INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 9, Issue 2, 2018 pp.187-194

Journal homepage: www.IJEE.IEEFoundation.org

Effect of chemical solutions on the mechanical properties of nano-silica reinforced (glass/Kevlar) fabrics polyester hybrid composite materials

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Received 21 Sep. 2017; Received in revised form 22 Nov. 2017; Accepted 30 Nov. 2017; Available online 1 Mar. 2018

Abstract
Polymer matrix composite structures can be exposed to a variety of severe corrosive environments during their service, which lead to degrade their structure and deteriorate their properties. The both influence of the alkaline and acid solutions on the mechanical properties of the hybrid polymer composite materials are illustrated in this paper. Hardness, tensile properties and impact strength of the nano-silica particles reinforced (glass/Kevlar) fabrics polyester hybrid composite before and after immersing in (HCl) and (NaOH) solutions studied. Regardless of the solution, hardness, tensile and impact strength decrease with increasing the exposure time. On the other hand, the alkaline solution led to high decreasing in these properties than the acid solution. In addition, the hybrid composite showed remark enhanced in the mentioned properties than the glass fiber polyester alone.

Keywords: Hybrid composite; Acid solution; Tensile strength; Nano silica; Alkaline solution.

1. Introduction
The concern in glass fiber-reinforced polymers (GFRP) for extremely corrosive environments, as an alternative to cast iron, stainless or other conventional materials ones, is becoming common. The attraction for using (GFRP) ascribed to the high reduction in weight, besides their high specific strength and stiffness, impact, reasonable cost, good resistance to the chemical attack and easy to manufacture. Currently, the polymer composite materials generally used as pipes in many sectors such as chemical industry, infrastructures and building structures [1].
However, because of the high velocity of the solid species and chemical solutions inside (GFRP) pipelines, different degradation process may be occurring due to abrasion, change in the hardness, delamination of fiber from the matrix and matrix deterioration [2]. According to these conditions, there is an urgent necessity to enhance the resistance of the (GFRP) composite pipelines for the various types of corrosive environment [3]. The effect of (HCl) acid on the flexural strength and hardness of glass fiber/polyester composite are studied by Mahmoud. It was found that the flexural strength and hardness values decreased around 10% and 15% respectively after (30) days of immersion for the flexural and (90) days of immersion in (HCL) acid for the hardness [4].
The high temperature of the solution and the exposure duration of two types of resin when immersed in the sulphuric acid are studied by Banna. It observed that the polyester resin had lower modulus values

when exposed to sulphuric acid compared to the "bisphenol epoxy vinyl ester resin". For both resins the hardness decreased after (4) weeks of exposure and at higher temperature of the exposure, the microstructure of the polyester degraded at more rate than the lower temperature in the same acid [5].
The effect of pH of solution on the tensile properties of glass-polyester composites are studied by Rakin, it was found that, the ultimate tensile strength and the modulus of composite decreased with increasing pH value of the solution [2]. The tensile properties of (GRP) in the NaCl solution are studied by Joseph, It was observed that the tensile strength and modulus of elasticity decreases within these environments in contrast to the acid environments. The decreasing in properties will be even higher if the concentration of the solvent is increased [6].
The delamination in glass fiber polymer composite when subjected to low velocity impact combined with the highly corrosive environments are studied by Reis. It was found that, the environment plays a critical role in the delamination process of composite, which led to severe effects on the performance of those materials [7]. The flexural strength and flexural modulus of glass/epoxy composites when immersed in different chemical solutions are studied by Amaro. It was concluded from achieved results, the corrosive environment affects significantly on above-mentioned properties and their influences increased with increasing the pH value of solutions [8].

2. Experimental works

2.1 Materials

The raw materials used in work involves unsaturated polyester (provided from SIROPOL.GP) with its hardener (MEKP) as matrix materials and both types of glass and Kevlar fibers with nano silica particles which used as reinforcing materials. The particle size of the nano silica is about (15-20) nm with 99.5% purity provided from NANOSHEL American company.

2.2 Procedure

By means of hand lay-up technique, composite and hybrid composite materials are prepared in this work. In order to prepare the composite materials, the unsaturated polyester are mixed with (2wt%) of (MEKP) hardener, the later is liquid and transparent material, for (3) min in addition to (2wt%) of cobalt accelerator for another (2) min into a plastic cup in order to cure the polyester resin.
At the same time, six layers of glass fabrics laid in a metallic mold and then applied the polyester mixture with help of clean brush. On the other hand, the hybrid composites are prepared by same approach but by stacking three layers of glass fabrics and three layers of Kevlar fabrics into polyester resin as shown in Figure 1. Another group of hybrid composite is prepared in this study by incorporating the nano silica particles inside (glass/Kevlar) fabrics polyester hybrid composite with different volume fraction and examines its influence on the above-mentioned properties.

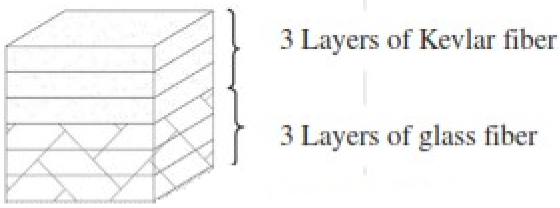


Figure 1. Schematic diagram of glass and Kevlar fabrics hybrid composite.

In this case, the nano silica particles mixed with the polyester mixture until homogeneous mixture is achieved and then applied onto the prepared fabrics layers in the mold. In order to prevent the precipitation of the ceramic particles in the base of the sample, the particles must have added before the gelation stage forming in the mixture.

3. Characterization

In order to determine the required properties, three samples are prepared for each test by cutting the produced hybrid composite into the required geometry according to ASTM standard and applying the procedures for each required test.

3.1 Tensile measurements

The tensile properties are measured based on the ASTM D3039 specification provided from Tinius Olsen universal material machine device with 100 KN load at a strain rate of 10 mm/min. The obtained data involved the tensile strength, the tensile modulus and the elongation at the break. The geometry of the tensile test specimen shown in Figure 2.

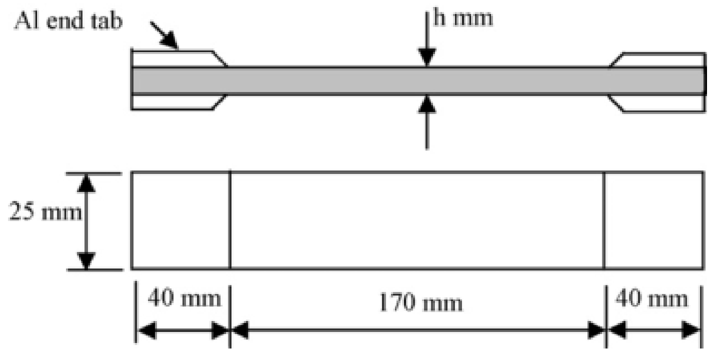


Figure 2. Tension test geometry.

3.2 Impact measurements

The impact strength of the prepared hybrid composite determined by Izod impact device provided from Time Testing Machines XJU-22 according to the ASTM standard D-256.The geometry of the impact test specimen shown in Figure 3.

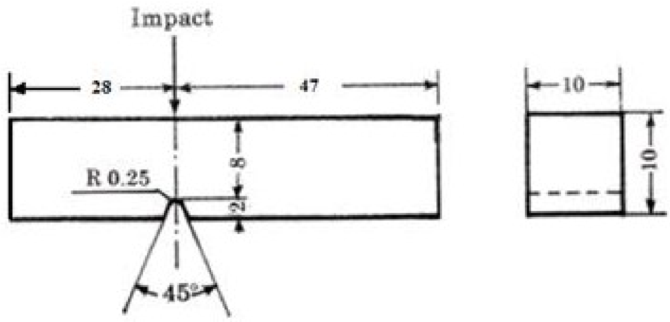


Figure 3. Impact test geometry.

3.3 Hardness measurements

In hardness test, shore (D) device was used to perform the experiment which is provided from the W-Tester Amsler Durometer (DIN 53505-ISO P858) in order to determine the hardness values of the prepared hybrid composite. In the opinion of the author, this is the suitable method for the polymeric materials. Shore (D) is a device similar to a compass has a needle in the middle. In order to obtain good results, the device must put perpendicular to the smooth surface of sample and must be in touch with the surface of the sample to be measured in order to poking the needle into the surface of a material for three seconds and then taken the value of the hardness from the device. The geometry of the hardness test specimen shown in Figure 4.

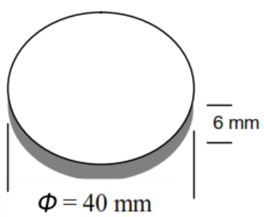


Figure 4. Hardness test geometry.

3.4 SEM characterization

TESCAN Vega II XMU SEM characterization used in this effort, which are provides high-resolution images. Separate at least (3) small samples from each specimen to ensure homogeneity and unified structure. After that, the samples are cleaned, dried and finally mounted on a stub of metal with adhesive, coated with (40-60) nm of gold.

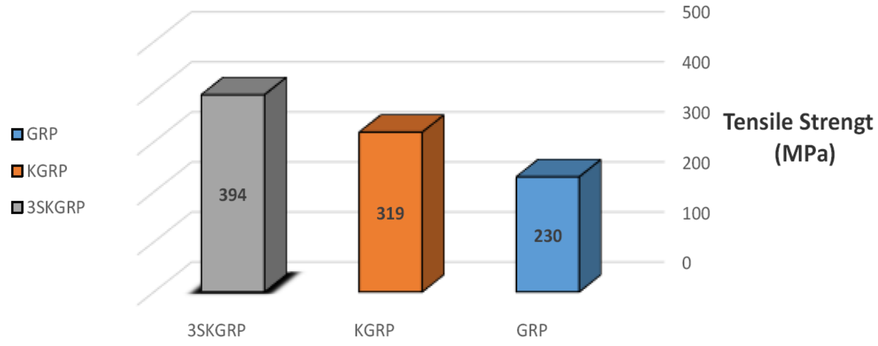
4. Results and discussion

Three groups of samples are prepared in this study, glass fiber reinforced polyester (GRP), Kevlar glass fibers reinforced polyester (KGRP) and nano silica reinforced the (Kevlar/glass) fabric polyester resin (SKGRP). Figure 5 (a, b, c, d, e) show the effect of these groups on tensile properties, impact strength and hardness of polyester resin. It was found from the results shown in Table 1, that the (3SKGRP) with (3%) volume fraction of nano silica showed better properties than (KGRP) which already have high properties when compared with (GRP) alone.

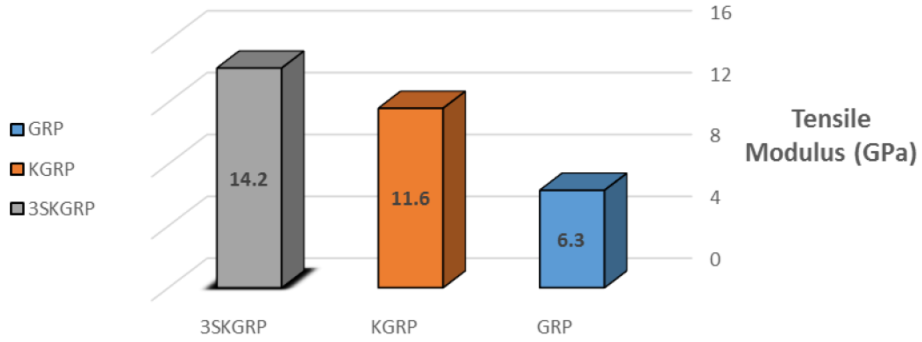
The enhancement in above properties is attributed to the inherent properties of these fabric fibers, where Kevlar fibers has the highest tensile strength among all the fibers, besides with the high-energy absorption properties of these fibers, which led to improve the impact strength of polyester resin. All these reasons combined with the well dispersion of nano-silica particles within the polyester resin matrix, which play a critical role in enhancing the mechanical properties by inhibiting the crack propagation due to stresses.

In addition, it observed from Table 1, the mechanical properties of the prepared hybrid composite increased with increasing the volume fraction of nano particles up to (3%), beyond this ratio, there is a slight decrease in the mentioned properties up to (5%) ratio.

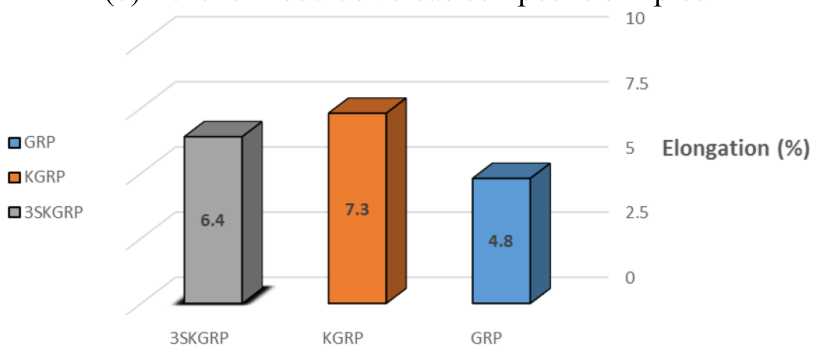
This reduction in the properties is ascribed to the agglomeration of nano silica particles in the polymer matrix due to the high viscosity of the mixture at high volume fraction of nano particles, which in turn can cause more void formations in the samples.



(a). Tensile strength versus composite samples.

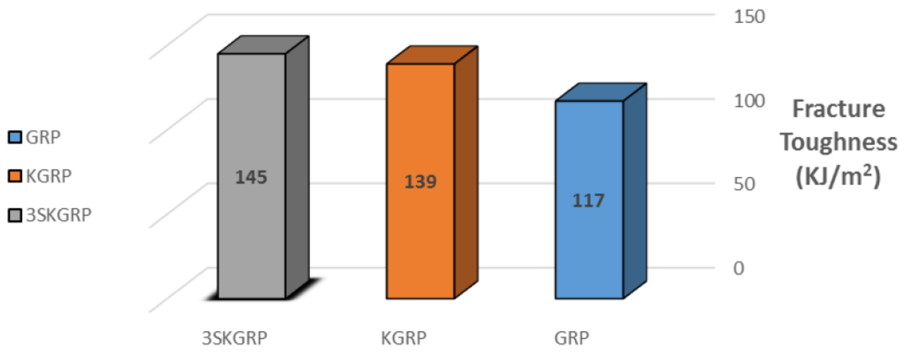


(b) Tensile Modulus versus composite samples.

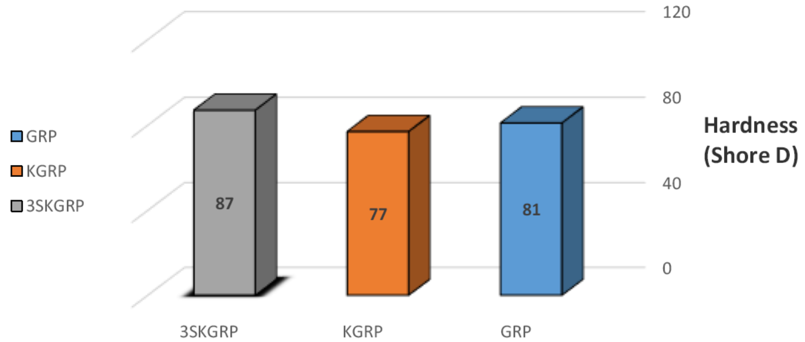


(c) Elongation versus composite samples.

Figure 5. Continued.



(d) Impact strength versus composite samples.



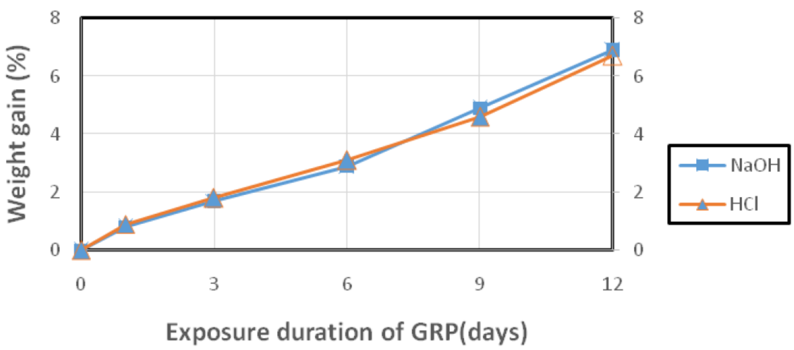
(e). Hardness versus composite samples.

Figure 5.

Table 1. Mechanical properties of different types of composite.

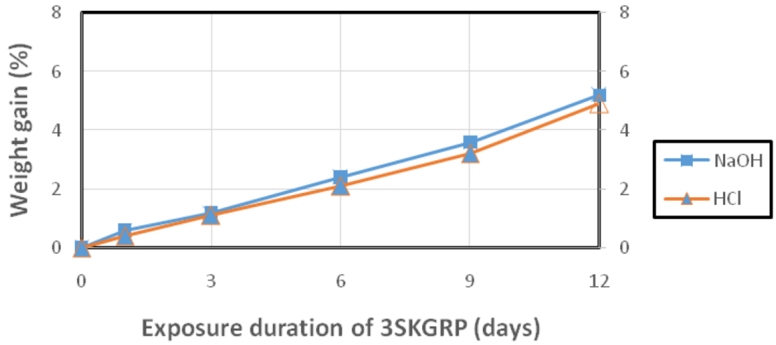
Samples	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation (%)	Impact Strength (KJ/m^2)	Hardness
GRP	230	6.3	4.8	117	81
KGRP	319	11.6	7.3	139	77
1SKGRP	355	12.8	6.9	142	83
3SKGRP	394	14.2	6.4	145	87
5SKGRP	290	9.7	6.1	118	82

Figure 6 (a, b) show the behavior of the prepared composite (GRP) and hybrid composite (3SKGRP) when immersed in both of alkaline and acid solutions as a function of the exposure duration. Different duration times of (1, 3, 6, 9 and 12 days) respectively are used in this work. From the obtained results, it is possible to detect a weight gain up to (12) days, with values quite close when immersed in the two types of alkaline and acid solutions for the two types of composite. Therefore, this absorption leads to matrix expansion results in the occurrence of the pits and development of micro stresses in the prepared composites.



(a). Weight gain versus exposure duration of (GRP) composite.

Figure 6. Continued.



(b). Weight gain versus exposure duration of (3SKGRP) hybrid composite.

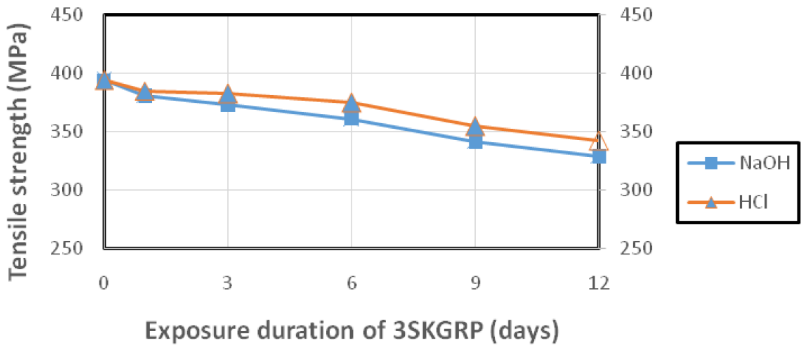
Figure 6.

It also observed from the behavior of the two groups, the (3SKGRP) hybrid composite exhibited more resistance to chemical solutions attack than (GRP) composite. The enhancement in the resistance of the hybrid composite to the attack of chemical solutions is ascribed to the increasing in the hardness values of the hybrid composite that make the polyester resin more resist to the penetration of chemical solutions by enhancing the surface hardness of the polyester matrix.

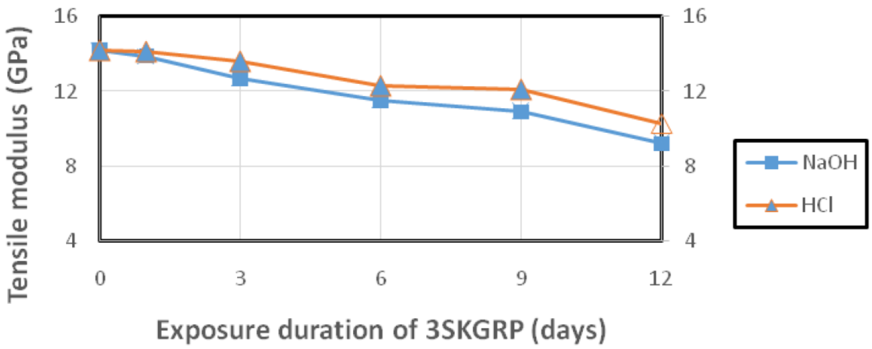
Figure 7 (a, b, c, d, e) show effect of alkaline and acid solutions on tensile properties, impact strength and hardness of (3SKGRP) hybrid composite. It is possible to detect that the measured tensile properties and impact strength of hybrid composite decreased when immersed in these solution and these deceasing increased with increasing the duration of the immersion. In addition, the results show that the (NaOH) solution have aggressive effect on the mentioned properties than (HCl) solution as shown in the SEM images in Figure 8 (a, b, c, d, e).

From the SEM images, it can be noticed that, the occurrence of the pits in the microstructure due to chemicals attacks leading to the development of micro stresses in the prepared hybrid composites.

The reduction in the mechanical properties may attributed to the absorption of the chemical solution by the matrix which reducing the connectivity between the phases leading to weak interphase bonds and reduction of the mechanical properties. On the other hand, it is possible to conclude that the measured hardness of the hybrid composite slightly increased after immersion in both solutions for (1) day exposure, but later hardness values decreases with exposure time up to (12) day.

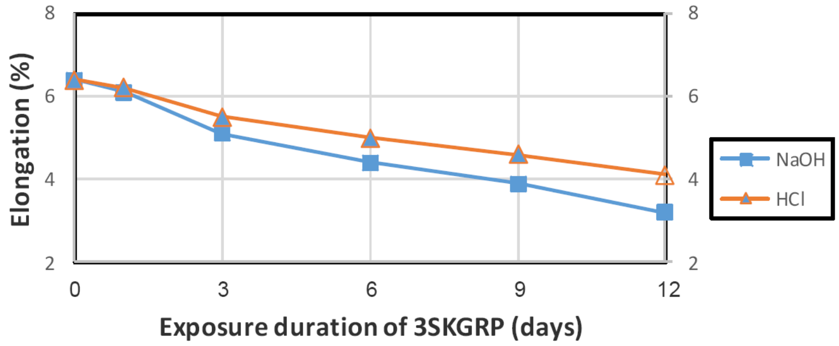


(a) Tensile strength versus exposure duration of (3SKGRP) hybrid composite.

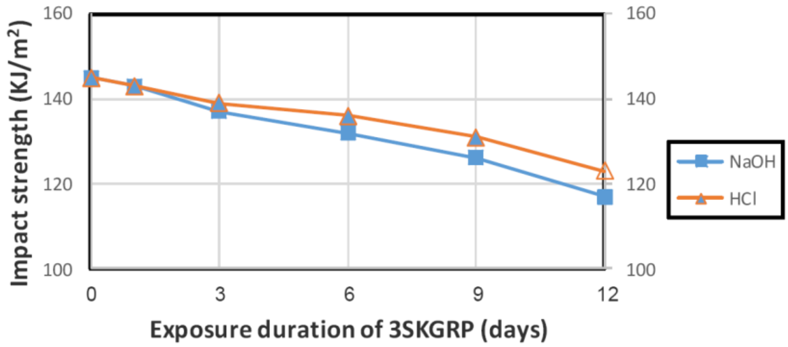


(b) Tensile modulus versus exposure duration of (3SKGRP) hybrid composite.

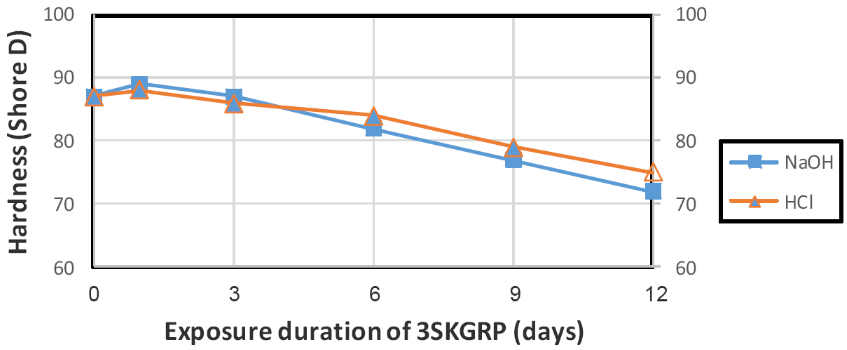
Figure 7. Continued.



(c) Elongation versus exposure duration of (3SKGRP) hybrid composite.

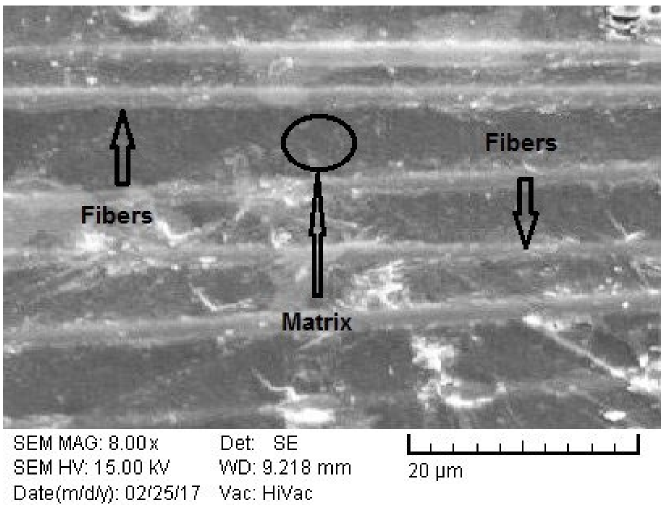


(d) Impact strength versus exposure duration of (3SKGRP) hybrid composite.



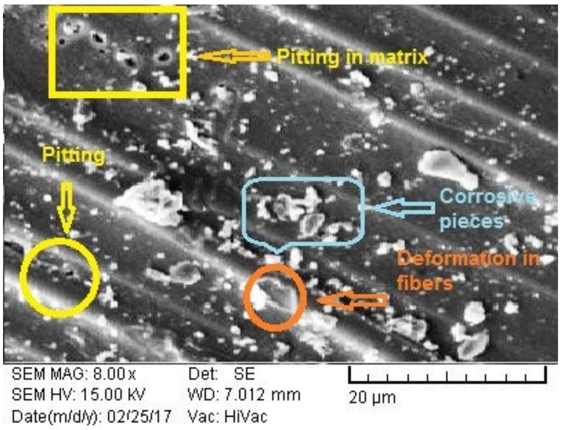
(e) Hardness versus exposure duration of (3SKGRP) hybrid composite.

Figure 7.

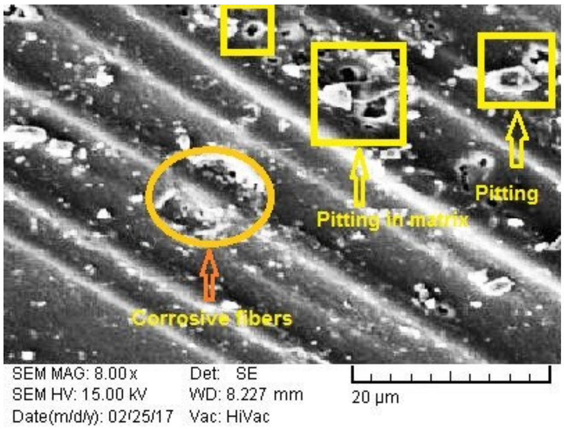


(a)

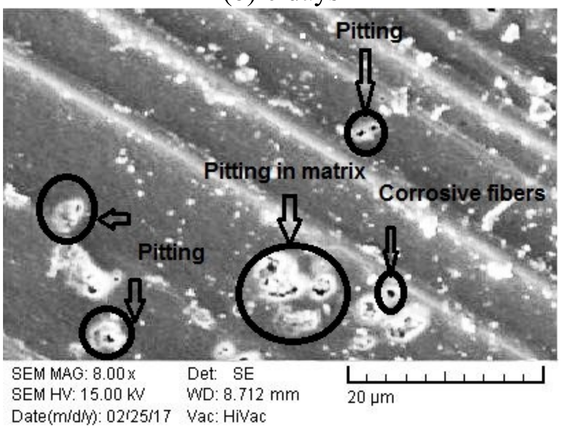
Figure 8. Continued.



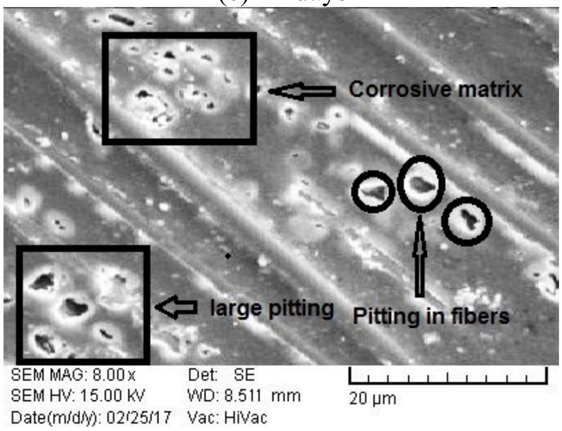
(b) 6 days



(c) 12 days



(d). 6 days



(e). 12 days

Figure 8. (a) SEM image of (3SKGRP) hybrid composite, (b, c) SEM images of (3SKGRP) composite after exposed to HCl during 6 and 12 days, (d, e) SEM images of (3SKGRP) composite after exposed to NaOH during 6 and 12 days.

5. Conclusions

This effort studied the tensile properties, impact strength and hardness of nano silica ceramic particles reinforced (glass/Kevlar) fabrics polyester hybrid composite before and after immersing in the (HCl) and (NaOH) solutions. It was concluded that the corrosive environmental affects significantly the above-mentioned properties. The exposure time was determinant on the properties degradation. The alkaline solution shows to be more aggressive than the acid solution as shown from the SEM images, promoting the lowest properties. In addition, the prepared hybrid composite exhibited more resistant to these chemical solutions due to their high tensile properties, impact strength and hardness than normal composite.

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