ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 5, May 2017

Effect of Deep Cryogenic Treatment on Corrosion Behaviour of Al6061/Al2O3 MMCs

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Abstract: -- The Al6061/Al2O3 composites were prepared with varying proportions of alumina particles with an average particle size of 30µm by liquid metallurgy route. The composites were then subjected to deep cryogenic treatment at liquid nitrogen temperature -1960C.The samples were cryo-treated for different durations. As-cast and cryogenic treated samples were subjected to corrosion testing in NaCl solution for 60, 70, 80 & 90 days. Corrosion rate was calculated by weight loss method. The results showed significant improvement in corrosion resistance with increase in reinforcement particles and duration of cryogenic treatment.

Keywords: Cryogenic, corrosion, Alumina, composites, microstructure, reinforcement, matrix, metallurgy

INTRODUCTION

Advanced and fast growing technology in recent years demands high performing lightweight materials [1].The obvious option is Aluminium composites. In this work Al 6061 alloy matrix reinforced with alumina (Al2O3) reinforcement were selected as it finds great application in aerospace and automotive industry [2]. The aluminium composites prepared through various routes were normally subjected to elevated temperature heat treatment. The ferrous alloys are also treated at elevated temperature by various methods. Most of the times these methods are incapable of transforming unstable retained austenite in the metal structure into a stable phase. The retained austenite in metal structure plays detrimental role to its performance. The treatment of metals and alloys below the room temperature to stabilize their structures is quite a new concept. Hence deep cryogenic treatment of aluminium alloy Al 6061 reinforced with alumina (Al2O3) particles at liquid nitrogen temperature was undertaken in the present work to study the corrosion behavior of the composite.

EXPERIMENTATION

The composites were prepared by the liquid metallurgy technique with the average alumina particle size of 30 µm by varying the percentage by weight of Al2O3 particles. The alumina percentage was varied from 0%-20% in steps of 5% by weight. The castings were obtained by stirring the molten alloy for thorough homogenizing the mixture and the composite slurry was poured in to the die to obtain the castings.

The composition, characteristics of the base material and the reinforcement are listed in Table 1 -3[3].

Table 1: Composition of AL6061 Alloy.

Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Be	V	Al
0.92	0.76	0.28	0.22	0.10	0.07	0.06	0.04	0.003	0.01	Bal

Table 2: Properties of Matrix Alloy

Density	2.7 gm/cc
Young’s modulus	75 GPa.
UTS	170 MPa.
Ductility	13.5%
Melting temperature	650°C

Table 3: Physical and Chemical Properties of Alumina (Al_2O_3)

Molecular formula	Al_2O_3
Molar Mass	101.96 g/mol^{-1}
Density	3.95 g/cm^3
Melting Point	2,072 °C
Boiling Point	2,977 °C
Thermal Conductivity	30 Wm^{-1}K^{-1}

The prepared composites were tested under as-cast condition and also the specimen were subjected to deep cryogenic temperature of -1960C using liquid Nitrogen for

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ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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varying durations of 0-50 hours in steps of 10 hours. The specimens were exposed for corrosion environment of NaCl solution for 60, 70, 80 & 90 days. The rate of corrosion was measured by weight loss method for as-cast and cryogenic treated specimen.

Effect of Test Duration

The corrosion rate was measured as a function of exposure time in the static immersion test as shown in Fig.1. The observed trends in all the cases exhibit a decrease in corrosion rate with increase in test duration. It is clear from the tables and graphs that the corrosion resistance of the composites increases with the exposure time. The phenomenon of gradually decreasing corrosion rate indicates a possible passivation of the matrix alloy. The protective black film consists of hydroxyl chloride film, which retards the forward reaction [4]. The black film consists of aluminium hydroxide compound. This layer protects further corrosion in acid media. But exact chemical nature of such protective film is still not established [5].

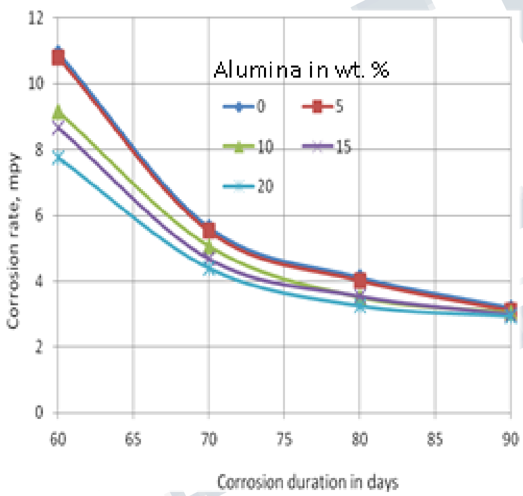

Fig. 1 Effect of Test Duration on Corrosion Rate of as-cast Al/Al_2O_3 MMCs

Effect of Reinforcement

From the Fig.2, it can be clearly observed that for both as cast and cryogenic treatment conditions, corrosion rate decreases monotonically with increase in Al2O3 content. In the present case, the corrosion rate of the composites as well as the matrix alloy is predominant due to the formation of pits and cracks on the surface. In the case of the base alloy, the severity of the acid used induces crack formation on the surface, which eventually leads to the formation of pits, thereby causing the loss of material. The presence of cracks and pits on the base alloy surface was observed clearly, since there is no reinforcement provided in any form the base alloy fails to provide any sort of resistance to the acidic medium. Hence the weight loss in the case of un-reinforced alloy is higher than in the case of composites.

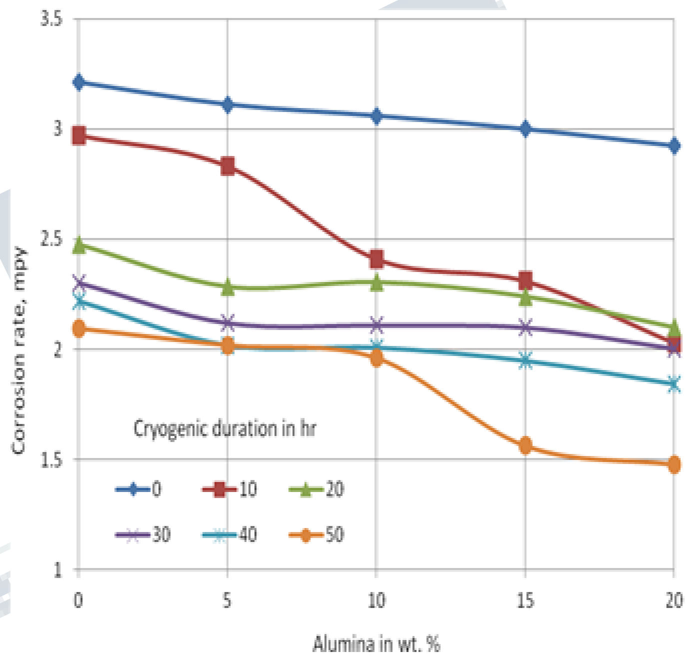

Fig.2 Effect of % of Al_2O_3 on Corrosion Rate of as-cast and Cryogenic Treated Al/Al_2O_3 MMCs for 90 days

Effect of Cryogenic Treatment

The Fig.3 shows that Cryogenic treatment, for 0, 10, 20, 30, 40 and 50 hours significantly improves the corrosion resistance of the composites, with all percentage of Al2O3 content. Solution cryogenic treatment is used to improve material strength for precipitation-hardening alloys. These precipitates have been found to segregate preferentially at the matrix-reinforcement interface in composites. Due to these precipitates, corrosion rates decrease with increasing cryogenic cooling time duration. It can be said that

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cryogenic treatment for ten hours causes the corrosion percentage weight loss to drop by about 1/3.

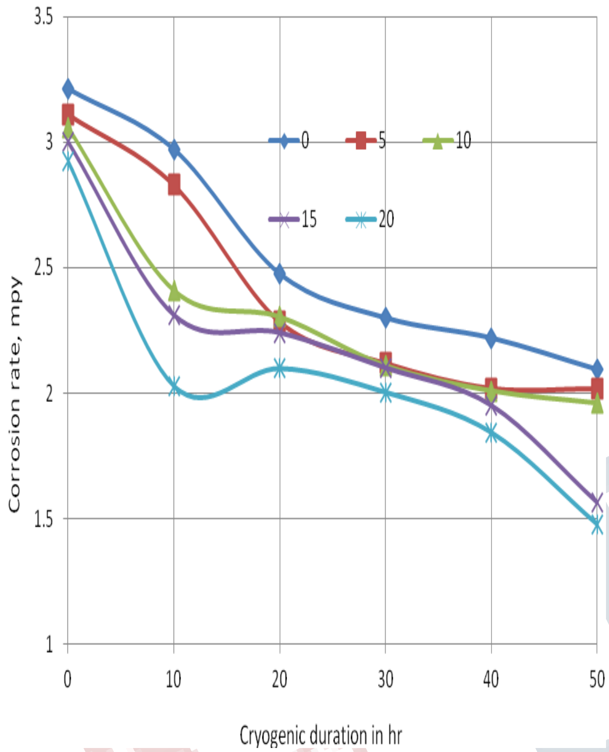

Fig.3 Effect of Cryogenic Duration on Corrosion Rate of as-cast and Cryogenic Treated Al/Al_2O_3 MMCs for 90 days

The cryogenic ageing has enhanced the protective layer of aluminium oxide described above, conferring greater corrosion resistance in the composite which is seen in all the specimens, unreinforced as well as reinforced, irrespective of the Al2O3 content. Though various reports suggest that MMCs show increased susceptibility to pitting attack compared to unreinforced alloys and the major contribution to the enhanced attack arises from the voids at the reinforcement/matrix interface, in the present case however no such observations were made.

Study of Corroded Surfaces

In order to understand the effect of cryogenic treatment on corrosion mechanism in greater detail, the corroded surfaces of samples for 60 days and 90 days exposure were carefully analysed under SEM. Few selected SEM micrographs are shown in Figs.4 and 5.

Corrosion of the as-cast microstructure initiated at the primary □-Al matrix in the eutectic region as indicated by arrows in Fig. 4(a). Corroded morphologies of the samples after longer exposure clearly showed that the changes in distribution, configuration and size of the □-Mg17Al12-phase due long exposure resulted in higher corrosion damage (Fig.5(A)) compared to shorter duration exposure (Fig.4(A)). Al/Al2O3 MMCs shows similar behavior in short duration exposure (Fig.4(B) and longer duration (Fig.5(B)) but only difference is more pits could be seen in the MMCs specimens which is due to fall of reinforcement after corrosion. In longer duration of exposure to corrosion, more cracks and flakes are seen in both the specimens.

Longer duration of exposure in corrosion media both as-cast and cryogenic treated condition of Al6061 alloy matrix and Al/Al2O3 corroded surface as shown in Fig.4.

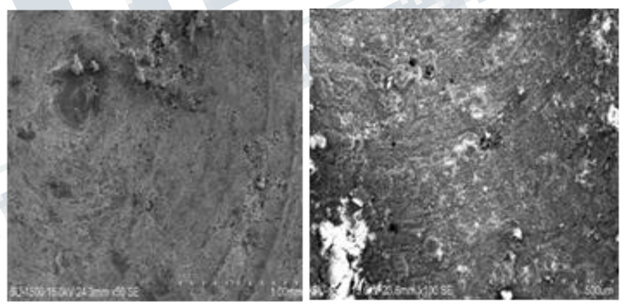

Fig. 4 Corrosion Surfaces of Al Matrix Expose to a) 60 days & b) 90 days (As-cast Condition)

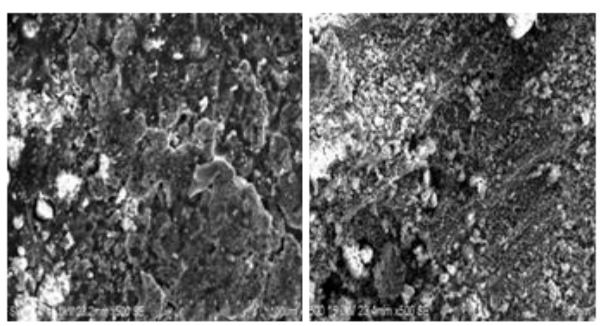

Fig. 5 Corrosion Surfaces of Al/20% Al2O3 MMCs to A) 60 days &B) 90 days (As-cast Condition)

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The examination of Al matrix alloy after corrosion for 90 days showed a few deep pits, flakes and crack formed on the unreinforced matrix alloy and cracks were perpendicular to the axis of the specimen. In the case of MMCs more widespread superficial pitting was observed and a few or no cracks were seen on the surface of the MMCs [6]. In the case of cryogenic testament microstructure for longer duration, localized attack was observed around residual □-Mg17Al12phase at grain boundaries (Fig.6 (c)). For the cryogenic microstructures, corrosion occurred preferentially along the grain boundary and some pits were found within grains as indicated by arrows in Fig.6 (d).

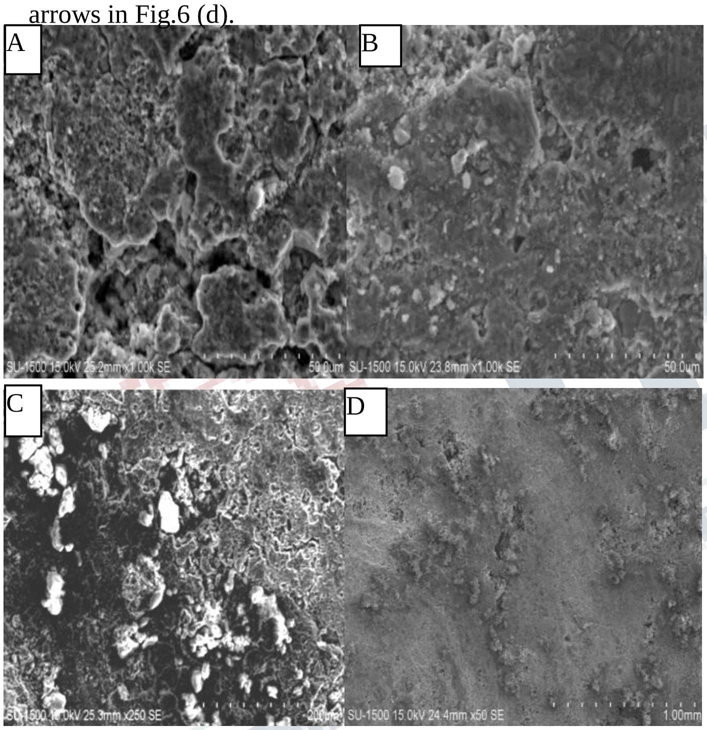

Fig.6 Corrosion Surfaces of Al Matrix a) As-cast Condition & c) Cryo-Treated (20 h) and Al/20% Al_2O_3 MMCs to b) As-cast Condition & d) Cryo-Treated (20 h) for 90 Days Exposure

CONCLUSIONS

Corrosion resistance of the unreinforced matrix alloy and the composites were found to improve with duration of exposure to the corrodent. Cryogenic treatment followed by normalizing was found to improve the corrosion resistance of every specimen tested. The improvement in corrosion resistance due to these two factors is attributed to a protective layer formed on the surface of the material. Corrosion resistance was also found to improve with increase in garnet content, probably due to the Al2O3 particles acting as physical barriers to the corrosion process. The corroded surface shows that the extent of corrosion damage was reduced with increasing reinforcement and cryogenic treatment, which may be due to increase in the bonding strength between particle and matrix alloy.

Acknowledgement: The authors are thankful to the management of R.R. Institutions for the kind support and encouragement.

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