Perspectives in Science (2016) 8, 172—175

ELSEVIER
ScienceDirect
journal homepage: www.elsevier.com/pisc

Corrosion behaviour of TiB_2 reinforced aluminium based in situ metal matrix composites☆

G.S. Pradeep Kumar[a,*], R. Keshavamurthy[b], Prachi Kumari[a], Chirag Dubey[a]

[a] Automobile Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India
[b] Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India

Received 13 January 2016; accepted 4 April 2016
Available online 23 April 2016

KEYWORDS
Al6061;
TiB_2;
Salt spray test;
Forging

Summary This paper focuses on corrosion characteristics of cast and forged aluminium 6061 based composites reinforced with TiB_2 particles. Composites were synthesised by in situ technique using potassium hexafluorotitanate salt (K_2TiF_6) and potassium tetrafluroborate (KBF_4) halide salts by stir casting route at a temperature of 850 °C. Cast aluminium alloy and its in situ composites were subjected to open die drop forging at a temperature of 500 °C. Both cast and forged alloy 6061 and in situ composites were then subjected to microstructure studies, salt spray test. Salt spray test was conducted as per ASTM B117 standard test procedure using 5% sodium chloride test solution. Result reveals that, forged alloy and its in situ composites exhibited improved corrosion resistance compared to cast ones.

Introduction

Aluminium 6000 series alloys are being used extensively for various engineering applications due to its superior strength to weight ratio. Possessing dimensional stability, excellent structural rigidity and a low thermal expansion coefficient (Kumar et al., 2008), its excellent formability allows easier usage for secondary processes such as hot extrusion, rolling and forging (Ramesh et al., 2011; Ramesh and Safiulla, 2007). The properties of pure aluminium can be improved to a great extent by using reinforcements in the form of ceramic such as SiO_2, Al_2O_3 and SiC as particulates to name the more common ones (Zou et al., 2003; Birol, 2007). Aluminium alloys are used in the automobile industry for production of pistons, connecting rod etc. (Bharath et al., 2014; Pradeep Kumar et al., 2015) Research now also extends to aluminium composites that use continuous/discontinuous fibres, whiskers with

☆ This article belongs to the special issue on Engineering and Material Sciences.

* Corresponding author. Tel.: +91 9538661599.
E-mail address: pradeepgs.87@gmail.com (G.S.P. Kumar).

http://dx.doi.org/10.1016/j.pisc.2016.04.025

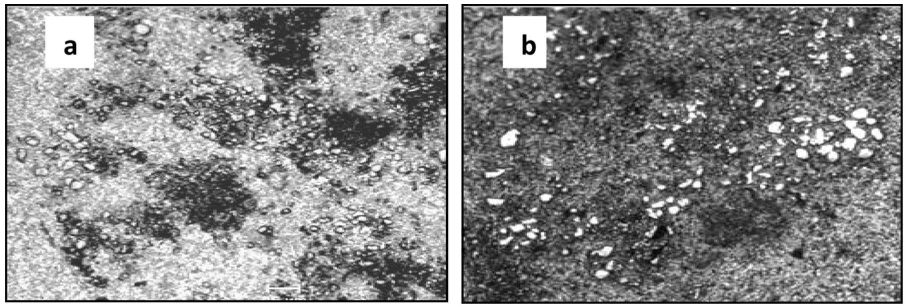


Figure 1 (a, b) Optical micrographs of Al6061-TiB_2 in situ composites.

varying volume fractions. Compared with the commonly used ceramic reinforcements, TiB_2 takes the higher stand due to its exceptional characteristics in terms of higher thermodynamic stability, higher modulus (530×10^3 GPa), higher hardness and low density (Gao et al., 2015; Tee et al., 1999). In recent years, researchers are focusing on development of aluminium—TiB_2 in situ metal matrix composites owing to its several advantages over ex situ technique. The exothermic reaction and better wettability of TiB_2 with aluminium is causative for improved in situ preparation of aluminium alloys allowing a better interface bonding and less differences between thermo physical properties during heating between the two (Tee et al., 1999; Smagorinski et al., 1998). Poor wettability of ceramics leads to uneven dispersion, lower mechanical properties and high porosity (Bharath et al., 2014). Selection of fabrication method is important as the mechanical properties of the resulting alloy depend on it (Ramesh and Safiulla, 2007; Bharath et al., 2014). Amongst various in situ fabrication methods utilizing liquid metallurgy, the more prevalent method is to use halide salts. On the other hand, it is reported that secondary process such as extrusion, forging rolling are commonly used methods to processing aluminium alloys for many engineering applications. Further, secondary processing of aluminium based composites offers several benefits like uniform dispersion of reinforcements, elimination of casting defects, excellent union between matrix and reinforced phase etc. Among all secondary process exist; forging method induces a significant improvement in terms of strength and stiffness of aluminium components. Literature review reveals that limited work been carried out in terms of characterizing corrosion behaviour of cast and forged aluminium—TiB_2 composite processed by in situ reaction technique. In light of above, the present work focuses on development of cast and hot forged Al6061-TiB_2 in situ metal matrix composites and characterizing its microstructure and corrosion behaviour by using salt spray test.

Experimentation

Al6061-TiB_2 composites were prepared by first melting the base aluminium 6061, obtained in a graphite crucible using electric resistance furnace. Molten aluminium alloy maintained at a temperature of 860 °C was added with halide salts, potassium hexafluorotitanate salt (K_2TiF_6) and potassium tetrafluroborate (KBF_4) in a stoichiometric ratio to obtain, 5 wt% TiB_2, 10 wt% TiB_2. The cast alloy and its composites were subjected to open die hot forging. More details on the composite preparation and forging are available in our earlier works (Pradeep Kumar et al., 2015). Cast and forged samples of alloy and its composites were machined to the size of $10 \times 10 \times 10$ mm cubes and polished metallographically. The polished samples were then subjected to salt spray test as per ASTM B 117 standard test procedures, using salt spray chamber (Make-Calture Instruments, Model-NSSOI-01). The test samples were suspended in salts spray chamber at 30° from the vertical, containing dissolved 5% NaCl (AR Grade) in distilled water for a period of total of 96 h and weight loss was recorded at an interval of every 12 h. The pH and the temperature of the solution were maintained at 7.08 and 35 °C respectively. After the test, the samples were cleaned with running water and air dried before measuring for weight loss.

Results and discussion

Optical microstructure

Fig. 1(a) and (b) shows optical micrographs of cast and forged Al6061-alloy and Al6061-TiB_2 in situ composites. It is seen from the micrographs that TiB_2 particles are dispersed in aluminium matrix in a fairly uniform manner under both cast and forged conditions. However, when compared with the cast composites, forged composites shows more uniformity in distribution of TiB_2 particles, which can be attributed to thermo-mechanical deformation during forging.

Salt spray corrosion test

Fig. 2 shows variation of weight loss in salt sprayed specimens of cast and forged Al6061 alloy and its composites. It is observed from the graph that weight loss increases with increase in test duration for all the specimens. It is also observed that, composites exhibited marginally lower weight loss compared with alloys in cast and forged conditions.

Corrosion resistance of the in situ metal matrix composites increases with increase in TiB_2 content in cast and forged conditions. On the other hand, forged composites shows least weight loss compared to cast ones which may be attributed to the fact that, during thermo-chemical processing, TiB_2 particles are distributed more homogeneously compared with agglomerated cast composite which is evident from micro-structure studies. Further,

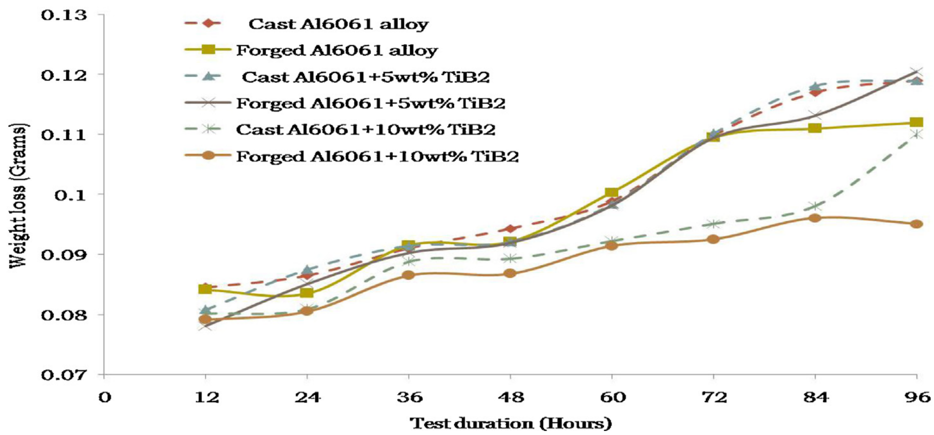
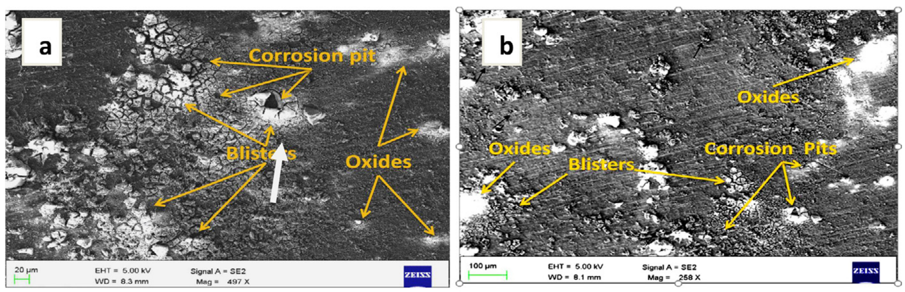


Figure 2 Salt spray test results for cast and forged alloy and its composites.



Cast Al6061-10wt%TiB_2 Forged Al6061--10wt%TiB_2

Figure 3 (a, b) SEM micrographs of cast and forged Al6061-TiB_2 in situ composites.

the improved corrosion behaviour of forged composites over cast ones may also be attributed to reason that some of the micro-porosities and other defects observed in casting process are minimised in forged composites. It is noticed from the graph that weight loss increases rapidly up to 36 h of exposure to salt spray action. After first 36 h of exposure, oxidation of aluminium leads to a formation of a protective oxide layer on the surface of the specimens. This oxide layer protects the underlying surface from further corrosion attack. However, the thickness and continuity of oxide/protection layer largely depends on the distribution and percentage of TiB_2 content in both cast and forged composites. Decrease in the rate of weight loss after 36 h of salt spray exposure may also be attributed to formation of oxide layer which contributes to weight gain. Further, it is also observed from the graph that the rate of oxidation is lower for forged samples when compared with cast ones. The cast alloy and its composites allow a larger amount of the base metal to be oxidised. TiB_2 reinforced samples are protected to a larger extent, owing to the fact that the quality of passive oxide layer is better than the non-reinforced samples.

Corrosion mechanism in in situ composite

Fig. 3(a) and (b) shows scanning electron micrographs of salt sprayed in situ composites. It can be clearly observed from the micrograph that; In situ composite is largely affected by pitting corrosion. This phenomenon is influenced by TiB_2 content and distribution. Among various corrosion mechanisms proposed by researchers, mechanism of breakdown of passive layer by chloride ions and penetration of Cl through the oxide layer is the significant mechanism observed. Formation of a protective passive layer on the surface exposed after initial with the solution/attacking Cl ions during initial exposure.

Localised dissolution at the metal/oxide interfacing producing a localised acidic environment increases the matrix dissolution beneath the oxide layer to form blister. The surface area which is unable to form the passive layer becomes instrumental in the formation of pits (Frankel, 1998; McCafferty, 2003). Formation of blister which is purported to be under oxide layer through the adsorption of Cl ions is favoured by positively charged surface of the samples with the intermetallic partners acting as local cathodes to the Cl ions. These blisters under favourable conditions enlarge and rupture to form a new open pit (Natishan and O'grady, 2014).

Conclusion

Al6061-TiB_2 in situ composites were synthesised by liquid metallurgy route and hot forged successfully. Corrosion of cast and forged alloy and its composites increases with increase in salt spray duration. Decrease in weight loss was observed with increased content of TiB_2 in both cast and forged conditions. However, under all conditions studied the corrosion resistance and forged alloy and its composites exhibited lower weight loss compared its cast counter parts.

Conflict of interest

None.

References

Bharath, V., Nagaral, M., Auradi, V., Kori, S.A., 2014. Preparation of 6061Al-Al_2O_3 MMC's by stir casting and evaluation of mechanical and wear properties. Proc. Mater. Sci. 6, 1658—1667.

Birol, Y., 2007. Response to thermal exposure of the mechanically alloyed Al—Ti/C powders. J. Mater. Sci. 42 (13), 5123—5128.

Frankel, G.S., 1998. Pitting corrosion of metals a review of the critical factors. J. Electrochem. Soc. 145 (6), 2186—2198.

Gao, Q., Wu, S., Lü, S., Duan, X., Zhong, Z., 2015. Preparation of in-situ TiB_2 and Mg_2Si hybrid particulates reinforced Al-matrix composites. J. Alloys Compd. 651, 521—527.

Kumar, S., Chakraborty, M., Sarma, V.S., Murty, B.S., 2008. Tensile and wear behaviour of in situ Al—7Si/TiB_2 particulate composites. Wear 265 (1), 134—142.

McCafferty, E., 2003. Sequence of steps in the pitting of aluminum by chloride ions. Corros. Sci. 45 (7), 1421—1438.

Natishan, P.M., O'grady, W.E., 2014. Chloride ion interactions with oxide-covered aluminum leading to pitting corrosion: a review. J. Electrochem. Soc. 161 (9), C421—C432.

Pradeep Kumar, G.S., Keshavamurthy, R., Ramesh, C.S., Bharathesh, T.P., 2015. Mechanical properties of hot forged Al6061-TiB_2 in-situ metal matrix composites. Mater. Today: Proc. 2 (4), 3107—3115.

Ramesh, C.S., Safiulla, M., 2007. Wear behavior of hot extruded Al6061 based composites. Wear 263 (1), 629—635.

Ramesh, C.S., Pramod, S., Keshavamurthy, R., 2011. A study on microstructure and mechanical properties of Al 6061—TiB_2 in-situ composites. Mater. Sci. Eng.: A 528 (12), 4125—4132.

Smagorinski, M.E., Tsantrizos, P.G., Grenier, S., Cavasin, A., Brzezinski, T., Kim, G., 1998. The properties and microstructure of Al-based composites reinforced with ceramic particles. Mater. Sci. Eng.: A 244 (1), 86—90.

Tee, K., Lu, L., Lai, M.O., 1999. In situ processing of Al—TiB_2 composite by the stir-casting technique. J. Mater. Process. Technol. 89, 513—519.

Zou, X.G., Miyahara, H., Yamamoto, K., Ogi, K., 2003. Quantitative evaluation on wear resistance of aluminum alloy composites densely packed with SiC particles. Mater. Sci. Technol. 19 (11), 1527—1530.