Corrosion Behaviour of Short Basalt Fiber Reinforced with Al7075 Metal Matrix Composites in Sodium Chloride Alkaline Medium

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Abstract: The aim of the research work was to investigate the corrosion behaviour of basalt short fiber reinforced aluminum metal matrix composites (MMCs) in alkaline solution using weight loss method. The Al/basalt MMCs contains basalt short fiber from 2.5 to 10 % in steps of 2.5 wt. % and fabricated using liquid metallurgy technique. The corrosion characteristics of Al/basalt short fiber composite and the unreinforced alloy were experimentally assessed. The corrosion test was carried out at different temperatures in mixture of sodium-chloride alkaline solution at a concentration of 1N, 2N & 3N for different exposure time were subjected to corrosive media to evaluate their corrosion resistance. The results indicated that corrosion rate of metal matrix composites was lower than that of matrix material Al 7075 under the corrosive atmosphere for both unheat treated and heat treated conditions. Al/basalt short fiber composite become more corrosion prone as the basalt short fiber content is increased, and the corrosion rate in sodium chloride alkaline decreases with time, probably because of the formation of stable oxide layer over the specimens. Scanning Electron Microscopy (SEM) show the degree of attack of alkaline solution on the surface of the investigated material.

Key words: Metal Matrix Composite (MMCs), basalt fiber, corrosion loss, weight loss.

1. Introduction

Metal matrix composites are important class of materials, with non metallic reinforcements incorporated in metal matrices. Aluminium based Metal Matrix Composites (AMMCs) reinforced with alumina particles or fibers possess enhanced physical and mechanical properties. They provide significantly enhanced properties over conventional monolithic materials, such as higher strength, high stiffness, weight savings, high fatigue strength and abrasion resistance, as well as their excellent performance at high temperatures make alumina reinforced MMCs ideal for applications in aerospace, power utility, automotive, and military sectors [1, 2]. MMCs reinforced with short fibers offer outstanding specific strength and stiffness along the fiber direction when compared to those with particulate reinforcements that have more isotropic properties. Most research on alumina-reinforced MMCs has focused on their manufacturing and mechanical properties [3-7]. Relatively little research has been conducted on their corrosion behaviour, and therefore, corrosion mechanisms are not well understood. Conflicting data and interpretations exist regarding fundamental issues, such as corrosion initiation sites and the role of alumina in corrosion susceptibility [8-10].

Corrosion can affect the metal matrix composite in a variety of ways which depend on its nature and the environmental conditions prevailing. Studying corrosion resistance of Al-based materials is important especially for automotive and aircraft applications

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where the parts are prone to corrosive media like salt water solutions, acidic and alkaline media. The major advantages of AMMCs compared to unreinforced materials areas follows: greater strength, improved stiffness, reduced density, good corrosion resistance, improved high temperature properties, controlled thermal expansion coefficient, thermal/heat management, improved wear resistance and improved damping capabilities [1-6]. One of the main disadvantages in the use of metal matrix composite is the influence of reinforcement on corrosion rate. This is particularly important in aluminum alloy based composites, where a protective oxide film imparts corrosion resistance.

The addition of a reinforcing phase could lead to discontinuities in the film, thereby increasing the number of sites where corrosion can be initiated and making the composites more susceptible for corrosion [11]. Due to the wide applications of such composites, they frequently come in contact with acid during cleaning, pickling, descaling, etc. Hence studying their corrosion behavior in acid medium is of prime importance. Though, a significant amount of efforts have been spent to understand the corrosion behavior of these composites, the results are not matching since the corrosion resistance of these composites vary with processing techniques, type of reinforcements and particulate size of the reinforcements.

The corrosion damage is promoted by contaminations found in the alloys, and also the inhomogeneity of the chemical composition. The environment of chlorides increases susceptibility of aluminum and its alloys to pitting corrosion, and presence of various contaminations prevents development of the compact protective layer; therefore, in these locations pitting centres may develop. The number of pits will be increasing the more alloy elements will be present being more cathodic than pure aluminum, causing acceleration of propagation of pits and promoting depassivation [12, 13]. The study on the corrosion

behaviour of metal matrix composites in different aggressive environments has continued to attract considerable attention because of the several important applications of these materials [14]. These composites frequently come in contact with acids or bases during the process like cleaning, pickling, de-scaling, etc. It is known that aluminum and its alloys exhibit high corrosion rate in solutions containing aggressive anions or in highly alkaline solutions [15]. Therefore, studying the corrosion behavior of aluminum alloys and their composites in the alkaline medium is of prime importance.

As far as we know, although many researchers have worked on corrosion characteristics of fiber reinforced metal matrix composites but no concrete investigation has been made on basalt fiber reinforced with aluminum alloy 7075 metal matrix composites. The present work is focused on corrosion characteristics of Al 7075/basalt short fiber metal matrix composites.

2. Materials and Methods

2.1 Materials

The Al and basalt short fiber used as the MMCs in the present study are obtained from commercial ingots with correct chemical composition, the presence of these elements have been confirmed by SEM/EDS spectra. The EDS spectrum also shows the presence of impurities such as iron and basalt short fiber in traces. The alloy is found to be pollution free in the foundry. Because of its low energy requirements and excellent machinability, it is expected to reduce production time and lengthen tool life during its fabrication process. The matrix alloy used in the present investigation was Al 7075 alloy, which has basalt short fiber reinforcement and chemical composition is as shown in Table 1.

2.2 Reinforcement

The basalt fiber was made from naturally occurring basalt rock in the Washington State area, USA. The

basalt short fiber used as reinforcement in the present investigation has been purchased from a mineralogical research company. The chemical composition of the fibers is determined by the native basalt rock used as a raw material, which has the main composition as shown in Table 2.

The fiber was produced in a prototype device. The basalt rock was melted in a platinum-rhodium crucible at 1,250 ± 1,350 °C. The fiber was drawn from the melt through an fiber in the crucible and wound onto a rotating drum continuously. Fibers in roving form were bundled and cut into short fibers of uniform length about 0.5 to 1 mm in size by constant-length cutter. The short Basalt short fiber was cleaned in distilled water and dried at 90 °C.

2.3 Composite Preparation

The liquid metallurgy route using vortex technique is employed to prepare the composites. A mechanical stirrer was used to create the vortex. A muffle furnace was used to preheat the cu coated basalt short fiber to a temperature of 500 °C and maintained at that temperature till it was introduced into the Al alloying elements melt. The preheating of the reinforcement is necessary in order to reduce the temperature gradient and to improve wetting between the molten metal and the basal short fiber. An known quantities of these metals ingots were pickled in 10% NaOH solution at room temperature for ten minutes. Pickling was done to remove the surface impurities. The smut formed was removed by immersing the ingots for one minute in a mixture of 1 part nitric acid and 1 part water followed by washing in methanol. These cleaned ingots after drying in air were loaded into different

Table 1   Chemical composition of Al alloy (weight percentage).

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Bal

Table 2   Chemical composition of short basalt fiber.

Element	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
%	69.51	14.18	3.92	2.41	5.62	2.74	1.01	0.55	.04

alumina crucibles. These crucibles kept in composites furnace, which were setting metals respected melting temperature. The melts were super heated and maintained at that temperature. The temperatures were recorded using a chromel alumel thermocouple. The molten metals were then degassed using purified nitrogen gas. Purification process with commercially pure nitrogen was carried out by passing the gas through an assembly of chemicals arranged in a row (concentrated sulphuric acid and anhydrous calcium chloride, etc.) at the rate of 1,000 cc/minute for about 8 minutes.

A stainless steel impeller or stirrer coated with alumina was used to stir the molten metal and create a vortex. The impeller used for stirring was of centrifugal type with three blades welded at 45° inclination and 120° apart. The stirrer was rotated at a speed of 500 rpm and a vortex was created in the melt. The depth of immersion of the impeller was approximately one third the height of the molten metal above the bottom of the crucible. The reinforcing basalt short fiber, which were preheated in the muffle furnace, were introduced into the vortex at the rate of 120 gm/min. Stirring was continued until interface interactions between the basalt short fiber and the matrix promoted wetting. Then the melt was degassed using pure nitrogen for about 3-4 minutes and after reheating to super heat temperature (540 °C), it was poured into the pre heated lower half die of the hydraulic press. The top die was brought down to solidify the composite by applying a pressure of 100 kg/sq.cm. Both the lower die and the upper dies were preheated to 280 °C, before the melt was poured into it. The pressure applied enables uniform distribution of the basalt short fiber in the developed composite.

2.4 Specimen Preparation

The specimens were obtained from the bar castings. Small cylindrical disks of diameter 20 mm and thickness 10 mm were used for study. The material was cut into 20 × 20 mm pieces as per ASTM

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standards using an abrasive cutting wheel. The samples were successively ground using 240, 320, 400 and 600 SiC paper and were polished according to standard metallographic techniques and dipped in acetone and dried. The samples were weighed up to fourth decimal place using electronic balance and also the specimen dimensions were noted down using vernier gauze.

2.5 Corrosion Test

The corrosion tests were conducted as per the ASTM standards of G1 at room temperature (28 °C) using the conventional weight loss method. The corrodent used was 1N, 2N & 3N NaCl. The specimens were obtained from the bar castings. Small cylindrical disks of diameter 20 mm and 20 mm length were used for study. These specimens were polished with SiC emery paper of grade 400 to 600 grit in order to obtain a smooth and identical surface finish on all the specimens. The specimens were then washed with distilled water, followed by acetone, and then allowed to dry thoroughly. They were finally weighed to an accuracy of three decimal places. This same cleaning procedure was used before each weighing at each stage of the corrosion test. The initially weighed specimens were immersed in the corrosive environments as shown in Fig. 1 and taken out at 10 days intervals for testing up to a total of 90 days. One specimen was used for each test condition. Each time, the corrosion products formed on the corroded specimens were removed with a bristle brush. The cleaned specimens were dried and weighed. The

Fig. 1 Specimens dipped in NaCl Solution in 1N, 2N & 3N normality.

weight loss was measured and the percentage weight loss values were computed taking the original weight of the non corroded specimen as datum.

3. Results and Discussion

3.1 Corrosion Behaviour

3.1.1 Effect of Corrosion Duration

The plots of corrosion loss (in mg) of as cast Al7075 alloy and Al7075/basalt short fiber reinforced composites against different exposure times (in days) in 1N, 2N & 3N NaCl solution using weight loss method have been presented in Fig. 2. The measured mean values of corrosion loss (in mg) were plotted against different exposure times (in days). From the study it can be observed that within the scope of this investigation as the exposure time (in days) was increased, there has been an increase in the corrosion loss. The variation of the corrosion loss (in mg) against different exposure times (in days) in 1N, 2N & 3N NaCl solution for basalt short fiber-reinforced composite as well as the as cast Al7075 alloy has been computed and tabulated in Table 3. It can be seen that in every case, there is an increase in corrosion loss with increase in duration of exposure to the corrodent, implying that the corrosion resistance of the material tested increases as the exposure time is increased. The trend observed was that there is an appreciable increase in corrosion loss at initial state and thereafter increases monotonically with increase in duration of the test. Severe weight loss and high corrosion loss were experienced at 90 days exposure time. The

phenomenon of gradually increasing corrosion loss and slope of the curve increasing with exposure time indicates a possible passivation of the matrix alloy. The thin protective layer formation on the surface of the specimen when exposed to NaCl protects the base metal from the aggressive environment. Henry et al. [16] explained that the protective film consists of a hydrogen hydroxy chloride film which retards the forward reaction. Moshier et al. [17] have pointed out that the film consists of aluminum hydroxide compound. This layer protects the specimen from further corrosion in NaCl solution, but the exact chemical nature of such protective film is still not known. Mc. Cafferty [18] is of opinion that this behaviour is probably due to the solution being excessively concentrated by Al^{3+} ions, which retard the progress of forward reaction. As the reaction proceeds, the solution becomes depleted in hydrogen ions so that the reaction slows down.

3.1.2 The Effect of Basalt Short Fiber Content on Corrosion

The plots of the corrosion loss (in mg) with a variation of basalt dispersoid in metal matrix composite in NaCl solution has been presented in Fig. 3. The measured mean values of corrosion loss (in mg) were plotted as a function of weight percentage of

basalt short fiber. From the study it can be observed that within the scope of this investigation as the basalt short fiber content was increased, there has been a decrease in the corrosion loss. The corrosion loss (in mg) with variation in weight percentage of basalt short fiber for different exposure times (in days) in 1N, 2N & 3N NaCl solution has been computed and tabulated in Table 4. From the Fig. 3, it can be clearly seen that, the percentage weight loss due to corrosion decreases monotonically with basalt short fiber content. In other words, more the basalt short fiber added more is the corrosion resistance of the composite. This decrease in the corrosion resistance of the basalt short fiber reinforced composite may be attributed due to the presence of interface between the basalt short fiber and the Al alloy matrix, which has generated during manufacturing. The presence of a more conductive phase at the interface provides an easier path for the electron exchange necessary for oxygen reduction and will drive the anodic reaction to higher level. The results obtained show that, for both reinforced composite as well as the unreinforced matrix alloy, the corrosion loss seems to decrease with duration of the corrosion test. Since the specimens were thoroughly cleaned and weighed at each time, it is safe to assume that each time this was done, the hydrogen bubbles

Table 3   Corrosion loss (in mg) for different exposure times (in days) in NaCl solution of as cast Al7075 alloy/basalt dispersed metal matrix composites.

Normality of solution [N]	Wt. % basalt short fiber	Corrosion duration in days					
		40	50	60	70	80	90
	0	2.3933	3.1891	3.5236	3.7502	3.8082	3.8594
	2.5	1.9808	2.7766	3.1111	3.3377	3.3957	3.4469
1N	5	1.5683	2.3641	2.6986	2.9252	2.9832	3.0344
	7.5	1.1558	1.9516	2.2861	2.5127	2.5707	2.6219
	10	0.7433	1.5391	1.8736	2.1002	2.1582	2.2094
	0	2.4635	3.2594	3.5938	3.8205	3.8785	3.9296
	2.5	2.051	2.8469	3.1813	3.408	3.466	3.5171
2N	5	1.6385	2.4344	2.7688	2.9955	3.0535	3.1046
	7.5	1.226	2.0219	2.3563	2.583	2.641	2.6921
	10	0.8135	1.6094	1.9438	2.1705	2.2285	2.2796
	0	2.5619	3.3577	3.6922	3.9188	3.9768	4.028
	2.5	2.1494	2.9452	3.2797	3.5063	3.5643	3.6155
3N	5	1.7369	2.5327	2.8672	3.0938	3.1518	3.203
	7.5	1.3244	2.1202	2.4547	2.6813	2.7393	2.7905
	10	0.9119	1.7077	2.0422	2.2688	2.3268	2.378

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would have been cleaned off. This eliminates the possibility of hydrogen bubbles clinging to the surface of the specimens and forming permanent layer affecting the corrosion process. The phenomenon of gradually decreasing corrosion loss is probably due to protective layer formed, which 'is quite stable in neutral and many acid solutions but is attacked by alkalis.
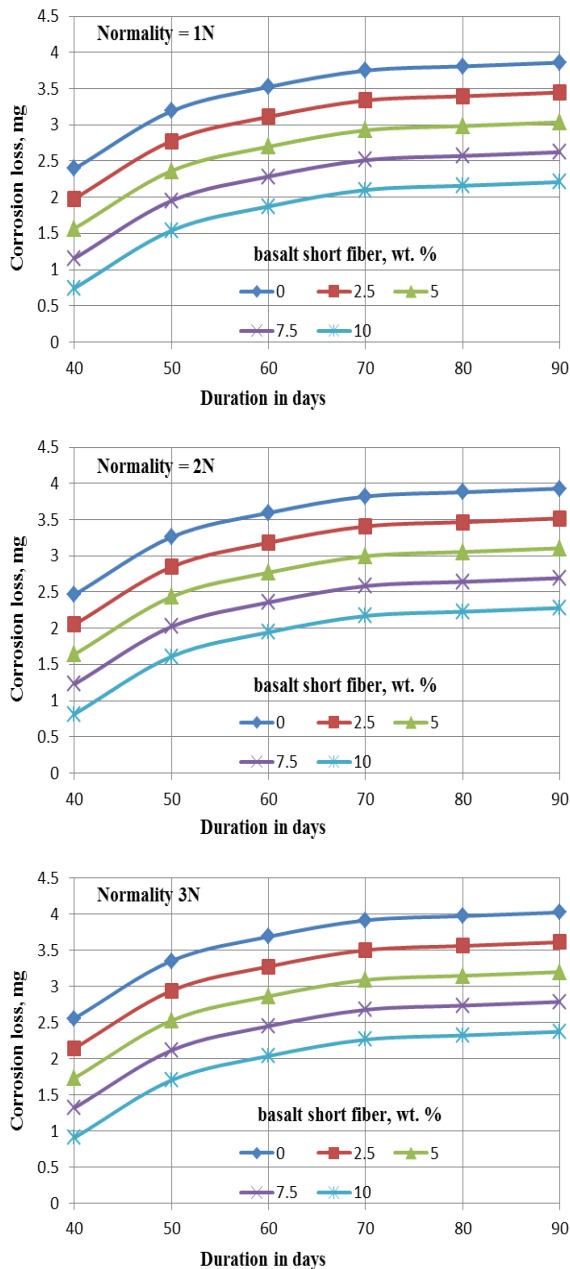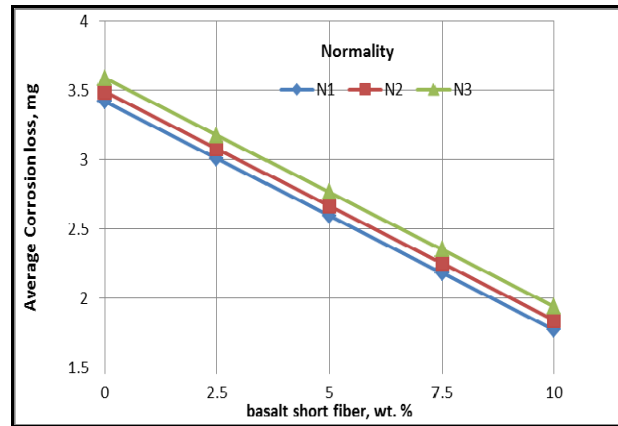

Fig. 3   Effect of basalt short fiber on corrosion weight loss of Al7075/basalt short fiber composites.

Table 4   Effect of basalt short fiber on Corrosion loss (in mg) for different Normality in NaCl solution of as cast Al7075 alloy/basalt dispersed metal matrix composites.

Normality	Basalt short fiber, wt.%				
	0	2.5	5	7.5	10
1	3.4206	3.0081	2.5956	2.1831	1.7706
2	3.49088	3.078383	2.66588	2.25338	1.84088
3	3.5892	3.1767	2.7642	2.3517	1.9392

3.1.3 The Effect of Normality on Corrosion

The plots of corrosion loss (in mg) of as cast Al 7075 alloy and Al7075/ basalt short fiber reinforced composites as function of normality of NaCl solution have been presented in Fig. 4. The measured mean values of corrosion loss (in mg) were plotted as function of normality of NaCl solution. From the study it can be observed that within the scope of this investigation as the normality of NaCl solution was increased, there has been an increase in the corrosion loss. The variation of the corrosion loss (in mg) as function of normality of NaCl solution for both basalt short fiber reinforced basalt short fiber composite as well as the as cast Al7075 alloy has been computed and tabulated in Table 5. It can be seen that the shape of the corrosion curves as function of normality depends on the concentration of NaCl. The corrosion loss increases monotonically with increase in the concentration of NaCl solution for both the basalt short fiber- reinforced composite as well as cast Al7075 alloy. The basalt short fiber reinforced composite exhibited lesser corrosion loss than that of

Fig. 2   Effect of corrosion duration on corrosion weight loss of Al7075/basalt short fiber composites.

as cast Al7075 alloy alloy. It is well known that the chemical reaction depends on the concentration of solution, area of the reaction surfaces, etc. The intensity of the corrosion attack increased with increase in concentration. On the same line some researchers [19-23] attributed this trend to the intensity of Cl-concentration of the solution, which increases corrosion loss.

3.2 Corrosion Morphology

Fig. 5 shows corroded surface of the a) Al matrix alloy b) Al7075/ 5 weight percentage of basalt short fiber reinforced composite and c) Al7075/10 weight percentage of basalt short fiber reinforced composite. All the corroded specimen surfaces were observed in Scanning Electron Microscope (SEM). Specimens tested in 1 NaCl deaerated solution showed round pits distributed all over the surface. No evidence of generalized corrosion of the matrix was observed. Fewer, wider, and deeper pits, were observed on the samples immersed in the saturated solution. Inside
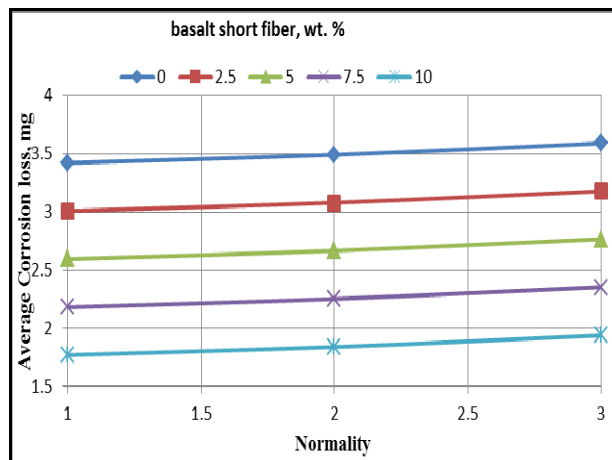

Fig. 4 Effect of normality on corrosion weight loss of Al/basalt short fiber composites.

Table 5 Effect of normality on Corrosion loss (in mg) for different weight percentages of basalt short fiber of as cast Al7075 alloy/basalt dispersed metal matrix composite.

Normality	Basalt short fiber (wt.%)				
	0	2.5	5	7.5	10
1N	3.4206	3.0081	2.5956	2.1831	1.7706
2N	3.49088	3.078383	2.66588	2.25338	1.84088
3N	3.5892	3.1767	2.7642	2.3517	1.9392

these pits, the attack was selective along certain crystallographic directions. In the case of composites, intense localized attacks were observed at the fiber-matrix interface as shown in the Fig. 5(b). In the neighborhoods of the pits, the matrix did not show a generalized attack, as that observed on the remaining surfaces as shown in the Fig. 5(c). Pitting occurred preferentially in correspondence with basalt short fiber clusters. It gave rise to a few wide pits, which were distributed on the surface of the specimen. This was particularly evident by volcano-shaped pits which appeared to be covered by white, thick, flaky corrosion product as was the case for composites. In the present investigation, Al alloy/basalt short fiber reinforced composites, the basalt short fiber is a ceramic; it is chemically inert in both alkali and acidic solutions. The reinforcement acts as a physical barrier for the corrosion reactions and also it reduces area of the matrix alloy to react in the media [24]. The presence of the reinforcement phase decreases the corrosion current density [25], which is further retarded by additional reinforcement [26]. It may also increase the bonding strength of the matrix and reinforcement. The bonding strength avoids the crack getting developed in the composite due to corrosion, which may also be one of the reasons for the increase in the corrosion resistance [27]. One more reason for the decreasing corrosion loss of the composite is the interface of reinforcement and matrix, which becomes the site of corrosion. It is due to the formation of magnesium inter-metallic layer adjacent to the particle during manufacture as discussed by Trzaskoma [28]. McIntyre et al. [29] further showed that the magnesium inter-metallic compound is more active than the alloy matrix. Pitting in the composites is associated with the particle-matrix interface, because of the higher magnesium concentration in this region. With increase in pitting, corrosion would continue to occur at random sites on the particle matrix interface. The active nature of the crevices would cathodically protect the remainder of the matrix and
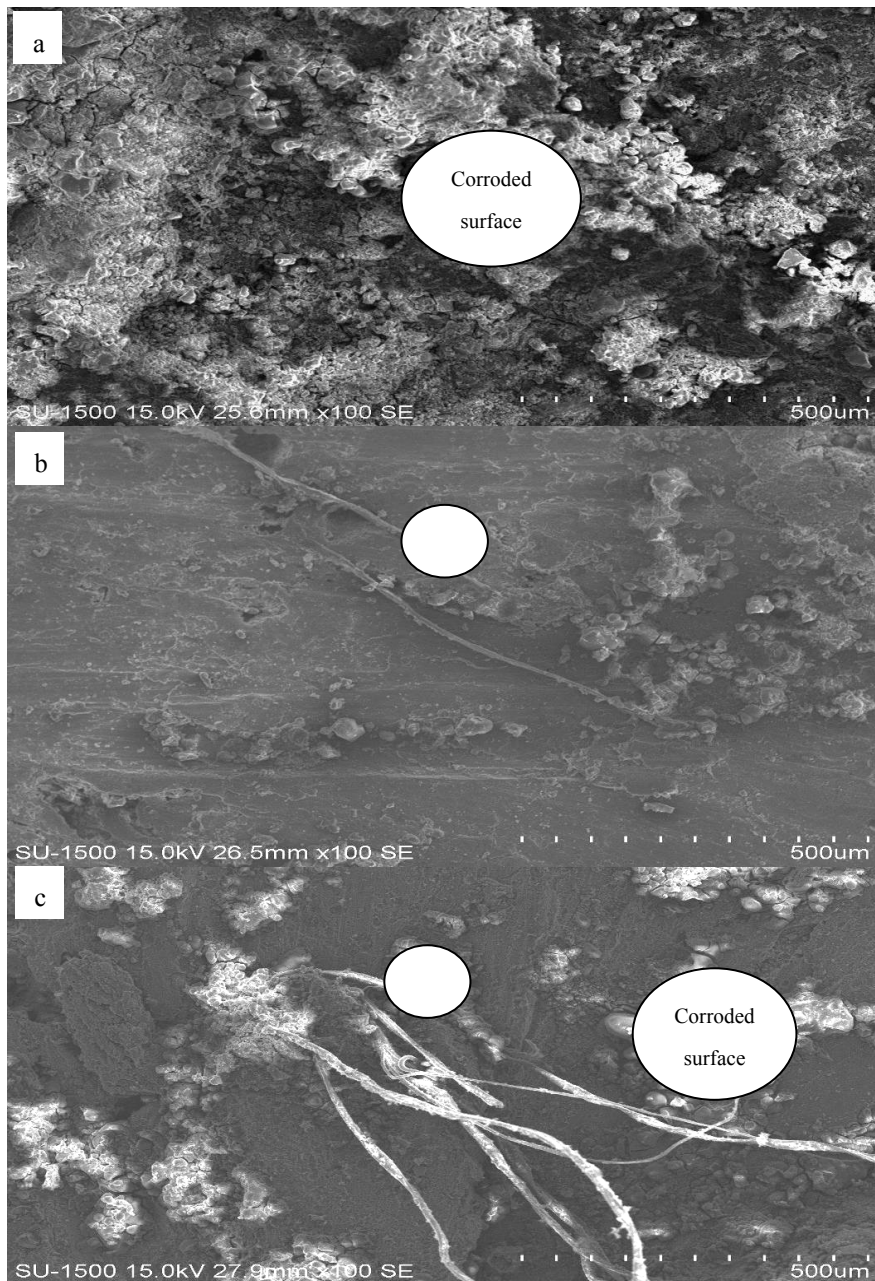
Fig. 5   Shows corroded surface of the a) as cast Al7075 alloy, b) Al/ 5 wt. % of basalt short fiber   and c) Al/ 10 wt.% of basalt short fiber composite.

restrict pit formation and propagation. On the same line, Badawy et al. [30] explained that of presence of small amount of Mg in Al alloy improves the passivation behavior of the alloy, which increases the corrosion resistance.

4. Conclusion

Based on the results of the present investigation, the following conclusions have been drawn.

The Al 7075/short basalt fiber reinforced composites of weight percentage varying from 2.5% to 10% are successfully developed using liquid metallurgy method.

Al/basalt short fiber MMCs were found to corrode in 1N, 2N & 3N NaCl solutions.

The corrosion rate in NaCl solution decreases with time, probably because of the formation of stable oxide layer over the specimens.

The rate of corrosion of both the alloy and composite decreased with increase in time duration.

As the basalt short fiber content is increased, the basalt short fiber reinforced composite become more corrosion prone due to increase in electrochemical between the matrix alloy and the basalt short fiber.

The corrosion resistance of the basalt short fiber reinforced composite was enhanced when compared to that of the base Al alloy. Scanning electron micrographs of the basalt short fiber reinforced composite reveal numerous shallow pits in the tested sample.

Scanning electron micrographs of the MMCs reveal numerous shallow pits in the modified tested for corrosion.

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