In-plane shear tensile characteristics of polyester composites: Effects of sunlight exposition

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Abstract

This work focusses on the analysis of in-plane shear tensile test carried out on samples aged by UV-Visible light. The tendency of in-plane shear properties with exposure time fits to a decreasing exponential curve. Different thermosetting polyester resins, curing temperatures profiles, and fibreglass fabrics are employed for this study. The type of resin and curing temperature influence on elastic modulus and shear strength of composite. The ageing degree varies between 14% and 25%, depending on shear property and the composition.

Keywords

In-plane shear, polyester, composite, cure, ageing, sunlight

1. Introduction

Unsaturated polyester-glass fibre composites are being increasingly used because of good strength and stiffness, low cost and weight, and easy processing procedures in different sectors like civil construction, transport media, naval, and chemical industries. Effects of radiation on non-reinforced polymers are well known but similar information is particularly scarce regarding thermosetting composites [1,2]. Short-beam interlaminar shear strength test is quite useful to study degradation effects on matrix and matrix-fibre interface [3–7] although no information is available about in-plane tensile shear characteristics of sunlight exposed composites. The influence of processing variables on the ageing behaviour of the composite is also an interesting industrial aspect that has not been studied extensively. This work presents the in-plane shear tensile test method ability to correlates shear mechanical characteristics with light ageing time exposition for composites elaborated from different unsaturated polyesters and glass fibres fabrics.

2. Materials and Method

2.1. Materials

Two different O-Phthalic polyester resins have been selected for this study: Basf-P5™ (stiff resin A, medium reactivity) and Basf-P61™ (tough resin B, high reactivity). MEK-peroxide is used as catalyst (2.0% v/v) and cobalt octoate as accelerator (0.2% v/v). The E-fibreglass fabrics are taffeta (specific weight of 300 g/m^2) and plane multiaxial (440 g/m^2). Both composites content 8 reinforcement plies of fibres arranged at ±45°, and elaborated by a hand lay-up process.

Composites have been cured at different temperatures for 24 hours. The lowest temperature (18ºC) is appropriately in low-cost manufacturing and rate production. The second one (40ºC) is more adequate for larger products that need better curing conditions at highest production rate, like the case of trucks, cars, railway and also for some specific pipes and tanks. Characteristics and nomenclature of these samples are shown in Table 1.

Table 1. Composite characteristics

Laminate	Resin	Styrene (%vol)	Curing Temperature	Reinforcing Fabric	Density (g/cm^3)	Fibre (%vol)	Void (%vol)
AT1	A	35	18 °C	Taffeta	1.61	32.7	2.5
BM1	B	41	18 °C	Multiaxial	1.58	33.4	5.6
BM4	B	41	40 °C	Multiaxial	1.57	33.6	6.7

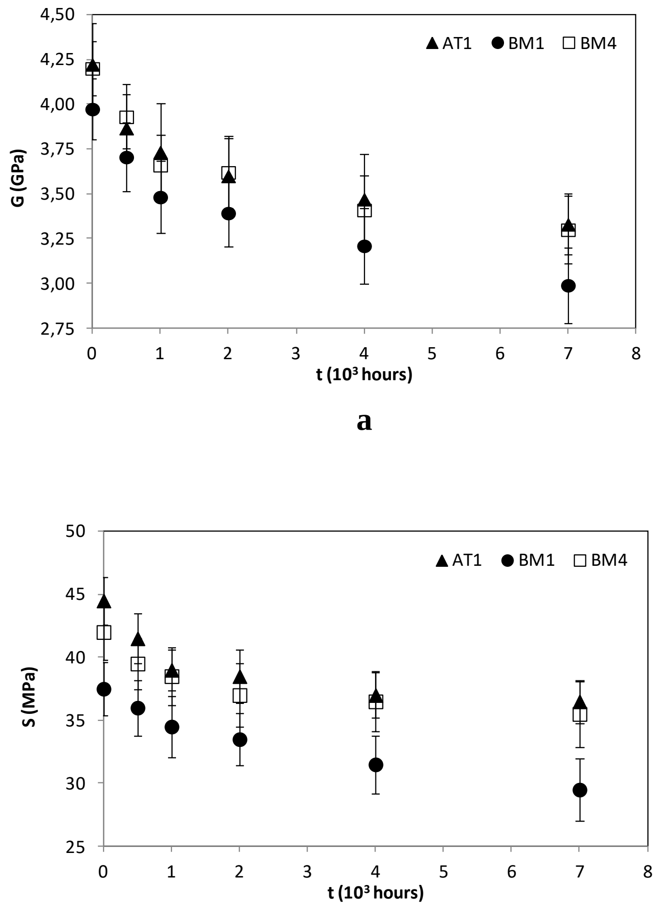
2.2. Test Procedure

In-shear tests are performed in accordance with ASTM standard D 3518M-13. Seven coupons for each condition are tested on the tensile testing machine.

Wavelength light from lamps as ageing source was adjusted to the ultraviolet and visible emission (UVV) of the solar spectrum (300-2000 nm). Samples are placed in a closed chamber which are maintained under three lamps each rated at 300 W. The coupons received an irradiation dose equivalent to 1700 W/m^2. Our university is located at 39°30’-N/0°25’-W. The Spanish Forecast Weather Service reports that this region receives about 310 W/m^2 in a standard day of 10 hours. It was estimated that 10^3 h of exposition equals 1.64 years of real time.

3. Results and Discussion

The accelerated exposure to simulated solar spectrum source ages the unsaturated polyester glass fibre composites. Elastic modulus G and shear strength S (Fig.1) obtained decrease with exposure time. Results from in-plane shear tensile test are able to discern the degree of ageing for irradiated coupons. Degradation is focus on the resin, mainly in the outer surface layer because the material light attenuation follows an exponential law.



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b

Fig.1. Shear properties with exposure time: a) Elastic modulus, b) Shear strength

Losses in mechanical properties by UVV light irradiation is attributed to a photo-oxidation mechanism that are correlated with changes on mechanical strength and toughness in polymers [8,9]. Therefore, photo-oxidation affects unreacted vinyl groups resin, as well as unreacted free styrene and free peroxide catalyst that were not removed during polyester-styrene polymerization [10–13].

The resin influence is shown in Fig.1. Composite AT1 presents 4.2 GPa and 45 MPa for modulus (G) and shear strength (S) before exposition. Those mechanical characteristics from composite BM1 are 4.0 GPa and 37 MPa. The polymer cross-linking at lower curing temperature profile is more effective when styrene content is lower [14,15]. The nature of the resin including the styrene content influences the initial mechanical properties of composites. Losses of G and S are higher at 7000 h when resin B is used: 25% to the modulus and 22% to the shear strength while they achieve values of 21% and 18% respectively in resin A composites. UVV radiation degrades the thermosetting matrix and reduces the cross-linking density being less evident for more efficiently cross-linking degree. It also produces negative effects in the stability of the resin and the resin-fibre interface such as stress concentration, brittleness and a tendency of matrix-fibre debonding [16].

Results obtained from composites, BM1 cured at room temperature and BM4 cured at 40°C are also given in Fig.1. Shear properties grow up to 4.2 GPa (G) and 42 MPa (S) to composite BM4. This test method illustrates the improving effect of the curing temperature. Ranging from 18 to 40ºC, both modulus and shear resistance are increased by 5% and 14% respectively. The ageing degree at 7000 hours in BM1 samples are 25% (G) and 22% (S), overcome those observed for BM4: 21% and 14% respectively. As the cure temperature rises, a higher degree of polymerization of the resin and cross-link density are also achieved, which results in better adherence of the matrix-fibre[10,11,13,17,18]. Increasing the polymerization and cross-linking degree improve the resistance to degradation from radical species activated by UVV radiation. In fact, composite cured at high temperature (BM4) exhibits weak tendency to worsen its properties beyond 4000 hours while the composite BM1 continues its relentless loss of shear properties.

Coupons from composite AT1 have the best values of G and S, although composite cured at 40ºC (BM4) shows near values to those. It indicates that taffeta fabric has several advantages over multiaxial. First, taffeta fibres beams are waved while multiaxial are placed +45º in a plane above of -45º ones. Waved fibres branch off and come out regularly from interlaminar plane so the fibres support more load up to debonding and collapse [1,2]. Furthermore, the easiest capacity of taffeta fibres to spread during elaboration step. Multiaxial fabrics fibres have no freedom grades because of beams at +45º are placed over -45º ones and strongly fixed by sewing spinning. It appears resin rich zones without fibres or fibres beams are too away ones from themselves. So, the in-plane shear test method can discriminate between mechanical properties for both composites accordingly to the sunlight degradation effect. Multiaxial composites need to cure at higher temperature to improve properties and to reduce their ageing degree (BM4), obtaining properties so close to those achieved for AT1, with different resin system and reinforcement fabric. Several authors have confirmed that the weaved fibre used inhibits the final curing levels delaying the polymerization kinetic when large amounts of fibre are present [14,15]. Ray et al.[16] find easier faculty to activate the degradation on the surface by using fly ash particles in contact with vinylester resins. That could mean that the surface of rich silica E-fibres can catalyse and amplify the degradation reaction rate of polyester matrix.

4. Conclusions

ASTM D3518-13 method is a good testing protocol to evaluate in-plane shear characteristics of fabric reinforced polyester composites and their durability to sunlight exposition as well as to detect variations on those properties by factors as the combination resin-reinforcing fabric and curing temperature profile. The test highlights the exponential decay in shear modulus and strength with irradiation time.

The exposure of glass fibre polyester composites to sunlight produces significant reduction in-plane shear characteristics. Shear modulus and strength reach relevant losses: between 21% and 25% to G, and from 14% to 21% to S. This behaviour is related to the induced brittleness in the resin and fibre-matrix interface because of photo-oxidation resin process.

Lesser styrene content resins with taffeta fabric composites cured at room temperature show mechanical properties as close as ones from higher styrene content resins and multiaxial fabric composite if the latter is cured at higher temperature because higher cross-linking density and improved fibre-matrix adhesion.

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