Journal of Asian Ceramic Societies 5 (2017) 71–75

Contents lists available at ScienceDirect

Journal of Asian Ceramic Societies

journal homepage: www.elsevier.com/locate/jascer

Full Length Article

Corrosion behaviour of Aluminium Metal Matrix reinforced with Multi-wall Carbon Nanotube

P.S. Samuel Ratna Kumar[a,*], D.S. Robinson Smart[b], S. John Alexis[c]

[a] Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore 641 049, India
[b] School of Mechanical Sciences, Karunya University, Coimbatore 641 114, India
[c] Department of Automobile Engineering, Kumaraguru College of Technology, Coimbatore 641 049, India

ARTICLE INFO

Article history:
Received 24 September 2016
Received in revised form 19 January 2017
Accepted 21 January 2017
Available online 10 February 2017

Keywords:
Aluminium Nano Metal Matrix Composite
Multi-wall Carbon Nanotube
AA5083
Corrosion
Immersion test

ABSTRACT

Compared to other alloys of Aluminium, AA5083 alloy is one of the most promising material which is used in corrosive and cryogenic environment. The effect of the purity and weight percentage of Multi-wall Carbon Nanotube (MWCNT) added to the Aluminium alloy is the widely focused research area in the field of Cryogenics in recent years. In this present work, MWCNT having more than 98% purity, 5–20 nm mean diameter (D) and 1–10 μm average length (L) was used with different compositions like 1, 1.25, 1.5 and 1.75 by weight % to improve the corrosion behaviour of the Aluminium Nano Metal Matrix Composite (ANMMC). The results show Aluminium alloy AA5083 reinforced with MWCNT exhibit nominal changes in density than pure AA5083 and the uniform immersion corrosion tests (ASTM-G31) of the same composite in 90 ml of HCl shows increase in corrosion resistance as compared to AA5083 alloy.

1. Introduction

Aluminium Metal Matrix composite plays a major role in fabricating corrosive and cryogenic environment application products like Moss- and SPB-type tanks (LNG carrier insulation systems), Arctic chemical processing equipments, pressure vessels, subsea pipelines, and drill pipes (offshore structures). An alternative material for corrosion and cryogenic environment with increased life span without affecting the properties was mainly focused by many researches. Aluminium alloy is one of the widely used matrix material due to its low density to weight ratio, high strength and corrosion resistance property. In addition, Aluminium alloys exhibit high ductility and strength at cryogenic environment than at normal temperature. ANMMC was introduced which has a wide range of applications in ships, offshore structures, LNG carrier, pressure vessel because of its high strength to weight ratio, specific stiffness and corrosion resistance [1–4]. Aluminium alloy AA5083 is selected as matrix material for many marine and low temperature applications [5–8]. By adding an appropriate reinforcement to the AA5083, corrosion resistance of the material will be improved. In this regard, Nano particle can be added as reinforcement for metal matrix composite [9]. Based on the reference data there are three important reinforcing mechanisms to be considered before adding the nano particle as reinforcement in metal matrix composite to obtain a high strengthening effect; Orowan mechanism, thermal mismatch and load transfer are the mechanisms used for reinforcing the metal matrix. As the number of particles increases, interparticle spacing and smaller yield for smaller particles of reinforcement in a certain volume fraction is Orowan mechanism. In order to create higher dislocation density around the reinforcement's thermal mismatch needs a high difference for the coefficient of thermal expansion, between the reinforcement and the matrix. The load can be transferred efficiently as much stronger and high aspect ratio of the reinforcement [9,10]. Based on the reinforcing mechanisms, Multiwall carbon nanotubes (MWCNTs) were selected as reinforcement material. Most of the researches show an effective usage of CNTs (carbon nanotubes) as reinforcement in Aluminium matrix with improved mechanical and corrosion properties. MWCNT was manufactured using two different methods 1. Arc-discharge and 2. Chemical vapor deposition (CVD). CVD–MWCNT is the most used material for an industrial level and large quantities can be produced in a cheap cost compare to the Arc-discharge–MWCNT [11–16]. Compare to the matrix material MWCNT is in nano size, agglomeration of MWCNT was

* Corresponding author.
E-mail addresses: samuelrathish@live.com (P.S. Samuel Ratna Kumar), smart@karunya.edu (D.S. Robinson Smart), johnalexis@rediffmail.com (S. John Alexis).

http://dx.doi.org/10.1016/j.jascer.2017.01.004
2187-0764/

reported as common problem that restricts the achievement of the desired properties. When above 1 wt% of MWCNT were mixed with the matrix material there will be a formation of clusters in the processed composites, reduces the ductility, strength and stiffness [11,17,18]. The main challenge faced by Polymer, ceramic or metal matrix composites reinforced with CNT is uniform dispersion. The cluster formations of CNT are due to van der Walls forces and have an incredible surface area of up to 200 $m^2 g^{-1}$. The properties of a composite are related to the volume fraction or weight fraction of the reinforcement added along with the matrix material. Hence, uniform dispersion of CNT is important as it provides uniform change in the properties of the composite [18]. In this present work the corrosion behaviour of ANMMC has been studied with the reinforcement of MWCNT by different weight percentages which were not concentrated in the earlier works. In order to enhance the uniform dispersion of MWCNT reinforcement in the matrix material, compo-casting method was employed. Density and strength of the Aluminium Nano Metal Matrix Composite was also investigated.

2. Experimental method

In this present work, compo-casting were used to produce the composite with uniformly dispersed MWCNT reinforcement in Aluminium alloy AA5083 using stir casting apparatus. The density of the Aluminium alloy AA5083 is 2.65 g/cc and that of the MWCNT is 2.6 g/cc, as both are relatively same, so the qualified distribution manifest. Five specimens were fabricated; the first specimen piece is pure AA5083. The other pattern being composites are structured with 500 g of AA5083 as the matrix and MWCNT reinforcement in the varying compositions (1%, 1.25%, 1.50% and 1.75%). Before mixing the reinforcement with the matrix material the MWCNT is taken in the alumina crucible and preheated at 773 K. Later, the liquid melt was degassed using nitrogen for about 3–4 min. The mechanism of degassing is of due significance such that it restricts the oxide formation. AA5083 is heated to 1173 K and formed to semi-solid state the preheated MWCNT is mixed with the AA5083 with the aid of the stirrer at 250–400 rpm [10,19]. After 2 min of stirring, the molten metal is poured into the mould cavity to obtain the composite material. For few minutes the Aluminium alloy AA5083 reinforced with MWCNT composite specimens was solidified done at room temperature and composite specimens of the dimension (100 mm × 100 mm × 10 mm) is obtained using compo-casting.

2.1. Field Emission Scanning Electron Microscope (FESEM) and EDX analysis study of AA5083/MWCNT nano-composite

The EDX pattern of the MWCNT and AA5083 in Fig. 1 shows that the strong reflection peak was found between 20°–28° and Fig. 2 shows 40°–45°. This peak of EDX pattern of MWCNT and AA5083 indicates the grapheme sheets nested together in a cylindrical form and the nature of carbon nanotubes are multi-walled and shows the presence of Aluminium–Magnesium [19]. The FESEM image of MWCNT is shown in Fig. 3. The figure shows the structure sample of MWCNT with the diameter of 10 nm, length in 5 μm and purity of 98%. Fig. 4(a) and (b) shows the FESEM image of dispersed 1 and 1.75 wt% MWCNT in the AA5083 alloy material after stirring. The mechanical interaction between MWCNT and AA5083 alloy particles has been achieved. Mixing of MWCNT on Aluminium alloy matrix during semi-solid state resulting a uniform dispersion in the composite. Due to the compo-casting process the clusters formation of MWCNT is reduced and it can be observed in the AA5083/MWCNT mixed particles. When MWCNT is mixed into the melt, MWCNT will provide sufficient wettability with the molten AA5083 alloy and bonding was good with the matrix. The uniform

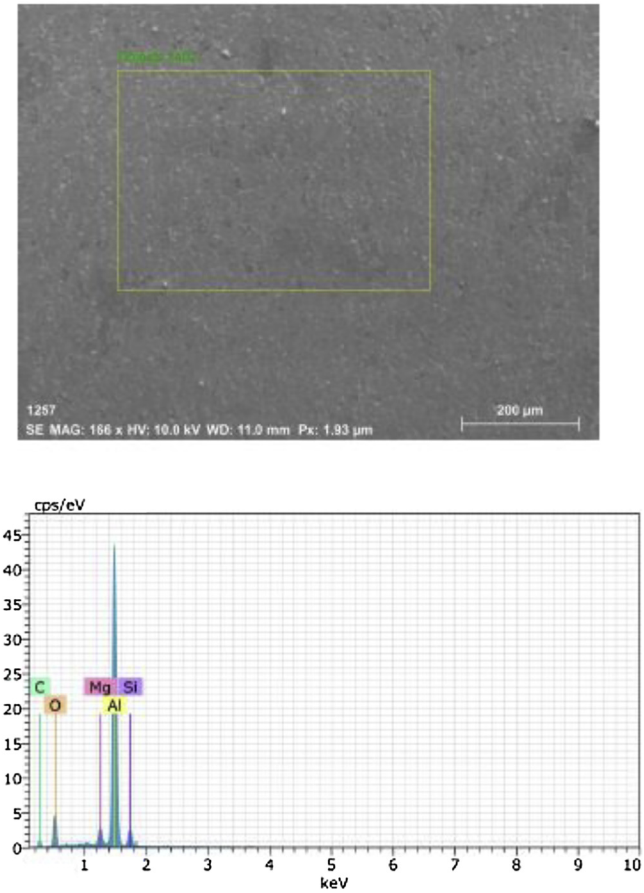

Fig. 1. EDX analysis showing percentage of AA5083 reinforced with 1.25wt% of MWCNT.

distribution of MWCNT in the melt is done by stirring process of the stirrer [19].

2.2. Hardness

Fig. 5 shows the addition of MWCNT with weight fraction has the influence on the Brinell Hardness of AA5083. Based on the (ASTM E10) standard the Brinell Hardness (BHN) test was conducted and found the hardness of the cast specimens has increased by addition of MWCNT in the matrix material, from 74 for the alloy AA5083 to 84 for 1.75 wt% of reinforced composite. The figure shows the hardness values have considerably increased for 1, 1.25 and 1.5 wt% addition of MWCNT. Fig. 6 shows the density of AA5083 alloy and AA5083/MWCNT nano-composite. It is observed that when the addition of MWCNT increased in weight percentage the density of the nano-composite is decreased. Decrease in density of nano-composite is because of the addition of high volume/weight fractions MWCNT and light weight compared to the matrix of composite, where the nano-composite samples porosity was filled with MWCNT [20].

2.3. Corrosion behaviour of the AA5083/MWCNT

Fig. 7 shows the corrosion rate of AA5083/MWCNT composite immersed in 90 ml HCl (dil) solution for 24 h at room temperature. Compare to NaCl the HCl (dil) is more acidic; therefore the AA5083/MWCNT composite can be used in more corrosive environment. AA5083/MWCNT composite have a better resistance to corrosion compare to AA5083 alloy. Increasing the weight percentage of MWCNT shows increased corrosion resistance of the

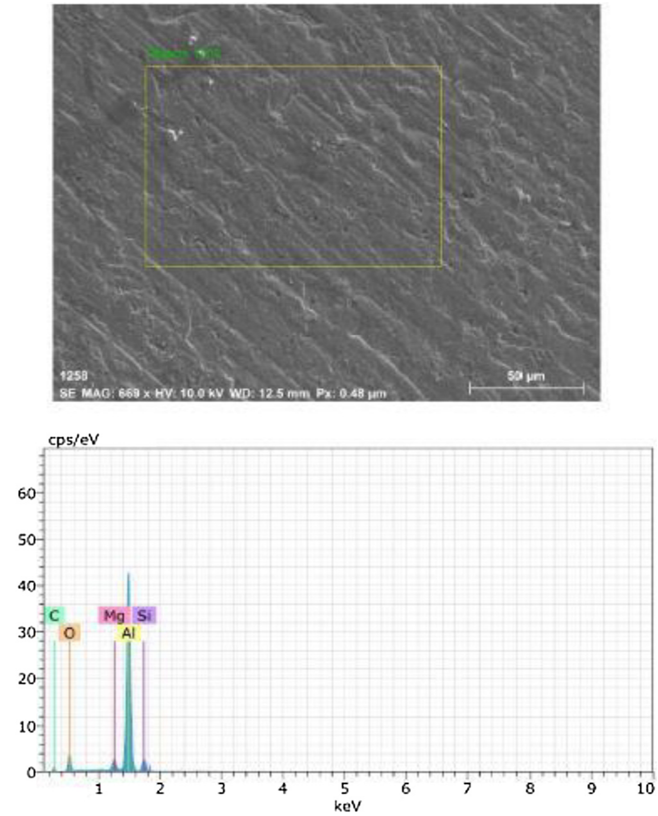

Fig. 2. EDX analysis showing percentage of AA5083 reinforced with 1.75wt% of MWCNT.

AA5083/MWCNT composite and reinforcement size also plays a major role in corrosion resistance of the AA5083/MWCNT composite. Thus, the improvement of corrosion resistance may also due the voids and pores of the matrix material were filled by CNT. Thus it leaves no place for initiating corrosion in the composite [18] (Table 1).

The corrosion rate CR (from the mass loss) was calculated using the following equation

$$\text{Corrosion rate mm/year} = \frac{87.6 \times \text{weightloss}}{\text{D} \times \text{A} \times \text{T}} \quad (1)$$

where

WL = weight loss in milligrams

D = density of specimen in gm/cm^3

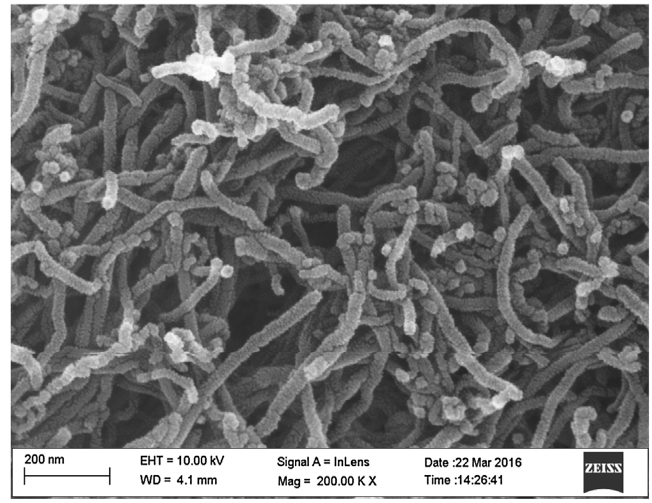

Fig. 3. Micro-structure of MWCNTs used in the present work; 5–20 nm in mean diameter and 1–10 µm in length.

Table 1
Corrosion rate of the AA 5083/composite material.

Material	Corrosion rate (mm/yr)
AA5083	472.836
AA5083 + 1wt% MWCNT	468.113
AA5083 + 1.25wt% MWCNT	441.456
AA5083 + 1.5wt% MWCNT	440.956
AA5083 + 1.75wt% MWCNT	438.88

A = area of specimen in cm^2

T = time of exposure in hours

Note: the conversion factor for mm/yr is 87.6

AA5083

Corrosion rate = 472.836 mm/yr

AA5083 + 1 wt% MWCNT

Corrosion rate = 468.113 mm/yr

AA5083 + 1.25 wt% MWCNT

Corrosion rate = 441.456 mm/yr

AA5083 + 1.5 wt% MWCNT

Corrosion rate = 440.956 mm/yr

AA5083 + 1.75 wt% MWCNT

Corrosion rate = 438.880 mm/yr

The corrosion resistance of Aluminium–Metal Matrix Composite is also dependent on different factors and one such factor is tech-

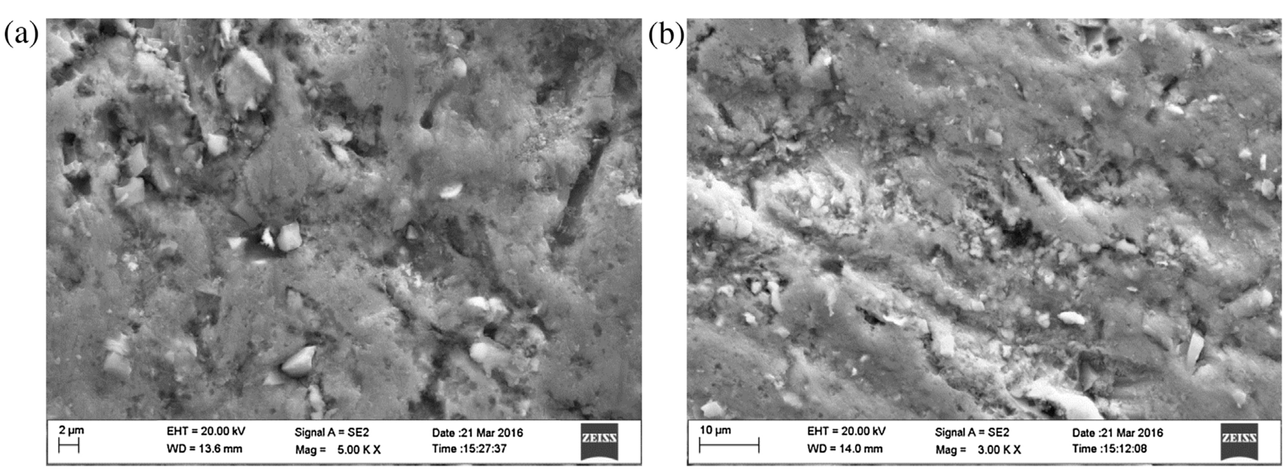

Fig. 4. (a) Micro-structure of 1 wt% MWCNTs/AA5083 (b) Micro-structure of 1.75 wt% MWCNTs/ AA5083.

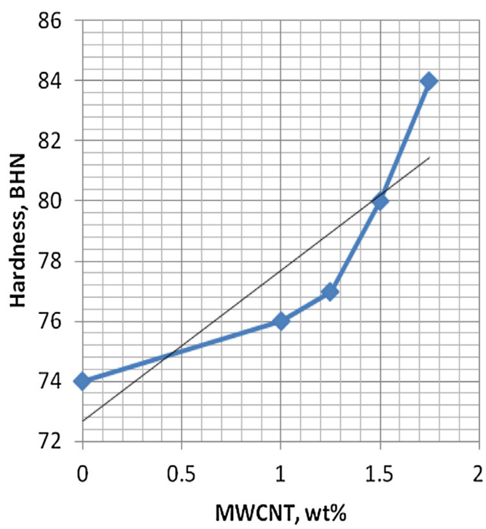

Fig. 5. Effect of AA5083/MWCNT Hardness (BHN).

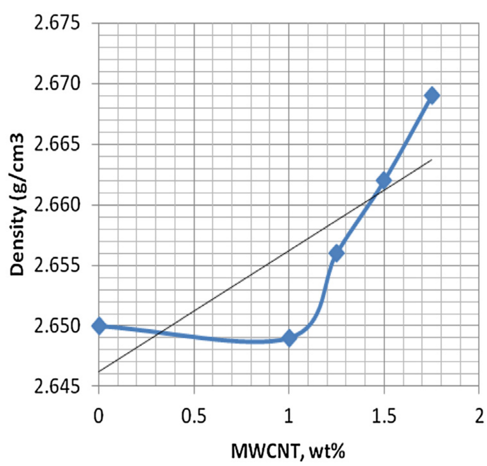

Fig. 6. Density of AA5083/MWCNT.

niques used for processing; wrought or cast characteristics of the matrix alloy; reinforcement shape, type and size and the environmental factors [20]. The influence of corrosion may also occur due to the manufacturing and processing techniques of Metal Matrix Composite may also direct to the development of an interphase between the reinforcement and matrix material. The weakest or the strongest part of particulate composite is the interface between the base alloy and the reinforcement. Interfacial bond is most significant one in the corrosion method. It is understood that the improved corrosion resistance of the AA5083/MWCNT composite in the present work is mainly due to the strong interfacial bonding between the matrix alloy and reinforcement. Thus, increased MWCNT with weight percentage increases the corrosion resistance of the composite (Fig. 8).

3. Conclusion

From the present experimental work the following details were concluded

1. AA5083/MWCNT in weight percentages of 0, 1, 1.25, 1.50 and 1.75 wt% were successfully fabricated using compo-casting method.

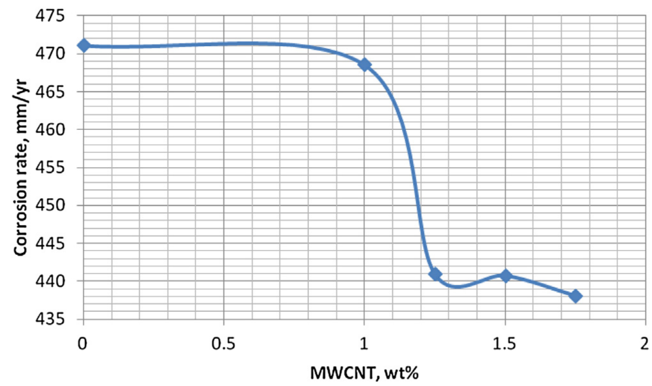

Fig. 7. Corrosion rate of AA5083 / MWCNT composite.

Fig. 8. Immersion corrosion test samples for different AA5083/MWCNT compositions.

2. Uniform dispersion and reduced cluster formation of MWCNT into the matrix material of the produced AA5083/MWCNT nano metal matrix composite with an improved hardness.
3. Hardness of the cast specimens has increased by addition of MWCNT in the matrix material, from 74 BHN for the alloy AA5083 to 84 BHN for 1.75 wt% of reinforced composite and considerably increased for 1, 1.25 and 1.5 wt% addition of MWCNT.
4. AA5083/MWCNT composite have better corrosion resistance than the AA5083 alloy in HCl (dil) at room temperature.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] M.S. Chun, M.S. Han and W.S. Park, Mater. Sci. Eng. A, 528, (18) 5790–5803 (2011).
[2] J. Liao and M. Jen Tan, Mater. Lett., 65, 2742–2744 (2011).
[3] J. Stein and B. Lenczowski, Carbon, 77, 44–52 (2014).
[4] D.H. Park, S.W. Choi, J.H. Kim and J.M. Lee, Cryogenics, 68, 44–58 (2015).
[5] B. Baudouy and A. Four, Cryogenics, 60, 1–4 (2014).
[6] M.H. Mina Bastwros, Wear, 307, 164–173 (2013).
[7] T. Miyajima and Y. Iwai, Wear, 225, 606–616 (2003).
[8] R. Casati and M. Vedani, Metals, 4, 65–83 (2014).
[9] Q. Li and A. Christian, Compos. Sci. Technol., 70, 2242–2247 (2010).
[10] A. Esawi, K. Morsi, A. Sayed and M. Taher, Compos. Sci. Technol., 70, 2237–2241 (2010).
[11] H.J. Choi, J.H. Shin and D.H. Bae, Compos. Sci. Technol., 71, 1699–1705 (2011).
[12] A. Esawi, K. Morsi, A. Sayed, M. Taher and S. Lanka, Composites A, 42, 234–243 (2011).
[13] Z.Y. Liu, S.J. Xu, B.L. Xiao, P. Xue and W.G. Wang, Composites A, 43, 2161–2168 (2012).

[14] H.J. Choi, J.H. Shin and D.H. Bae, Composites A, 43, 1061–1072 (2012).
[15] S.E. Shin and D.H. Bae, Mater. Charact., 83, 170–177 (2013).
[16] J.N. Coleman, U. Khan and W.J. Blau, Carbon, 44, 1624–1652 (2006).
[17] S.R. Bakshi, Int. Mater. Rev., 55, 41–64 (2010).
[18] J.N. Abou Bakr Elshalakany, J. Nanomater., 2014, 1–14 (2014).
[19] B. Abbasipour, Trans. Nonferrous Met. Soc. China, 20, 1561–1566 (2010).
[20] H.M. Zakaria, Ain Shams Eng J., 5, 831–838 (2014).