Corrosion Behaviour of Aluminium 6061-Silicon Nitride- Carbon Fiber Hybrid composite

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Abstract

Metal matrix composites containing reinforcements such as SiC, alumina, graphite and fly ash have been extensively studied to assess their mechanical properties as well as their corrosion resistance. Majority of the studies do report that improving the corrosion resistance of MMC's is really a challenging task owing to the following reasons: Processing defects galvanic reaction between the matrix and reinforcement, Weak bond between the matrix and the reinforcement, Formation of interfacial reaction products. The present work attempts to overcome the above challenges by using metallic coated reinforcements and also adopting secondary processing of the developed composites by means of hot extrusion. Al6061 -6Wt%Si_3N_4-1wt% C_f hybrid composites were developed by stir casting process followed by hot extrusion at temp of 550ºC with an extrusion ratio 1:10. The extruded matrix alloy and developed composites were subjected to metallographic studies and polarization studies in 3.5% NaCl environment. The corroded surfaces have been investigated using SEM with EDX to enunciate the mechanism of material removal.Si_3N_4 reinforced Al6061 composites have exhibited superior corrosion resistance in 3.5% NaCl solution when compared with matrix alloy and hybrid composite.

Keywords: Hybrid composite, hot extrusion, Silicon nitride (Si_3N_4), Carbon fibres(C_f), Polarization, Corrosion Current Density.

Introduction

Metal Matrix Composites are gaining wide spread applications in several technological fields, owing to the several advantages[1]. Metal Matrix Composites (MMCs) have many benefits such as high strength to weight ratio, high stiffness, high thermal stability, low structural weight, low density, good fabricability, high wear resistance, good corrosion resistance, high specific modulus and high fatigue life[2-6]. Metal alloys (especially aluminium) reinforced with addition of reinforcements such as SiC, Al_2O_3,graphite, fly ash, Si_3N_4, Carbon fibre find many applications which includes air frame components, automotive engine, brake disc components and bicycle frames as MMC materials are essentially isotropic and can be produced by either powder metallurgy or liquid metallurgy route[7-11]. However, there are still un explored applications where in MMCs can be an ideal choice especially in vanes and impellers handling chemicals. The feasibility of the use of MMCs in the above area can be explored by assessing the corrosion behavior of MMCs in corrosive environment. The focus of research on study of corrosion behavior of MMCs is limited, although, it is important aspect to judge the suitability of MMCs as a potential material to combat corrosion. Wheat et al. have reported that the anodic potentiodynamic polarization tests in the aerated 3.5% NaCl solution did not show much variation with increasing SiCp content. The polarization curves were almost identical[12]. Ramanathan et al. have observed that the pits initiates at flaws in the surface oxide, and the flaws corresponds to heterogeneities on the metallic surface. These heterogeneities were one or a combination of casting defects[13]. Trzaskoma et al. have found that the pits on the composites are significantly more numerous, shallow, and wider than those on unreinforced alloy[14]. Trowsdale et al. have found that the MMCs show increased susceptibility to pitting attack when compared to unreinforced matrix alloy, this attack arise from voids at the reinforcement/matrix interface. These voids forms due to the poor bonding or presence of cracked reinforcement particles at the matrix/reinforcement interface[15]. Bhat et al. have reported that Al6061/SiCp composites in the extruded state show relatively less corrosion attack compared to as cast condition, because of less defects in matrix and less agglomerates of SiCp[16]. The objective of the present investigation is aimed at studying the Corrosion Behaviour of Hot extruded Aluminium 6061-Silicon Nitride-Carbon Fiber Hybrid compositein 3.5% NaCl solution.

Experimental details

Preparation of Composites

Al6061 alloy and its composite(6Wt% Si_3N_4),hybrid composite(6 Wt% Si_3N_4+1 Wt% C_f) have been prepared by liquid metallurgy route as described in our earlier work [17].The reinforcements used in the present study was Ni-P coated Si_3N_4 and copper coated carbon fibres. The cast matrix alloy and its composite, hybrid composite were then subjected to hot extrusion at a temperature of 550^0C with an extrusion ratio of 1:10 using 200T hydraulic press.

Micro structural Studies

Samples were cut from the hot extruded base alloy, composite, hybrid composite and the surfaces were levelled using a belt polishing machine. This was followed by a rubbing with different grades from coarse to fine to remove the minor scratches. After emery polishing the samples were thoroughly washed, dried and polished on a velvet cloth using alumina as a abrasive on a two disc polishing machine. Further a highly polished mirror finished surfaces

were obtained using a diamond paste of grade 3µ. The highly polished surfaces were observed under metallurgical microscope and photographs were captured. (Courtesy: Advanced Metallurgical Laboratory, Bangalore.)

Corrosion Studies

Potentiostatic test

Both anodic and cathodic polarization studies on hot extruded base alloy, composite and hybrid composite have been carried out in 3.5% NaCl solution having pH 8 using potentiostat model CHI602D as shown in fig. 1. The Electrodes used are Ag/AgCl, platinum and sample having $1cm^2$ exposed area were used as reference, counter and working electrodes respectively, the samples were machined of size 20mm length, 10mm width and 1mm thickness as per ASTM standards G69-81[18]. Open circuit potential were measured and the experiments were conducted only after equilibrium was reached i.e. when a steady open circuit potential were observed to record both anodic and cathodic behaviour. A scan rate of 0.01 mv/sec was adopted. Using the plots of both anodic and cathodic, the corrosion current density have been evaluated using Tafel slope extrapolation.

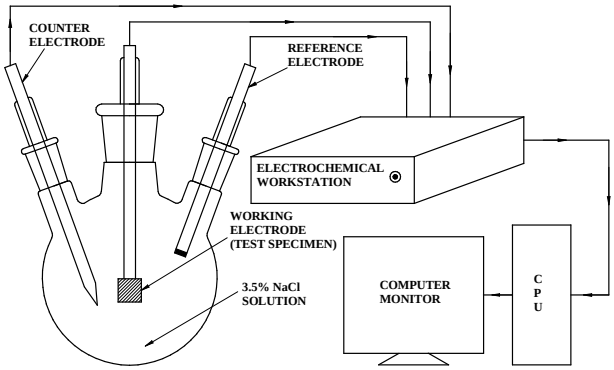


Fig. 1 Schematic arrangement of corrosion cell with potentiostat

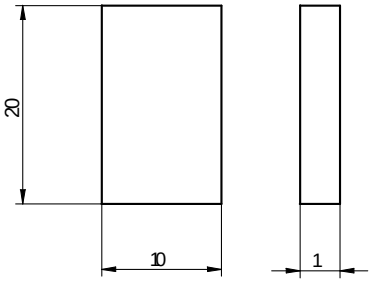


Fig. 2 Test Specimen

Results and Discussions

Microstructure Studies

The optical micrographs of hot extruded base alloy, composite and hybrid composite as shown in Fig. 3. The micrographs clearly indicate the evidence of minimal porosity in both hot extruded base alloy and the developed composites. The distribution of Ni-P coated Si_3N_4particles and copper coated carbon fibres in the matrix alloy is fairly uniform are observed as shown in Fig 3(b,c). Further, there is a drastic reduction in particle size within the matrix alloy after secondary process(extrusion) leads to improved mechanical properties.

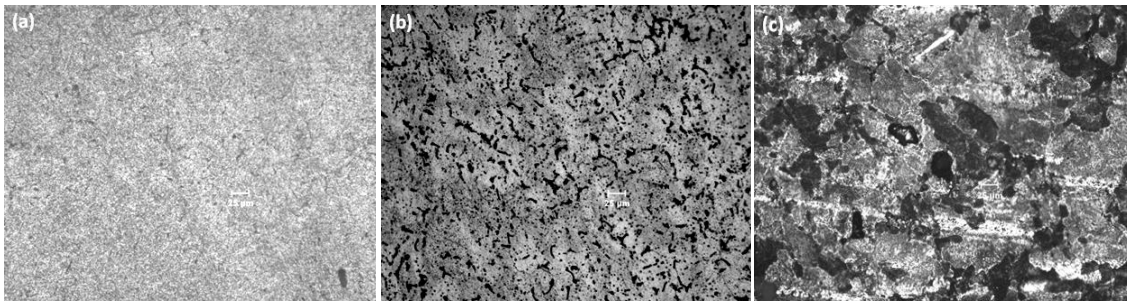


Fig. 3. *Microphotographs of (a) Hot extruded Al6061 (b) Hot extruded Al6061+6Wt% Si_3N_4 (c) Hot extruded Al6061+6Wt% Si_3N_4+1Wt% C_f*

Corrosion Studies

Polarization Test

Table 1:Electrochemical data in 3.5% NaCl

Material	I_{corr}(A)	E_{corr}(V)	Rp(Ω)
Hot extruded Al6061	$1.298X10^{-5}$	-0.6634	3339
Hot extruded Al6061+6Wt% Si_3N_4	$0.396X10^{-5}$	-0.5442	9690
Hot extruded Al6061+6Wt% Si_3N_4+1Wt% C_f	$1.255X10^{-5}$	-0.6320	3452

Table 1 shows the results from the potentiodynamic corrosion test in 3.5% NaCl. It is observed from the results that, the corrosion current density of hybrid composite increased when compared to composite. This can be attributed to the following reasons.

a) The corrosion current density seems to be strongly affected by the presence of carbon fibres and the fibre coating. Furthermore the carbon could diffuse in to aluminium during the fabrication of MMCs which is associated of a decrease of the integrity of the oxide film on the aluminium and leads to higher susceptibility of pitting. Similar observations have been reported for corrosion studies on aluminium reinforced with uncoated and coated carbon fibres[20].

b) Silicon nitride reacts with moisture and form thin silica layer which is highly protective in reducing the mass loss of the composite and improves the corrosion resistance. Similar observations have been reported by Ramesh et al[21].

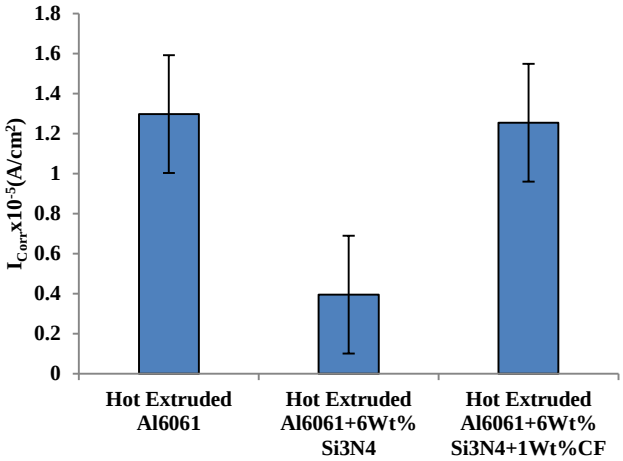


Fig. 4.*Variation of Corrosion Current density of Hot Extruded Al6061, its composite and hybrid composite.*

Fig.4 shows the Variation of Corrosion Current density of Hot Extruded Al6061, its composite and hybrid composite. It is observed that hot extruded 6 Wt% Si_3N_4 reinforced Al6061 composite have exhibited superior corrosion resistance in 3.5% NaCl solution when compared with matrix alloy and hybrid composite.

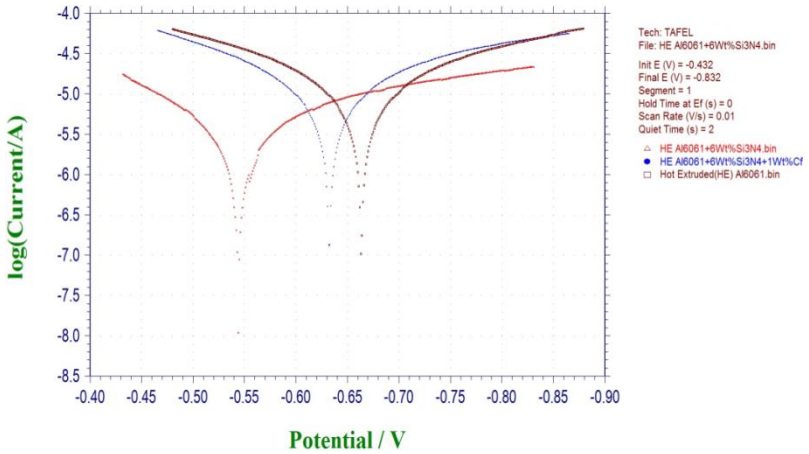


Fig. 5 Polarisation curves of Hot Extruded Al6061, its composite and hybrid composite.

Fig. 5 shows the Polarisation curves of Hot Extruded Al6061, its composite and hybrid composite in 3.5% NaCl.

It is observed that, the corrosion current density I_{corr} which is a indication of the extent of corrosion of material increases with the increased contents of reinforcements in the matrix alloy. This indicates that addition of Si_3N_4 particles and carbon fibers content in matrix alloy results in more material removal. This can be attributed to the following reasons.

a) Formation of extensive pits as observed in SEM photographs shown in fig. 6. The density of the pits noticed in the matrix alloy on subjecting it to potentiostat test in corrosive media of 3.5% NaCl is negligible. On the other hand the hybrid composite surfaces have exhibited intensive localized pitting especially at the matrix particle interface when compared to the composite. Ramanathan et al. have observed initiation of pits at the surface oxides[13]. Similar observations have been reported for Al6061 /albite and Ak12/9.0% fly ash composites[7,19].

Under all test conditions composites possessed least corrosion current density when compared with matrix alloy and hybrid composite. Al6061-6wt% Si_3N_4in 3.5% NaCl exhibited the lowest corrosion current density of $0.396X10^{-5}A/cm^2$, while the matrix alloy and hybrid composite exhibited a value of $1.298X10^{-5}A/cm^2$ and $1.25X10^{-5}A/cm^2$.

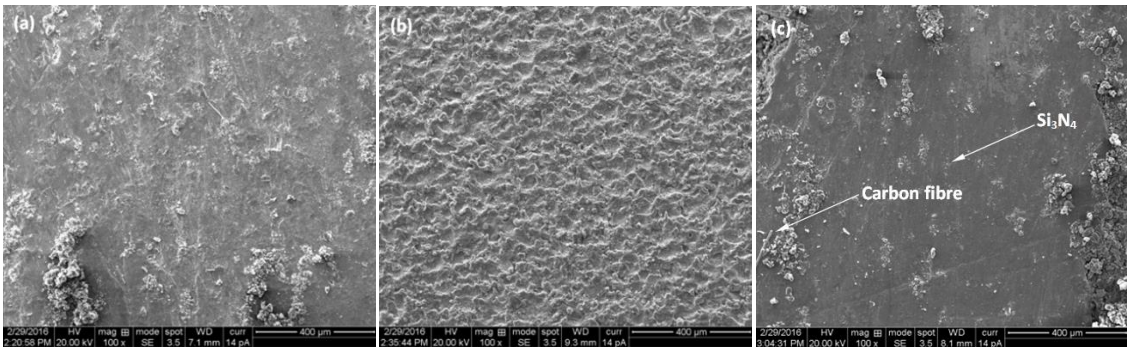
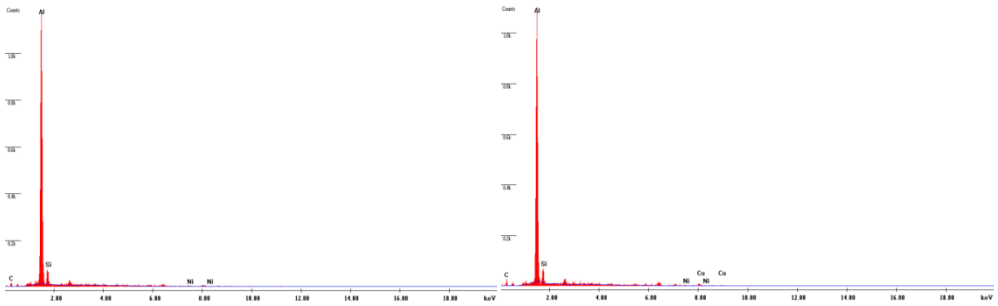


Fig. 6 SEM photographs of corroded surfaces of(a) Hot extruded Al6061 (b) Hot extruded Al6061+6Wt% Si_3N_4 (c) Hot extruded Al6061+6Wt% Si_3N_4+1Wt% C_f



(a)Hot extruded Al6061+6Wt% Si_3N_4 (b) Hot extruded Al6061+6Wt% Si_3N_4+1Wt% C_f

Fig. 7 EDAX pattern of corroded surfaces

Fig. 7 shows the EDAX pattern of corroded surfaces of hot extruded composite and hybrid composite. From the elemental analysis it is confirmed that there is a presence of Silicon, Nickel, Copper, Carbon and aluminium on the corroded surfaces.

Conclusions

Si_3N_4 reinforced Al6061 composites have exhibited superior corrosion resistance in 3.5% NaCl solution when compared with matrix alloy and hybrid composite

References

1. H. R. Ezatpour, M. Torabi-Parazi and S. A. Sajjadi, Microstructure and Mechanical properties of extruded Al/Al_2O_3 composites fabricated by stir-casting process, Trans. Nonferrous Met. Soc. China,**23**(2013) 1262-68.
2. C. S. Ramesh, R. Keshavamurthy, B. H. Channabasappa and Abrar Ahmed, Microstructure and mechanical properties of Ni-P coated Si_3N_4 reinforced Al6061 composites, Materials Science and Engineering A,**502**(2009) 99-106.
3. Halil Arik, Effect of mechanical alloying process on mechanical properties of α-Si3N4 reinforced aluminum-based composite materials. Materials and Design,**29**(2008)1856–61.
4. YUAN Wu-hua, AN Bai-ling, Effect of heat treatment on microstructure and mechanical property of extruded 7090/SiC_p composite, Trans. Nonferrous Met. Soc. China,**22**(2012) 2080-86.
5. C. S. Ramesh, C. K. Srinivas, B. H. Channabasappa, Abrasive wear behavior of laser sintered iron-SiC composites,Wear,**267**(2009)1763-2140.
6. W.NeilC.Garrard, The corrosion behavior of aluminum-silicon carbide composites in aerated 3.5% sodium chloride, Corrosion Science,**36**(1994)837-851.
7. J. Bienias, m.Walczak, Microstructure and corrosion behavior of aluminum fly ash composites, J. Opto electronics and advanced materials,**52**(2003)493-502.
8. C.S. Ramesh and MirSafiulla, Wear behavior of hot extruded Al6061 based composites, Wear,**263**(2007)629-35.
9. XIU Zi-yang, CHEN Guo-qin, WU Gao-hui, YANG Wen-shu and LIU Yan-mei, Effect of volume fraction on microstructure and mechanical properties of Si_3N_4/AL composites, Trans. Nonferrous Met. Soc. China,**21**(2011)s285-89.
10. C.S. Ramesh, H. Adarsha, S. Pramod, Zulfiqar Khan, Tribological characteristics of innovative Al6061-carbon fiber rod metal matrix composites. Materials and Design,**50** (2013)597-605.

11. V.Amigo, J.L. Ortiz and M. D. Salvador, Microstructure and Mechanical behavior of 6061Al reinforced with Silicon Nitride Particles, Processed By Powder Metallurgy,Scripta mater,**42**(2000)383–88.
12. H. Sun, E. Y. Koo and H.G. Wheat, Corrosion behavior of SicP/6061 al. Metal matrix composites, corrosion, **710**(1991)741-753.
13. P.C.R Nunes and L.V. Ramanathan, Corrosion behavior of alumina-alumiumand silicon carbide aluminum metal matrix composites, corrosion, **519**(995)610-617.
14. P.P. Trzaskoma, Pit morphology of aluminum alloy and silicon carbide/ aluminum alloy metal matrix composites, Corrosion,(1990)402-410.
15. A.J.Trowsdale, B. Noble, The influence of silicon carbide reinforcement on the pittingbehavior of aluminum, Corrosion Science, **389**(1996)177-191.
16. M.S.N. Bhat, M.K. Surappa, Corrosion behavior of silicon carbide particle reinforced 6061/Al alloy composites, J. Materials Science, **26**(1991)4991-4996.
17. C. S. Ramesh, Saleem Khan, Zulfiqar Khan and K. S. Sridhar, Slurry Erosive Wear Behaviour of Hot Extruded Al6061-Si_3N_4 Composite. Materials Science Forum **773-774**,(2013)454-60.
18. ASTM:G69-81,Standadrd practice for measurement of corrosion potentials of aluminum alloys.
19. S.C. Sharma, A study on stress corrosion behavior of Al6061/albite composite in higher temperature acidic medium using autoclave, Corrosion Science, **43**(2001)1877-1889.
20. B. Wielage, A. Dorner, Corrosion studies on aluminium reinforced with uncoated and coated carbon fibres. Composites Science and Technology, **59**(1999)1239-1245.
21. C.S. Ramesh, R. Keshavamurthy,Slurry erosive wear behavior of Ni–P coated Si_3N_4 reinforced Al6061 Composites, **32**(2011)1833-1843.