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Influence of Hot forging on Tribological behavior of Al6061-TiB_2 In-situ composites

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Abstract: Al6061-TiB_2 metal matrix composite was fabricated by stir casting technique via in-situ reaction, using mixture of Al6061 alloy, Potassium tetraflouroborate salt (KBF_4) and tetraflourotitanate (K_2TiF_6). The cast composites were processed to hot forging, SEM studies; X-ray Diffraction studies (XRD), Microhardness and Dry friction and wear tests. Pin on disc type machine was used to perform tribological tests over a load range of 20-100N and sliding velocities of 0.314-1.57m/s. SEM and XRD studies confirms formation of fine in-situ TiB_2 particles. Composites exhibit higher Microhardness, improved wear resistance and Lower COF with formation of TiB_2 particles when compared with the unreinforced alloy. Compared to cast alloy and its Composites, forged alloy and its composites show superior Tribological behavior under similar test conditions.

1. Introduction

Ceramic added Aluminium Matrix Composites are extensively used for Engineering applications. Reinforced Aluminium composites exhibits better frictional and wear characteristics compared to unreinforced ones [1-2]. Various researchers have reported on tribological behaviour of conventionally prepared Aluminium Metal Matrix composites reinforced with popular ceramic materials, for instance SiC[3], Al_2O_3 [4], graphite[5], TiC[6], B_4C[3], etc. On the other hand TiB_2 is emerged as an outstanding material as reinforcement for Aluminium Matrix composites with unique mechanical and physical properties such as high Elastic Modulus, high Hardness, high Thermal Conductivity and high melting point [7-8]. It has been reported that, conventional preparation of Metal Matrix Composites by Stir casting route leads to various problems such as agglomeration of ceramic particles owing to poor wettability of ceramic particles, poor bond between matrix and reinforcements, interfacial reactions between matrix and reinforcements [9-10].

As an alternative to conventional processing techniques, in-situ processing of Al Metal Matrix Composites offer several advantages, such as formation of fine ceramic particles, excellent union between matrix and reinforcement, good thermal stability etc [11-12].

On the other hand secondary processing techniques like Extrusion, Forging, Rolling of MMC’s contributes to improvement in characteristics of Mechanical and Tribological of Aluminium MMC’S [13]. Ramesh et al have studied on wear characteristics of Aluminium composites, It is observed that extruded composites possess lower rate of wears under all test conditions studied [4]. J.An, Y.B.Liu [14] et al have studied friction and wear characteristics of hot extruded leaded aluminum alloys. They have found that the co-efficient of friction and rate of wear decreased remarkably with hot extruded ones.

Dasguptha et al [15] have worked on tribological characteristics of cast and extruded SiC reinforced Aluminum composites, It has been noticed by them that under all the conditions studied extruded composites exhibited lower material loss than their cast counter parts. Reddappa et al [16] have studied on wear behavior of hot rolled Al-Beryl composites, results shows that hot rolled composite possesses lower specific rate of wears compared to cast ones owing to Dynamic recrystalization during rolling process.

However, too little information is available on the Tribological behavior of hot forged Composites. Forging process is widely used in industrial sector due to fact that it is possible to produce near net shaped parts in short duration. Further, due to rapid plastic deformation forging process induces larger strength to the components. In view of above facts, present work focuses on tribological characterization of cast and forged Al6061-TiB_2 composites processed by in-situ reaction technique.

2. Experimental details

Al6061-TiB_2 composites were synthesized by first melting the base Aluminium 6061, obtained in a crucible made of graphite using electric resistance furnace. Molten Aluminium alloy heated at a temperature of 860 ^{0}C was added with halide salts, Potassium hexafluorotitanate salt (K_2TiF_6) and potassium tetrafluroborate (KBF_4) in a stoichiometric ratio to obtain, 5wt% TiB_2, 10wt% TiB_2. The molten composite mixtures were stirred constantly by a mechanical stirrer for its uniform distribution of TiB_2 throughout the base metal. The Cast Metal Matrix Composites and Aluminium 6061 alloy were processed to Open Die Hot Forging. More details on the composite preparation and forging are available in our earlier works[6,13].Alloy and composites processed through cast condition and forging conditions were examined using SEM, XRD, Microhardness and tribological studies. More details on SEM studies, Microhardness test, Friction and wear studies are available in our published works [13].

Table 1. Chemical composition of Al6061 alloy

Elements	Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Sn	Mg	Cr	Al
Percentage	0.43	0.43	0.24	0.139	<0.05	0.024	0.006	0.022	0.001	0.802	0.184	Balance

3. Results and Discussions.

3.1 SEM and XRD of In-situ composite

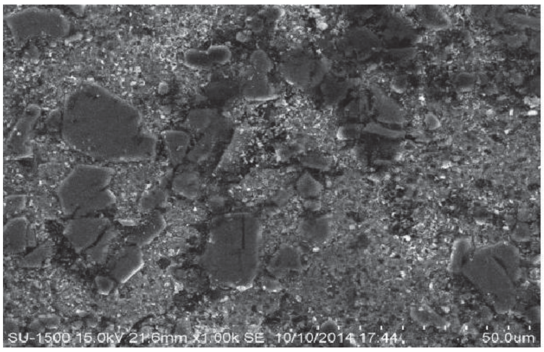


Figure1. SEM of cast Al6061-TiB_2 Composite

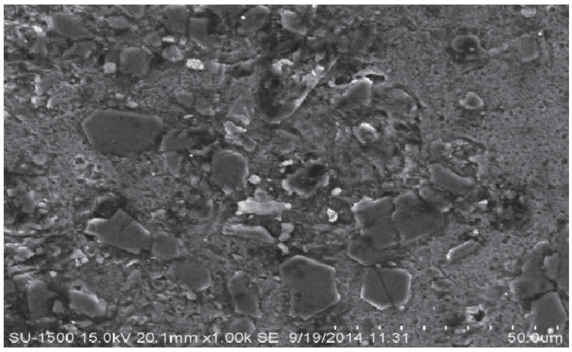


Figure 2. SEM of forged Al6061-TiB_2 composite

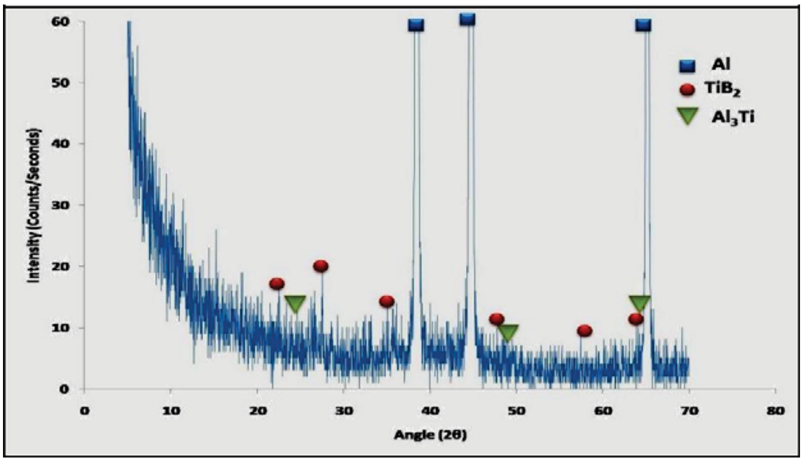


Figure 3. X-ray difraction pattern of Al6061-TiB_2 composite

'Figure1'and 'Figure 2' shows SEM of primary(cast) and secondary(forged) processed Al6061-TiB_2 in-situ metal matrix composite. It is observed those fine tiny particles are distributed in fairly homogenous manner all through the unreinforced alloy in primary and secondary processed conditions. Further, the micrograph also shows other dominant phases such as Al_3Ti, In addition to in-situ TiB_2 particles. It is also observed from the micrograph that cubic crystal, hexagonal and irregular plate shaped TiB_2 particles are dispersed throughout the matrix alloy. XRD pattern of Al6061-TiB_2 Composite shows formation of TiB_2 in-situ particles along with Al_3Ti phase is as shown in 'Figure3'. Micrograph does not show any fracture or debonding of reinforced particles after forging.

3.2 Microhardness

'Figure 4' shows difference of microhardness of primary and secondary processed Al6061 alloy and Al6061-TiB_2 in-situ matrix composite. It is observed that composite shows a higher microhardness when compared with matrix alloy in both conditions. Further, There is a increase in microhardness as the percentage of TiB_2 particles increases in both primary and secondary processing conditions. Compared to primary and secondary processed composite increased by an amount of 33% and 44% respectively. A maximum of 37% improvement in hardness was observed in the developed Composite. The radical enhancement in the hardness composite may be ascribed to the existence of hard particles of ceramic which demonstrate larger resistance to indentation of hardness, by depicting its inherent property of hardness to alloy.

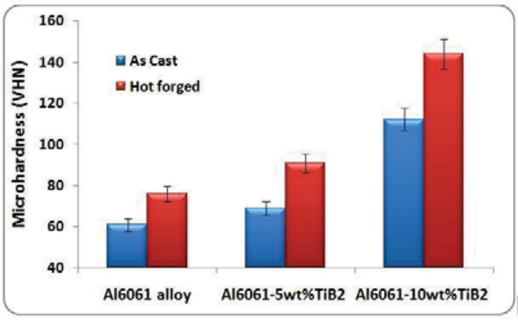


Figure 4. Variation of microhardness in Al6061-TiB_2 composite

3.3 Co efficient of friction (COF)

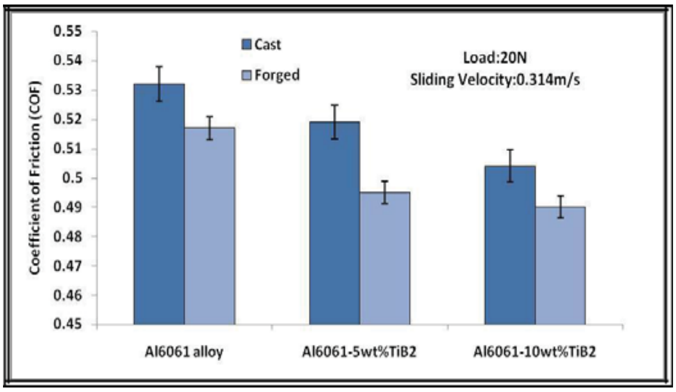


Figure 5. Variation of COF of cast and forged Al6061 alloy and Al6061-TiB_2 composite

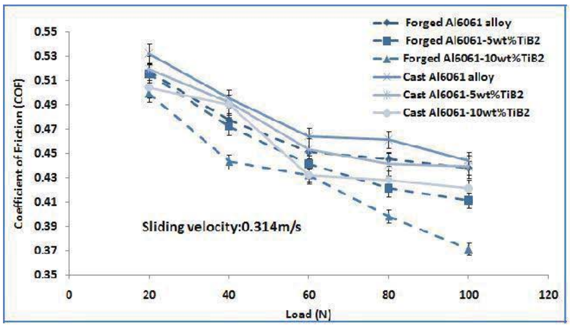


Figure 6. Variation of COF of cast and forged Al6061 alloy Al6061-TiB_2 composite with load

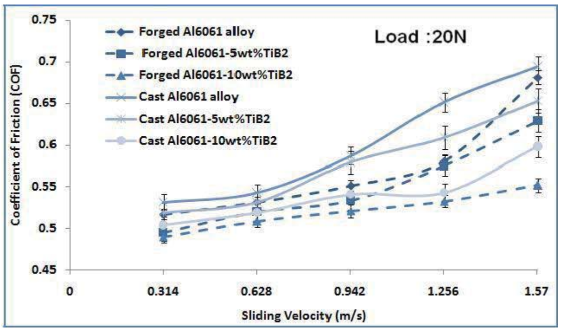


Figure 7. Variation of COF of cast Al6061 alloy and Al6061-TiB_2 composite with sliding velocity

'Figure 5' Shows the difference in COF of primary and secondary processed Al6061 alloy and Al6061-TiB_2 in-situ metal matrix composites. It is clear that addition of TiB_2 particles in the matrix alloy significantly alters the friction coefficient in both primary and secondary processed condition. It is noticed that COF decreases with increase TiB_2 content. Reduction in friction coefficient with increase in TiB_2 content may be ascribed to antifrictional characteristics of Titanium diboride particles and formation of tribolayer at the interface between steel disc and test sample. The mixture of oxides layer at the interface is generally termed as mechanically mixed layer (MML) or tribolayer which increases as the percentage of reinforced particles increases and is known to reduce the COF as studied by several researchers[17-18].

Basically, the triboloayer or MML consists of oxides of aluminum and iron which are known for their lubrication characteristics. Compared with primary processed alloy and composites, secondary processed alloy and composites exhibited lower COF under identical test conditions which may be due to improved distribution of TiB_2 particles. Uniformity in distribution of reinforcement enhances the antifrictional characteristics of composite materials as studied by many researchers [19-20].

This layer of oxide present between mating surfaces is an amorphous hydrated film which alters the friction characteristics by introducing viscous components of shear and acts as solid lubricants [21-22]. In the present study, development of such oxides layer at interface is confirmed by carrying out the XRD analysis on the worn surfaces of the test sample('Figure 8').

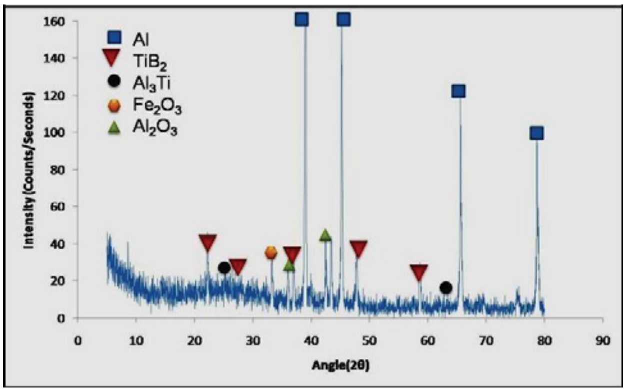


Figure 8. X-ray diffraction pattern of worn Al6061-10wt%TiB_2 composite

'Figure 6'and 'Figure 7' Shows the difference of COF of primary and secondary processed alloy and its composites with load and sliding velocity. The figure indicates that COF decreases with increase in load. Probably thermal softening below the contact surface owing to increase in temperature may be the reason for reduced COF. Lower coefficients of friction at higher loads are due to presence of fragmented particles which will be free to roll between mating surfaces resulting in lower COF [23].

Conversely, an increased trend in COF is noticed with increase in sliding velocity in both primary and secondary processed conditions. Increased COF with increase in sliding velocity may be due to following facts [24].

a. Fragmentation of tribo-layers / oxide layers with increase in sliding velocity.
b. Higher sliding velocities results in increased surface temperature leading to severe plastic deformation which can contribute to formation of more curtness junctions on the mating surfaces causing higher COF.

However, under all the loads and sliding velocities studied, forged composites exhibited lower COF when compared with cast ones.

3.4 Wear test

'Figure 9' Shows the difference of rate of wear of primary and secondary processed Al6061 alloy and Al6061-TiB_2 composite. It can be seen from the graphs that rate of wear decreases with increase in the percentage of TiB_2 particles in both primary and secondary processed conditions. TiB_2 particles contributes effectively to reduce the rate of wear by acting as load bearing elements in the initial sliding process and also offer resistance to plastic deformation[25].

Table-2. Tensile Strength of Al6061 alloy and its composites

Material	Tensile strength (MPa)	
	Primary processed	Secondary processed
Al6061 alloy	92	110
Al6061-5wt%TiB_2	120	136
Al6061-10wt%TiB_2	140	168

Higher wear resistance of hot forged in-situ composite may be due to superior hardness and tensile strength of secondary processed composites compared to primary processed ones. Betterment in mechanical properties generally adds wear and seizure resistance of composite materials. In addition to this, hot forging results in extensive grain refinement. Presence of TiB_2 particles in the matrix reduces the actual contact area of matrix material and contributes to reduction in rate of wear. Further, As a result of in- situ processing, composites posses excellent interfacial bond between Al6061 alloy and TiB_2 particles, Due to this good bond it enhances the wear resistance of composites. Presence of mechanically mixed layer (MML) at the interface between test sample and steel disc mainly includes oxides of aluminium and iron as discussed earlier. Improved wear resistance of secondary processed composites compared with primary processed ones may also be attributed to uniformity in dispersion of TiB_2 particles as discussed earlier. Further, it is also reported that some of the porosities observed during casting conditions are eliminated after forging and reduces the extent of plastic deformation and crack propagation contributing to improved wear resistance [26-27].

'Figure 10' and 'Figure 11' shows the difference of rate of wear of primary and secondary processed matrix alloy and Al6061-TiB_2 in-situ metal matrix composites with load and sliding velocities. It is observed that rate of wear increases rigorously with increase in loads and sliding velocities. Increase in rate of wear at higher loads may be attributed to the fact that the extent of the plastic deformation is severe resulting in increased rate of wear. Generally larger plastic deformation leads to subsurface cracking and delamination which in turn causes larger material removal. At higher sliding velocity tribolayer or mechanically mixed layer will be destructed and becomes unstable resulting in higher rate of wear Further; Increase in temperature at higher speed softens the contact surface and increases the rate of wear.

Increase in rate of wear is due to fact that, higher sliding velocities causes subsurface deformation leading to increase in rate of wears. Under all the loads and sliding velocities composites exhibited a significant improvement in wear resistance compared with Al6061 alloy. Superior wear resistance of the composites at higher loads and sliding velocities are due to presence of non-deformable TiB_2 particles. Further, secondary processed alloy and its composites show remarkable decrease in rate of wear. Under identical test conditions

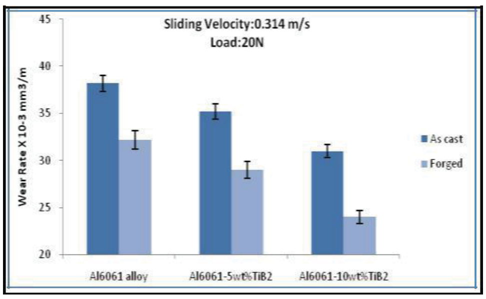


Figure 9. Variation of rate of wear of cast and forged Al6061 alloy and Al6061-TiB_2 composite

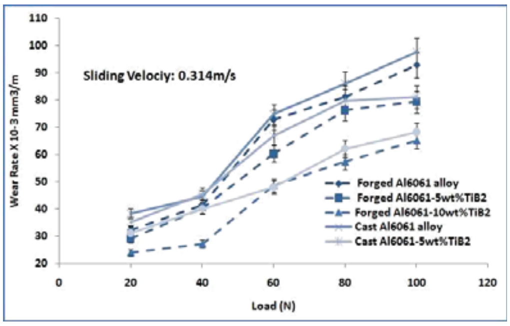


Figure 10 . Variation of rate of wear of cast alloy and Al6061-TiB_2 composite with load

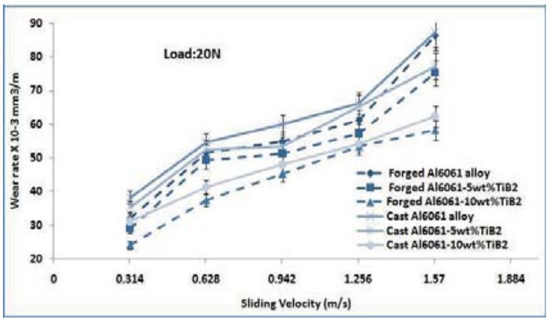
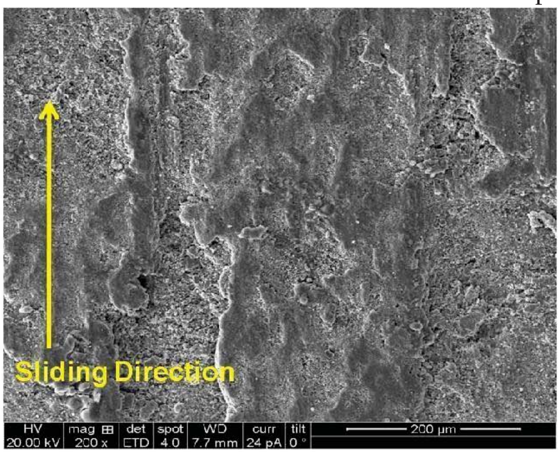


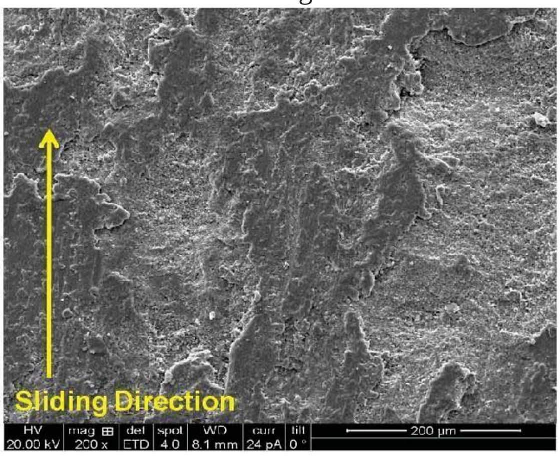
Figure 11. Variation of rate of wear of cast Al6061 alloy and Al6061-TiB_2 composite with sliding velocity

3.4.1 Worn surface Analysis

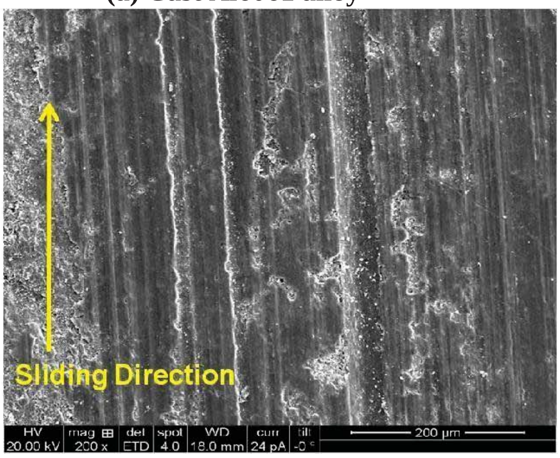
'Figure 12'(a-d) shows scanning electron microscopy of worn out surfaces of primary and secondary processed Al6061-TiB_2 in-situ metal matrix composites at various loads and sliding velocities.



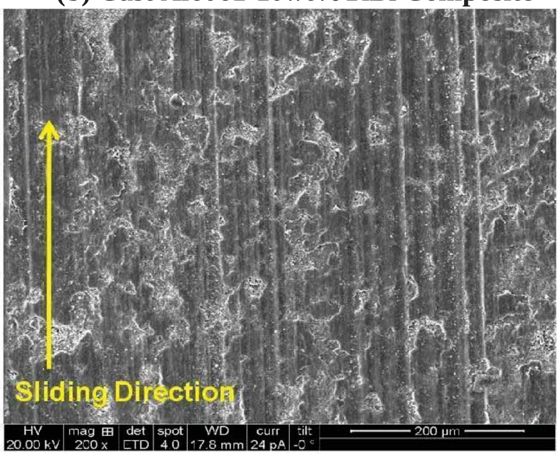
(a) Cast Al6061 alloy



(b) Cast Al6061-10wt%TiB_2 Composite



(c) Forged Al6061 alloy



(d) Forged Al6061- 10wt%TiB_2 Composite

Figure 12.(a-d) Worn out surfaces of Al6061 alloy and its composites

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It is noticed that, numerous scratches were seen on both unreinforced alloy and in-situ composites for a given load and sliding velocity. However, the scratch formation in forged alloy and its composites are found to be less compared to cast ones which may be due to improvement in bulk mechanical properties. In case of unreinforced alloy, continuous and long grooves are noticed commonly. In case of cast system scanning electron micrograph shows heavy scars and craters. However, on the other side, forged composites shows micro plouging which may be due to abrasive action of fractured particles. The Extent of plouging increases as applied load and sliding velocity increases. At higher loads and speeds extensive plastic deformations were observed. Worn out surfaces do not show any symptoms of pullout or debonding from the matrix indicating excellent union between matrix and reinforcement as a beneficial result of in-situ processing.

4. Conclusion

Al6061-TiB_2 Composite was synthesized by in-situ reaction and Hot Forged successfully. SEM , XRD studies confirm the existence of in-situ TiB_2 particles in the composite Forged composites shows more uniformity in dispersion of TiB_2 particles. Developed secondary processed Composite shows reduced co-efficient of friction at all loads and sliding velocities and a decrease in rate of wear was observed when compared to the cast composite.

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