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Material Properties

# Apparent shear strength of hybrid glass fibre reinforced composite joints

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ABSTRACT

The incorporation of nano or micro ceramic particles into fibre reinforced composites (FRC) to enhance their stiffness and durability has been widely investigated. This mechanism has been attributed to the increase in stiffness of the polymeric matrix phase and shear strength of FRCs due to the presence of particles at the interlaminar regions. In order to elucidate such effect, hybrid single-lap joints consisted of ceramic particles and glass fibre reinforced composites were evaluated to better assess the mechanical interlocking effect provided by silica and cement inclusions. A full factorial design ($2^3$) was performed to identify the effect of the type of particle (silica and cement), particle weight fraction (2.5 and 5 wt%) and glass fibre grammage (200 and 600 g/$m^2$) on the apparent shear strength and adherent strength of single-lap joints under tensile loading. The ceramic particle inclusions led to increased apparent shear strength and adherent strength. The inclusion of 5 wt% ceramic particles into 600 g/$m^2$ cross-ply glass fibre composites enhanced both adherent and apparent shear strengths.

## 1. Introduction

Fibre reinforced composites (FRCs) have been successfully used for many engineering applications, as structural and non-structural materials in aerospace, construction, and automotive industries as well as in biomedical applications, such as dentistry and orthopedy [1,2]. FRCs are superior to other structural materials, mainly due to their high specific strength and stiffness, high temperature and fatigue resistances [3,4]. The mechanical performance of FRCs is influenced by the properties of the phases and their interactions, since the interface must be strong enough to ensure efficient fibre-matrix load transfer. A better understanding of the interface and fibre-matrix bonding is quite important to enhance the effective mechanical properties of FRCs [5–7]. Hybrid composites, i.e., composites consisting of two or more reinforcement phases [8], have been widely used for this purpose. In Particular, the incorporation of nano-(0.5–3.5 wt%) [9–16] or micro ceramic particles (1–33 wt%) [9,17–20] into FRCs has been investigated to improve their mechanical performance and durability. Particle inclusions in FRCs have been used to enhance the stiffness of the polymeric matrix phase [9,18,21] and shear strength due to the fibre-matrix interlocking effect [5,14,17,22]. Such effects depend on the type of fibre, particle mass fraction, size and shape, particle treatments and manufacturing process used. The complex relationship between these factors and their interactions with the matrix and fibrous phases of laminate composites has been partially discussed in the literature. Most of the research has been focused on the incorporation of nanoparticles, instead of microparticles in hybrid composites. Microparticles are considered as a self-dispersing and low-cost filler in comparison to nanoparticles. In this context, this research project aims at contributing to a significantly improved understanding of the effects of microparticles at inter-laminar region of laminated composites.

This work evaluates the interlocking effect provided by silica or cement microparticle inclusions on glass-fibre reinforced composites. To do so, the apparent shear strength of single-lap joints composed of glass fibre reinforced composites was evaluated. Several methods have been developed to measure the adhesive shear modulus and shear strength, such as the single-lap joint, the Napkin and the short beam shear tests [23,24]. Although it has some disadvantages, such as non-uniform stress distribution, which also depends on the sample geometry and the overlap length, the single-lap joint test, due to its simplicity and low cost, is one of the most commonly used methods to evaluate interlaminar and adhesive shear strength [23]. In addition, as the joint is

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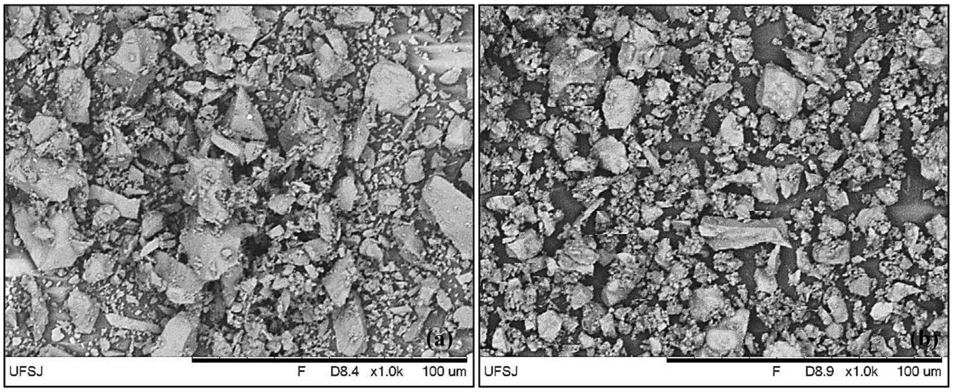


**Fig. 1.** SEM images: (a) silica and (b) cement particles.

used here as a model for the comparative evaluation of the interlocking effect provided by silica or cement microparticles in laminated composites, such simple test will be useful. A statistical methodology based on a full factorial design ($2^3$) was carried out to identify the effect of particle type (silica and cement), particle mass fraction (2.5 and 5 wt%) and glass fibre grammage (200 and 600 g/m$^2$) on the apparent shear strength, adherent strength and maximum load of single-lap joints subjected to tensile loading.

## 2. Materials and methods

Composite samples were fabricated using a polymeric matrix, two glass fibre grammages and two types of ceramic particles at two mass fraction levels. The matrix phase consisted of epoxy resin (RenLam M) and hardener (HY 951) supplied by Huntsman (Brazil), considering a mixing ratio of 10:1, respectively [25].

The silica particles were supplied by Moinhos Gerais Company (Brazil) and the Portland cement (ASTM III) was sourced by Holcim (Brazil). Silica and cement particles were both classified by sieving in a range of 325–400 US-Tyler (37–44 μm). Fig. 1a and b presents Scanning Electron Microscopy (SEM) images of silica and cement particles, respectively, at 1000 × magnification. Both particles exhibit a non-spherical shape, which may enhance the interlocking effect. The glass fibre fabrics (cross-ply, 200 and 600 g/m$^2$) were supplied by Texiglass (Brazil).

A full factorial design of $2^3$, providing 8 experimental treatments, was conducted to identify the effect of three factors, namely particle type (silica and cement), particle mass fraction (2.5 and 5 wt%) and glass fibre grammage (200 and 600 g/m$^2$) on the apparent shear strength of hybrid single-lap joints. Two reference conditions consisted of 200 g/m$^2$ (REF1) and 600 g/m$^2$ (REF2) with no ceramic particles were also fabricated for comparison (see Table 1). Three samples were fabricated for each experimental condition and two replicates were considered, running a total of 60 tests.

The laminates were fabricated by hand lay-up at room temperature. Initially, five layers of glass fibre fabric were laminated using the epoxy

**Table 1**
Full factorial design ($2^3$) and reference conditions.

| Condition | Glass fibre grammage | Type of particle | Particle mass fraction |
|---|---|---|---|
| REF1 | 200 | None | 0.0% |
| C1 | 200 | Silica | 2.5% |
| C2 | 200 | Silica | 5.0% |
| C3 | 200 | Cement | 2.5% |
| C4 | 200 | Cement | 5.0% |
| REF2 | 600 | None | 0.0% |
| C5 | 600 | Silica | 2.5% |
| C6 | 600 | Silica | 5.0% |
| C7 | 600 | Cement | 2.5% |
| C8 | 600 | Cement | 5.0% |

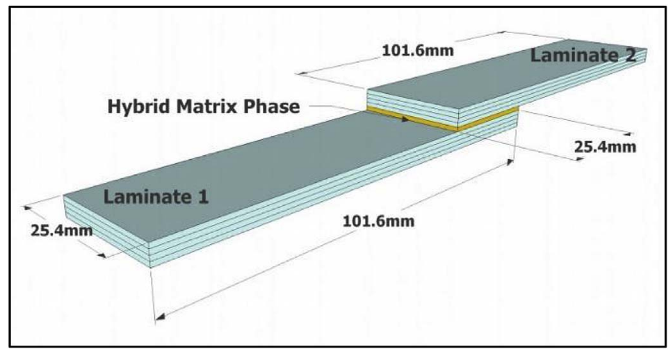


**Fig. 2.** Sample fabrication scheme.

polymer, previously mixed for five minutes. A constant fibre volume fraction of 50% was adopted in the experiments. The ceramic particles were incorporated into the matrix phase, hand mixed for 5 min and spread only on the bonding contact area (25.4 mm × 25.4 mm) located at the top composite layer (Fig. 2). Subsequently, a second laminate containing five layers of glass fibre fabric was laminated on the single-lap joint consisted of a hybrid matrix phase (Fig. 2). A metallic sheet was placed underneath the upper glass fibre laminate to ensure parallelism required in the single-lap joint test. After a curing time of 24 h, the samples were demoulded and sealed into plastic bags, keeping them at room temperature for 7 days.

Samples were cut according to ASTM D5868 [26] (Fig. 3). Tensile tests were conducted on the single-lap joints at a crosshead speed of 1 mm/min in a Shimadzu AG-X Plus universal testing machine equipped with a 100 kN load cell.

## 3. Results

Table 2 presents the mean maximum load, mean apparent shear strength and mean adherent strength of hybrid joints and joints in pristine condition (reference) for replicates 1 and 2. Apparent shear strength was calculated as the maximum load divided by the bonding area.

Fig. 4a and b shows load versus displacement graphs obtained via tensile tests. A characteristic curve is presented for each condition. Two different regions are seen in the graphs. One was in the range from 0 to 1000 N, and the second above these values. Adherent strength was calculated based on the slope of the load versus displacement curves from 20 to 200 N.

Table 3 shows the Analysis of Variance (ANOVA) for the mean of hybrid joints responses. A confidence level of 95% was adopted, which means that the factors or interactions among them are statistically significant for P-value ≤ 0.05. When one or more interaction effects are significant, the factors that interact should be considered together [27]. The bold P-values presented in Table 3 reveal interactions of superior