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Effect of corrosive solutions on composites laminates subjected to low velocity impact loading

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ABSTRACT

In recent years, there has been a rapid growth in the use of fibre reinforced composite materials in engineering applications and this phenomenon will be continuing. In this context, composite structures can be exposed to a range of corrosive environments during their in-service life, which causes degradation in terms of material properties. Some works can be found in open literature, but the studies presented are not sufficient to establish a full knowledge about this subject. Therefore, the aim of this work is study the low velocity impact response of Kevlar/epoxy laminates and carbon/epoxy laminates, after immersion into hydrochloric acid (HCl) and sodium hydroxide (NaOH). The aggressive solutions affect significantly the impact strength, but their effects are strongly dependent of the concentration. On the other hand, a significant effect of the temperature can be found, independently of the aggressive solution, on the impact performance and residual bending strength.

1. Introduction

In recent years, there has been a rapid growth in the use of fibre reinforced composite materials in engineering applications and there is a clear indication that this will be continuing. In this context, it is becoming common the components manufactured by composite materials for applications at highly corrosive environments, as an alternative to the stainless or coated steels. However, the studies presented on the open literature are not sufficient to establish a full knowledge about the effect of hostile solutions on the PMC mechanical properties.

Stamenovic et al. [1] compared, for glass/polyester composites, the effect of alkaline and acid solutions on their tensile properties, concluding that the alkaline solution decreases the ultimate tensile strength and modulus. However, the acid solution increases the tensile properties and this phenomenon was more relevant when the pH value decreases. On the other hand, for both solutions, Stamenovic et al. [1] concluded that the changes observed on the tensile properties are proportional with the number of days into immersion. The period of exposure was studied by Mahmoud and Tantawi [2] and significant influence of this parameter on the flexural strength, hardness and Charpy impact resistance was found by these authors. The flexural strength of the glass/polyester composite is insensitive until 30 days of immersion in HCl and, after this period, a decrease around 10% was observed. In terms of hardness, they showed that the Barcol hardness drops around 15% after 90 days of exposure. A slight decrease of the Charpy impact resistance (about 5%) was observed during the first 60 days of immersion but, between 60 and 90 days, a significant drop of 10% was found. Composites with different resins were immersed into two aqueous acid solutions and, according with Banna et al. [3], their final mechanical properties showed to be very dependents of the resins used. Amaro et al. [4] developed a systematic study about the effects of alkaline (NaOH) and acid (HCl) solutions on glass/epoxy composites. These authors found that, independently of the solution, the flexural strength and the flexural modulus decreases with the exposure time. On the other hand, the alkaline solution (NaOH) showed to be more aggressive than the acid solution (HCl), promoting the lowest flexural properties. The flexural strength, after 36 days of exposure, decreased around 22% for the NaOH solution and 16.2% for the HCl solution. Similar tendency was observed for the flexural modulus with values around 26.9% and 22.3%, respectively. Complementary tests were carried out and the ultramicroindentation showed a decreasing of the matrix mechanical properties. The roughness increased with the exposure time and was higher for the samples immersed in alkaline solutions. The effect of different acid solutions was studied, in a similar work, by the same authors [5]. In this case, a hydrochloric acid (HCl) and a sulphuric acid (H_2SO_4) were used and

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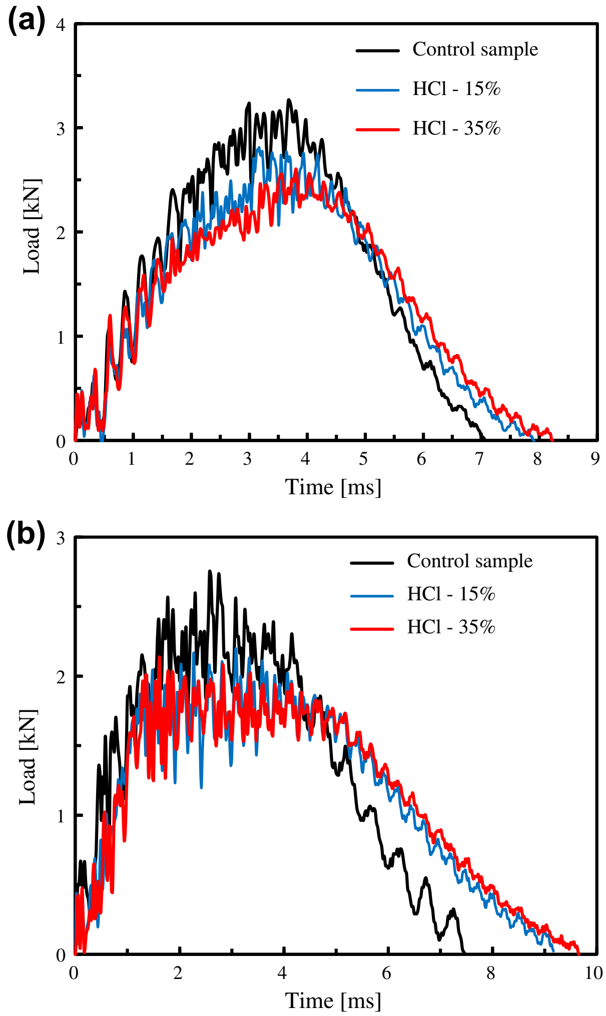

Fig. 1. Typical diagrams load versus time obtained at room temperature for: (a) Kevlar/epoxy laminates and (b) carbon/epoxy laminates.

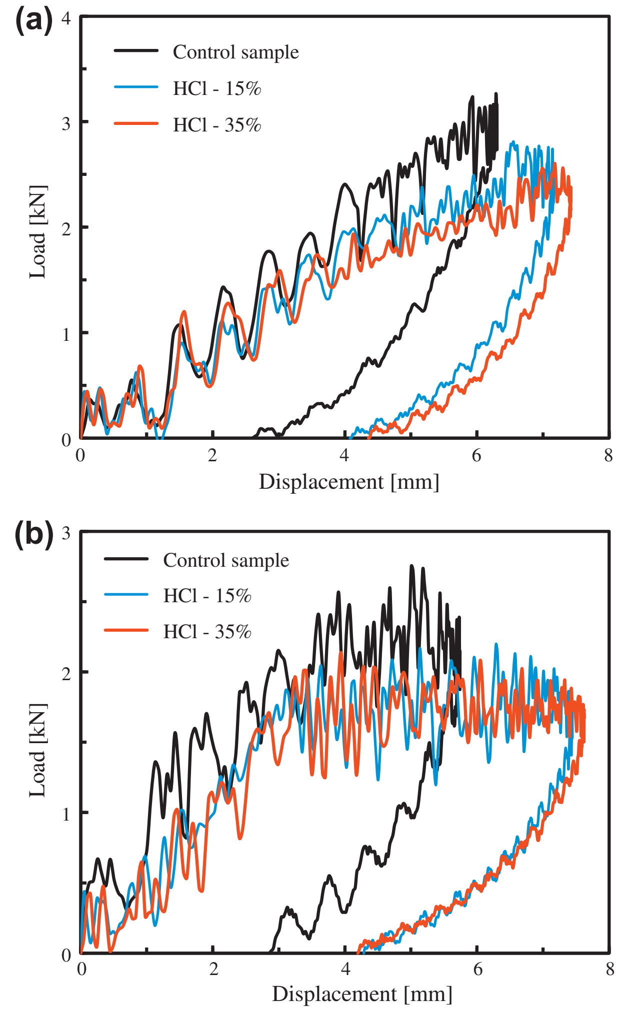

Fig. 2. Typical diagrams load versus displacement obtained, at room temperature, for: (a) Kevlar/epoxy laminates and (b) carbon/epoxy laminates.

the flexural properties were affected significantly by these solutions. For example, after 36 days of exposition, the flexural strength decreased around 16.2% for the HCl solution and 11.6% for the H_2SO_4 solution. Similar tendency was observed for the flexural modulus with values around 22.4% and 17.6%, respectively. It is evident that the hydrochloric acid was responsible by the worst results.

It is well known that the composites are very strong in the plane, but with very low impact performance through the thickness. Various types of damages can occur, which are very dangerous because they are not easily detected visually [6,7] and they can affect significantly the residual properties and structural integrity of those materials [8–12]. However, low velocity impact associated with highly corrosive environments, is reported in bibliography only by Amaro et al. [4,5] on glass/epoxy composites. According with these authors, the resistance of the glass/epoxy laminates to repeated low velocity impacts is very dependent of the corrosive environment and the exposure time. The alkaline solution shows to be more aggressive than the acid solution, promoting the lowest impact resistance. On the other hand, comparing the hydrochloric acid (HCl) with the sulphuric acid (H_2SO_4), the first one is responsible by the lowest impact performance.

Therefore, the aim of this work is study the low velocity impact response of Kevlar/epoxy laminates and carbon/epoxy laminates, after immersion into hydrochloric acid (HCl) and sodium hydroxide (NaOH). These solutions were selected because, according with Amaro et al. [4,5], they promoted the lowest impact performance. The effect of concentration and temperature of the solutions on the impact strength was analysed and the residual bending strength was compared with the control samples. In fact, composites reinforced by carbon or Kevlar fibres have several application fields, but the open literature does not report any study about the effect of corrosive environments on their impact strength.

2. Material and experimental procedure

Two different composite laminates were manufactured by hand lay-up and the overall dimensions of the plates obtained were 330 × 330 × 3 (mm). An Ampreg 22 epoxy resin and an Ampreg 22 hardener standard, supplied by Gurit, was used with nine layers, all in the same direction, of woven bi-directional Kevlar 170-1000P (170 g/m^2) and woven bi-directional carbon 195–1000 (195 g/m^2) to produce each laminate. The system was placed inside a vacuum bag and a load of 2.5 kN was applied for 48 h in order to maintain a constant fibre volume fraction and an uniform laminate thickness. During the first 10 h the bag remained attached to a vacuum pump to eliminate any air bubbles existing in the composite. The post-cure was carried out in an oven at 45 °C for 48 h.

The samples used in the experiments were cut from these plates to square specimens with 100 mm side and 3 mm thickness