Reinforced Epoxy Composites Chracteristics

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Abstract: An epoxy resin EP with backbone structure was obtained by curing o-cresol novolac epoxy resin with phenol novolac resin. The reinforced epoxy test specimens were prepared in the form of 45 × 35 mm², 10.0 mm thickness and adding four meshes of aluminium wires of 40 × 30 mm² with 5, 10, 15 and 20 wires of 0.2 mm to 1.0 mm diameters at 10mm from surface. The effect of the test temperature on the mechanical properties of the reinforced epoxy is carried out and investigated. The electrostatic charge is measured at a static loads ranging from 50 to 200 N at dry condition at various test parameters. A corrosion test is carried out and investigated on the produced reinforced epoxy composites using NaCl with concentration ranging from 0.01M to 1.0M at an immersion time of 50, 100, 150, 200 and 250 hrs at room temperature. Water sorption method is carried out to investigate the effect of the previous parameters on the reinforced epoxy composite properties.
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Keywords: EP epoxy resin, aluminium wires, corrosion, static electricity, water sorption, NaCl corrosion medium and composites.

1. Introduction

Manufacturing industry experts estimate product losses due to static electricity from 8% to 33%, or into the billions of dollars annually. Static electricity causes industrial handling problems such as unwanted adhesion or repulsion of sheet paper in the printing industry, damage to delicate integrated circuits, and the blocking of powders and dusts being conveyed in pipes. Modern buildings are inherent static generators and dry, fine weather often brings complaints of electric shocks from people touching metal objects such as radiators, door handles, filing cabinets and hand rails. Static electricity is generated by the contact and separation of materials, and clearly this generation often cannot be prevented in the industrial setting. Ashford [1] deduced that the term ESD (electrostatic discharge) generally used in the electronics industry to describe momentary unwanted currents that could cause damage to electronic (avionics) equipment. One of the causes of ESD is static electricity. Sun *et al.*[2], showed that electrical properties of dielectric materials, such as permittivity or conductivity, can be adjusted by adding appropriate filler into the dielectric matrix. Herous *et al.* [3], investigated surface potential decay (SPD) that highly conditioned by temperature, relative humidity and charge density on the material. Electrostatic charges can play an undesired role in diverse industrial applications, particularly in plastic industry and in high impedance circuitry.

Epoxy materials are versatile for many industrial applications, including coating, structural decoration and electronic encapsulation. In general, epoxy resins are viewed as cross linked thermosets which have good adhesion and also good resistance to chemicals, moisture, heat and electricity. Since several years, synthetic polymers have known a large application in electrical industry due to their excellent electrical, thermal, and mechanical properties. Epoxy resin is one of the most commonly used thermosetting materials in high voltage apparatus as insulation. In recent years, the nano reinforced epoxy resin has attracted a wide interest as it enhances the epoxy's properties significantly, [4]. Danikas *et al.* [5] presented an arrangement of three layers of epoxy resin with a void in middle layer. Different level voltages under inception voltage are applied to the arrangement and different PD waves are registered under different level voltages. Lorenzi *et al.* [6] investigated the results of two newly developed simulation tools: the first consisting of a quasi-static non linear model for epoxy spacer based on finite element method code ANSYS™, the other consisting of a spacer profile optimization package, whose kernel is based on a genetic algorithm. Epoxy based thermosetting polymer resins are widely used in the industry due to their superior characteristics such as good mechanical properties, and good resistance to chemicals. Significant use of epoxy resins as the matrix material in fiber reinforced composites, for the application in the aero-space and automotive industry. However, such composites are highly susceptible to environmental conditions, primarily due to the degradation of epoxy matrix, [7]. Jafar *et al.* [8], concluded that the dielectric properties of polymers have an increment importance because it provide an understanding to the movement of the molecular chains in the applications in electrical and electronic engineering. Epoxy resins are highly cross linked amorphous polymers used for insulation in electric transformers, switchgear, rotating machines, etc. Recently, epoxy nanodielectric systems are being increasingly investigated for their electrical properties, since the introduction of nano fillers demonstrate several advantages in their properties when compared with the similar properties obtained for epoxy systems with micrometer sized fillers, [9]. Composites attained higher properties compared to single element products, Ashraf *et al.* [10 and 11], discussed the corrosive wear parameters of the compacted and extruded Al/Cu composites. Also, a comparison between the corrosion parameters and results of the extruded aluminium and Al/Cu is obtained, [12]. Sulong *et al.* [13], studied the effects of chemical functionalized carbon nanotubes (CNTs) on the electrical conductivity of nano composites, to increase dispersion and interfacial bonding strength between CNTs and polymer matrix for the mechanical properties improvement. Also, Ashraf *et al.* [14] discussed the effect of graphite concentrations on the compaction of aluminium/graphite composites properties. Kosmidou *et al.* [15] presented an insight into the effect of composites preparation procedure and the filler content on both electrical and mechanical properties of a nano composite system. Wang [16] prepared the epoxy resin containing nano size SiO_2 and Al_2O_3 fillers, the influence of nano size filler on nano composites electrical properties was investigated. Kechaou *et al.* [17], compared the mechanical, tribological, and dielectric properties of glass fiber-reinforced epoxy.

Corrosion protection in non-barrier-type organic coatings is supplemented by the addition of sparingly soluble inorganic pigments into the coating resins. Ashraf *et al.* [18], investigated the corrosion wear of aluminium tubes before and after spinning. Both the corrosion and spinning operation parameters are discussed, [19]. Choi *et al.* [20], evaluated the corrosion performance of epoxy-coated reinforcing bars in Cl contaminated concrete by electrochemical impedance spectroscopy method. Mahajanam and Buchheit [21], used Zn-Al-[V10O28]6– hydrotalcite ion exchange compound as a corrosion inhibiting pigment additive for protective organic coatings. Ion exchange experiments showed that the compound is an amphoteric exchanger that releases Zn2+ and vanadates in millimolar concentrations when contacted by 0.0001 M to 1.0 M sodium chloride (NaCl) solutions. Akbas *et al.* [22] discussed the effect of the degree of exfoliation of the organoclay on water barrier and corrosion resistance. Pincheira [23], used steel reinforcement bars coated with epoxy to minimize corrosion, but policies and practices regarding the use of this coating have changed, and concerns remain about its effectiveness over the long term. The aim of the present work is to evaluate the effect of both the numbers and diameters of aluminium wires on the generated electrostatic charge of epoxy/Al composites. The effect of NaCl corrosion medium on both epoxy and epoxy/Al composites is carried out and investigated at various Al wires numbers and diameters at various NaCl concentrations and immersion periods. The mechanical properties and the water sorption properties are investigated.

2. Experimental

2.1 Specimen Preparation

Four meshes of aluminium of 5, 10, 15 and 20 wires with diameters ranging from 0.1 to 1.0mm are used to form boxes with area 30X40 mm^2 and 10 mm height as shown in Figures 1.a to 1.c. The EP epoxy was obtained by curing o-cresol novolac epoxy resin with phenol novolac resin and molded into the boxes. The composites became ready for experiments after one day, as shown in Fig. 1.d.

2.2 Static electricity measurements

Electrostatic tests were carried out at room temperature under applied normal loads of 50, 100, 150, and 200 N. The test specimens were contacts and separates against counter face (rubber) of 50$\times$420 mm² area and thickness 10 mm at dry test condition. The Ultra Stable Surface Voltmeter was used to measure the electrostatic charge (electrostatic filed) after contacting the specimens with rubber for 10 second and separating to measure the generated charge under 50, 100, 150 and 200 N applied loads. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings are normally done with the sensor 1" (2.5 cm) from the surface being tested. This sensor is unaffected by an ionizing environment (an environment with electric sparks nearby).

2.3 Sorption method

The gravimetric method is used to measure the water sorption at an immersion time ranging from 0 to 250 hrs. After immersion in deionized water at 25±0.2^{o}C for predetermined intervals of time, the sample was taken out from the water and weighed on an accurate balance with an accuracy up to 0.01mg after the liquid water on its surface was blotted away. The water sorption (M_t) of the sample defined as:

$$M_t = [(W_t - W_o)/W_o] * 100\% \quad (1)$$

Where; W_t is the mass of the sample at immersion time t, W_o is the mass of dry sample.

2.4 Corrosion test

Aluminium wires of different wire diameters and numbers are coated with EP epoxy and immersed in 0.01, 0.1, 0.5 and 1.0 NaCl solution at temperature ranges from 25 to 150^{o}C and immersion time of 6, 24, 36, 48 and 72 hrs. After the specified times, the specimens were removed from test solution, thoroughly washed with $NaHCo_3$ solution and de-ionized water, dried well and then weighed. The corrosion loss for various concentrations of NaCl was calculated, by measuring the advanced length of corrosion

3 Results and Discussions

3.1 Effect of wire diameter

Figure 2 illustrates the effect of wire diameter on the electrostatic charge at various of contact load. As the diameter of wire increases, the wire ability to conduct the electrostatic charge generated at the surface of epoxy increases because the cross area of wires decreased. The same trend of results is obtained with the increment of the number of wires in a mesh due the increment of the bulk of aluminium metal that increases the ability to conduct the electrostatic charge and enhance the conductivity of epoxy composites.

3.2 Effect of number of wires

Figure 3 illustrated the effect of number of wires on the electrostatic charge generation under various values of applied loads. It is clear that as the number of wires increases, the generated electrostatic charge increases due to the aluminium wires higher conductivity. Also, the figure showed that as the contact load increases, the static electricity increases for different wire diameters and number of wires, this behavior illustrates the ability of wires to conduct the electrostatic charge and enhance the conductivity of epoxy composites.

3.3 Epoxy composites mechanical properties

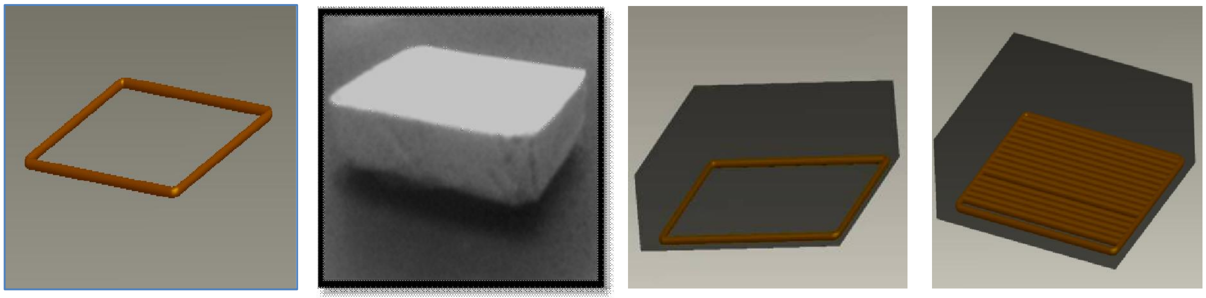
Figure 4 illustrates the variation the composites ultimate tensile strength with the number of wires at various test temperatures. It is clear that as the number of wires increases, the composite ultimate strength increases due to the aluminium amount increment. Also, as the temperature increases, the composite ultimate strength decreases, due the softening effect of temperature on the aluminium wires.Figure 5 illstrates the effect of test temperature on the elastic modulus of the epoxy/alumium composites at various test temperatures. It is clear that as the number of wires increases, the elastic modulus increases, due to the increment of the aluminium bulk and the epoxy/aluminium ultimate strength. Figure 6 illustrates the effect of test temperature on the epoxy/aluminium elongation at various number of wires. It is clear that as the number of wires decreases, the elongation increases due to the strength decrement. Also, as the temperature increases, the elongation increases due to the epoxy/aluminium composites softening.

3.4 Sorption test results

Figure 7 shows the variation of the epoxy sorption with immersion time obtained by the gravimetric method. It is clear that as the immersion time increases, the diffusion of the water molecules to access the free volume of the epoxy resin increases, i.e. the water molecules bind themselves to water groups in the epoxy. The diffusion of water in the resin is achieved by the jumping from one polar to another. This suggests that water affinity is more important in determining water sorption of the resin than the size and the amount of the free volume. As the water sorption increases, the effective cross sectional area of water passage in the epoxy increases. The figure also showed that as the number of aluminium wires increases, the amount of free water molecules detected in the epoxy/Al composites decreases due to the amount of free volume decrement in the resin. A special layer is confirmed in the epoxy. This special layer prevents water molecules from reaching the metal surface. Therefore the corroded area of the metal becomes much less than the cross area of NaCl passage, so corrosion decreases in the epoxy reinforced with 20 aluminium wires of 1.0 mm diameter compared to Al wires corrosion as shown in Fig. 8. The process can be divided by two parts. One part in which NaCl presents in the epoxy and the other reaches the surface of the substrate.

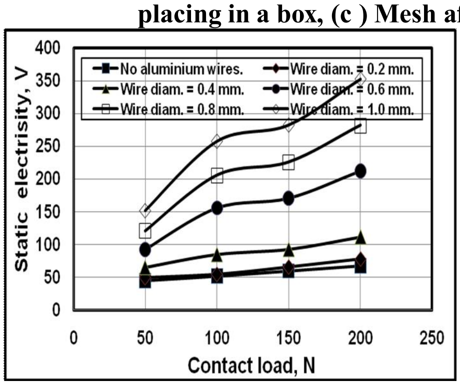
3.5 Corrosion test results

Figure 9 illustrates the effect of NaCl concentration on the length of corrosion of epoxy and epoxy/Al composites at various immersion periods. It is clear that as the NaCl concentration increases, the epoxy and epoxy/Al composites corrosion increases dueto the increment intensity of NaCl in agreement with Ashraf *et al.,* [11, 12, and 18]. Also, as the immersion period increases, the corrosion effect increases. As the test temperature increases, the epoxy and epoxy/Al composites softening increases, so their resistance to corrosion decreases.

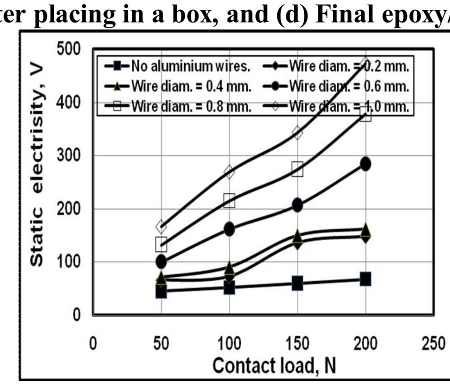


(1.a) (1.b) (1.c) (1.d)

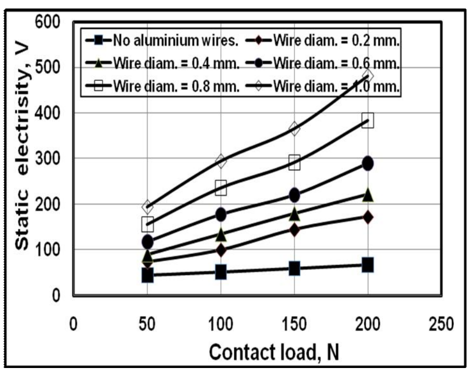
Fig. 1. Stages of preparation EP epoxy/Aluminium composites. (a)Mesh with free wires, (b) Mesh after placing in a box, (c) Mesh after placing in a box, and (d) Final epoxy/Al composites.



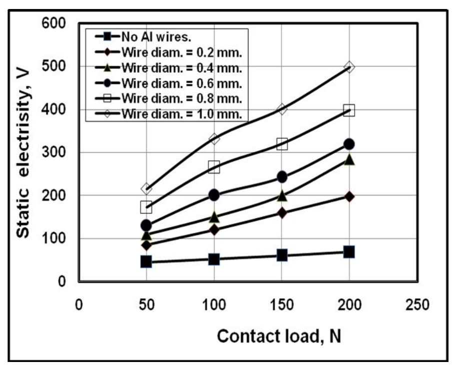
(2.a) 5 wires mesh



(2.b) 10 wires mesh

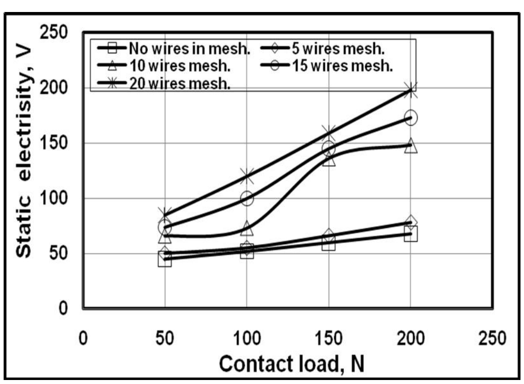


(2.c) 15 wires mesh

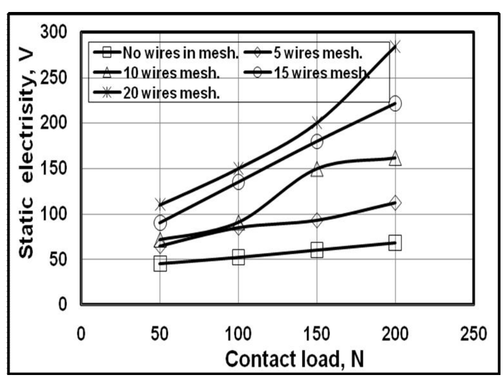


(2.d) 20 wires mesh

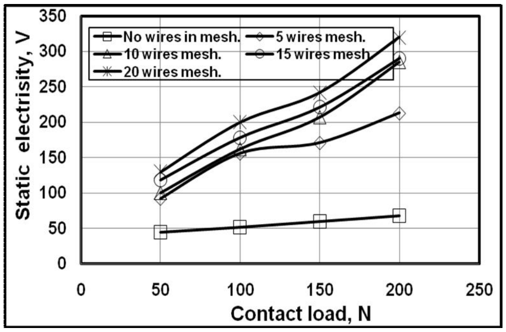
Figure 2. Effect of wire diameter on the static electricity at various contact loads.



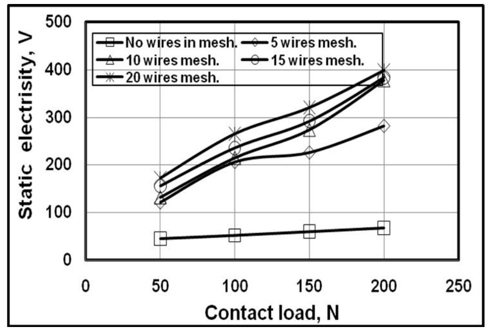
(3.a) 0.2 mm diam. wire.



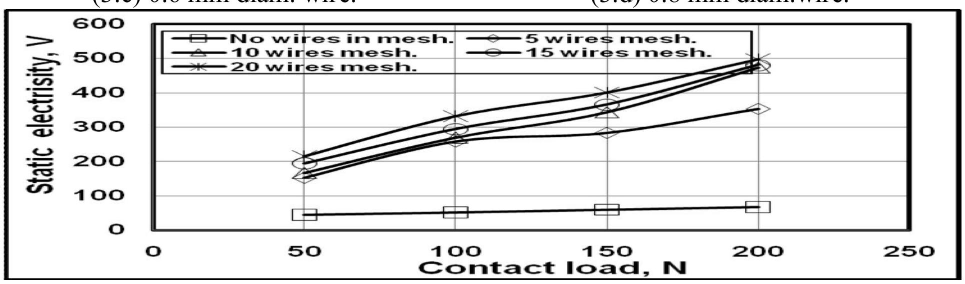
(3.b) 0.4 mm diam. wire.



(3.c) 0.6 mm diam. wire.



(3.d) 0.8 mm diam.wire.



(3.e) 1.0 mm diam.wire

Figure 3. Effect of number of wires on the electrostatic charge at different loads.

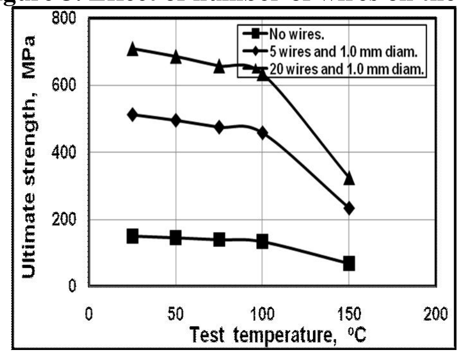


Figure 4. Effect of test temperature on the Epoxy/aluminium composites ultimate strength at various number of wires.

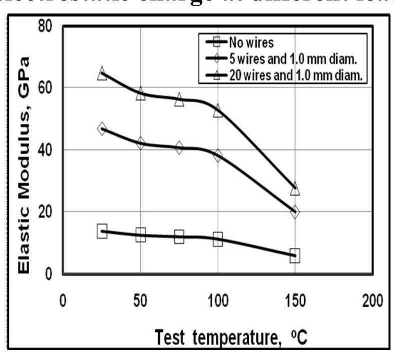


Figure 5. Effect of test temperature on the elastic modulus of epoxy/Al at various test temperatures.

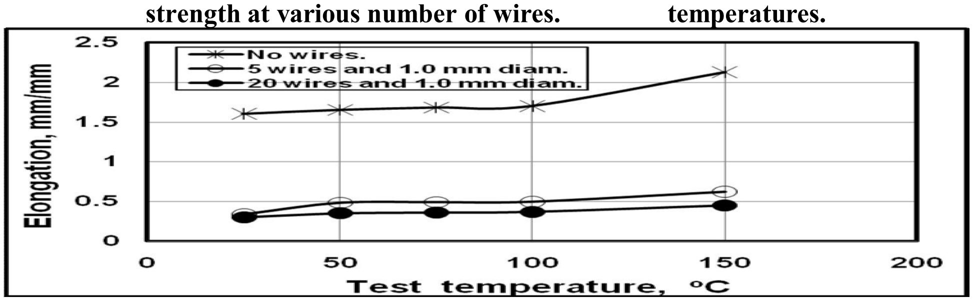


Figure 6. Effect of test temperature on the epoxy/aluminium composites elongation.

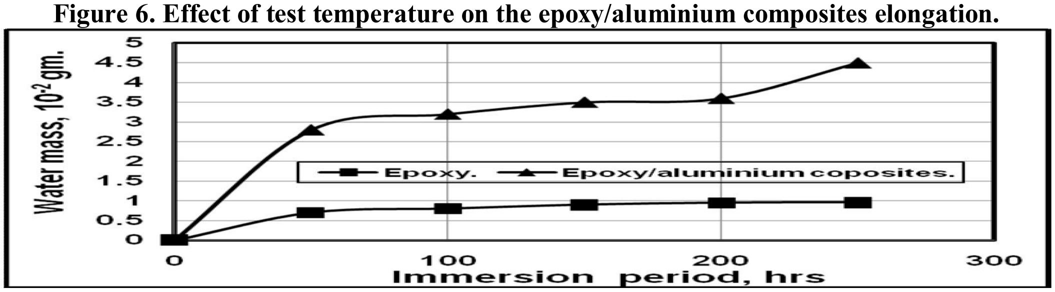


Figure 7. Sorption water/immersion period relation.

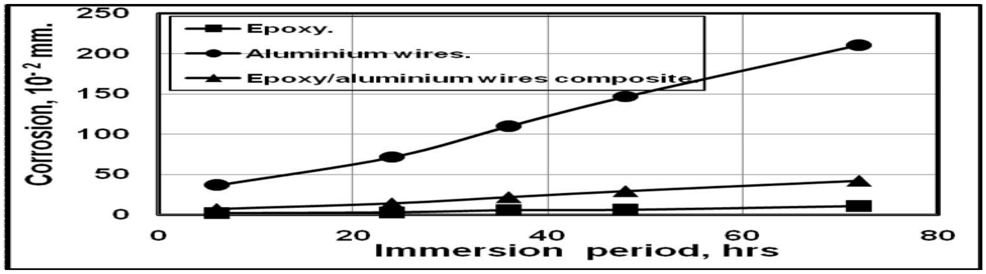
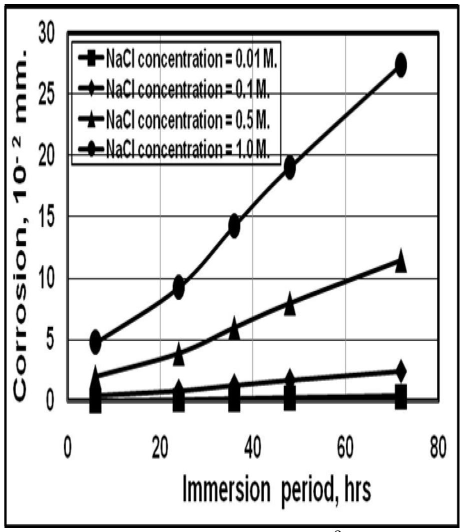
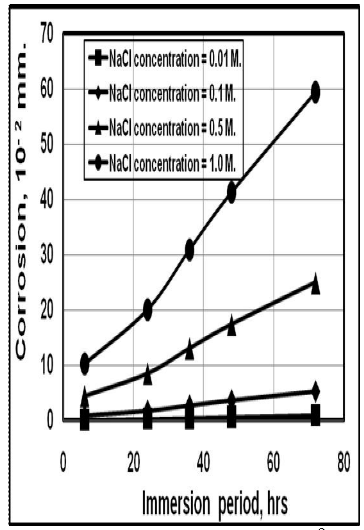


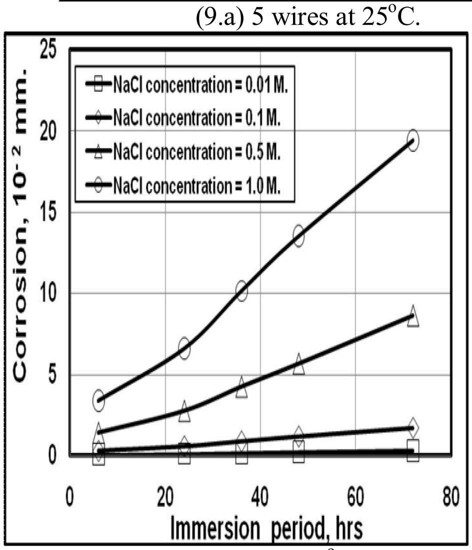
Figure 8. Corrosion advanced length/ immersion time relation at 1.0 M NaCl.



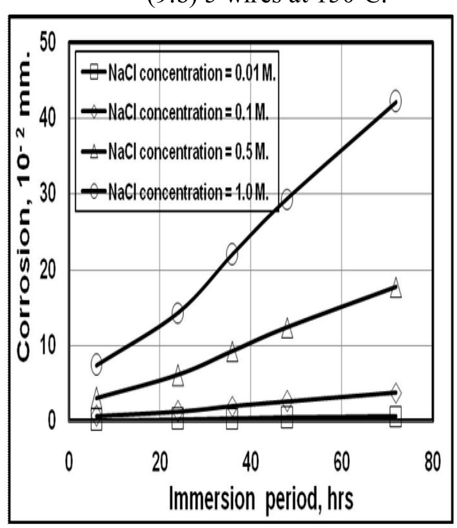
(9.a) 5 wires at 25^{o}C.



(9.b) 5 wires at 150^{o}C.



(9.c) 20 wires at 25^{o}C.



(9.d) 20 wires at 150^{o}C

Figure 9. Effect of immersion test period on the length of corrosion advanced.

Conclusions

The following conclusions are obtained;

1. The electrostatic charge increases with increasing aluminium wires numbers, diameters and contact loads.

2. The epoxy/Al composites ultimate strength and elastic modulus increases while the elongation decreases with the increment of wires numbers and diameters.

3. The sorption test illustrates the decrement of the water diffusion at the epoxy/Al composites.

4. The corrosion advanced length increases with both the immersion time and NaCl concentration increment and decreases with both wires diameters and numbers.

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