the case. The Figure also shows that with the increase in the load applied, the abrasion loss also increases. The abrasion loss shows a gradual increase for

weights up to 2kg and increases steeply thereafter for increasing loads. The abrasion loss is maximum in case of the aluminium alloy. The trend in case of the aluminium alloy is different from the other two reinforced samples and shows the steepest rise in abrasion loss when the load is increased from 2kg to 3kg.

Compression Load Test:

Aluminium Alloy Reinforced With 2% TiB₂:

Figure.9. Stress vs. Strain graph for aluminium alloy reinforced with 2% TiB₂

Figure.9, shows the stress versus strain graph for the aluminium alloy reinforced with 2% titanium diboride. The graph follows almost a straight line in the starting region of the graph which is referred to as the area of uniform deformation. After reaching a peak stress value of 238.56 N/mm², the graph is non-uniform which is also referred as the area of non-uniform deformation.

Aluminium Alloy Reinforced With 6% TiB₂:

Figure.10. Stress Vs. Strain graph for aluminium alloy reinforced with 6% TiB₂

Figure.10, shows the stress versus strain graph for the aluminium alloy reinforced with 6% titanium diboride. The graph follows almost a straight line in the starting region of the graph which is referred to as the area of uniform deformation. After reaching a peak stress value of 248.02 N/mm², the graph is non-uniform which is also referred as the area of non-uniform deformation.

Compressive Strength Comparison among Aluminium Alloy and 2%, 6% Composite:

Table.8. Compressive strength comparison

TiB ₂ (%)	0%	2%	6%
Compression Strength (MPa or N/mm ²)	180.45	238.56	248.02

Figure.11, shows a comparison of the compressive strength among the aluminium alloy and 2%, 6% TiB₂ composite. The comparison shows that the compressive strength of the aluminium alloy reinforced with 6% titanium diboride is maximum while the compressive strength of the aluminium alloy is the minimum among the three samples. The 2% TiB₂ sample shows an intermediate value of compressive strength among the three samples. The increase in the compressive strength of the alloy when it is reinforced with titanium diboride indicates that the alloy can now withstand greater loads tending to reduction in size.

Figure.11. Compressive strength bar chart

Sliding Wear Test:

Comparison Between Aluminium Alloy and Aluminium Alloy Reinforced With 6% TiB₂:

Figure.12. Coefficient of friction as a function of temperature

Comparison between aluminium alloy and aluminium alloy reinforced with 6% TiB₂: Figure.13, shows that the coefficient of friction for composite is less than that of the alloy. Figure.12, shows that coefficient of friction starts to increase with increase in temperature of the working conditions.

Figure.13. Coefficient of friction as a function of wt.% of TiB₂

Microstructure Analysis: The microstructure of matrix base alloy and the Al/TiB₂ MMC composites is shown in Figure.4 for load case of 30 N and speed of 300 rpm. The worn surface was characterized by fairly long and extensive ploughing grooves for the aluminium alloy. Short cracks parallel to sliding direction were present at the bottom of the grooves. It is noticed from Figure.4 that groove width size in the aluminium alloy was bigger when compared to composites.

Aluminium Alloy:

Figure.14. Aluminium alloy at 50X magnification

Figure.15. Aluminium alloy at 100X magnification

The reflective part of the magnified images indicated in Figure 14 and 15 shows the presence of aluminium matrix.

Aluminium Alloy Reinforced With 6% TiB₂:

Figure.16. Aluminium alloy reinforced with 6% TiB₂ at 50X magnification

Figure.17. Aluminium alloy reinforced with 6% TiB₂ at 100X magnification

The reflective part of the magnified images indicated in Figure.16 and 17, shows the presence of aluminium matrix while the darker region surrounding the aluminium matrix shows the presence of TiB₂ particles.

Aluminium alloy reinforced with 2% TiB₂:

Figure.18. Aluminium alloy reinforced with 2% TiB₂ at 50X magnification

The reflective part of the magnified images indicated in Figure.18 and 19 shows the presence of aluminium matrix while the darker region surrounding the aluminium matrix shows the presence of TiB₂ particles.

The discontinuous TiB₂ particles reinforcement phase, being non uniform in size and irregularly shaped, were found to be dispersed randomly through the aluminium alloy matrix. Agglomerations of the TiB₂ particles reinforcements of varying sizes and shapes were observed to be present in the Al alloy matrix. The micro hardness of the base alloy increased with addition of TiB₂ particulate.

Figure.19. Aluminium alloy reinforced with 2% TiB₂ at 100X magnification

Scanning electron micrographs of the fractured surface of the base alloy and Al MMC specimens provided evidences for locations where the reinforcement particles had resided in the matrix.

4. CONCLUSION

- The characterisation test confirms the presence of titanium diboride particles in the aluminium alloy matrix and hence the operation becomes feasible for industrial applications.
- The results of the microstructural studies revealed the absence of voids and reaction products, indicating good interfacial integrity between the in-situ produced titanium diboride.
- The average grain size of the aluminium titanium diboride composite is less than the aluminium alloy which indicates an increase in the strength of the composite. The decrease in the grain size of the composite may be attributed to the presence of fine titanium diboride particles.
- The micro hardness test shows an increase in the strength of the composite when compared to that of the alloy which may be attributed to the presence of titanium diboride particles in the composite.
- The compression load test shows an increase in the compressive strength of the aluminium titanium diboride when compared to that of the aluminium alloy which may be attributed to grain refinement which makes the dislocation of the particles difficult. This in turn improves the resistance to plastic deformation resulting in increased hardness.

- The wear load test shows that abrasion loss decreases with the reinforcement of titanium diboride particles in the aluminium alloy which indicates an increase in wear resistance of the alloy when it is reinforced with titanium diboride. Further, an increase in the amount of reinforcement further increases the wear resistance of the alloy.
- The sliding wear test shows that the coefficient of friction decreases when the aluminium alloy is reinforced with titanium diboride particles.

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