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Mechanical properties of hybrid fabrics in pultruded cement composites

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ABSTRACT

This work concerns the tensile properties of cement-based hybrid composites manufactured as: (i) sandwich composites that combine different layers of single fabric types; and (ii) hybrid composites, made from several yarn types within the same fabric. Hybrid combinations of low-modulus fabrics of polyethylene (PE) or polypropylene (PP) and high-modulus AR glass or aramid fabrics were prepared by the pultrusion process and tested in tension. Influence of pultrusion direction on the results was one of the parameters studied. It was found that hybrid composites made from PE and AR glass sustain strains better than 100% AR glass composites, and are stronger than a single PE fabric composite. A hybrid fabric composites made with combination of high strength–high cost aramid and low stiffness–low cost PP yarns performed better than a single aramid fabric composite relative to their reinforcing volume contents. Results show that making hybrid composites is an attractive option for cement-based elements. The performance of hybrid fabric composites is also influenced by the arrangement of fabric layers in the laminates. Composites with brittle and relatively strong fabrics (glass) at the mid-section and ductile fabrics (PE) near the surfaces of the composite performed better in tension than composites with the opposite arrangement.

1. Introduction

There is a growing interest in the use of fabrics as reinforcement for thin sheet cement composites. In addition to ease of manufacturing, non-linear geometry of individual yarns within the fabric results in excellent bond development due to mechanical anchorage. These characteristics result in improved strength due to strain-hardening behavior even though the reinforcing yarns have a low modulus of elasticity [1,2]. A wide variety of fabric production methods such as weaving, knitting, braiding, and non-woven, make fabric design a flexible process. This flexibility enables controlling of fabric geometry, yarn geometry, and orientation of yarns in various directions as well as yarn material combinations (hybrid fabrics).

One way to produce fabric–cement elements is by a recently developed method, the pultrusion technique [3]. The pultrusion method allows design flexibility, fast construction time, enhanced mechanical properties, and aesthetic appeal of the final component. This technique enables production of thin sheet laminated composites for a wide range of applications, including wall panels, exterior siding, roofing tiles, flooring tiles, and pressure pipes.

Hybrid systems with two or more fiber materials are used to combine the benefits of each fiber into a single composite product. Strength and toughness optimization of hybrid thin sheet composites has been studied extensively using combination of different fiber types with low and high modulus of elasticity [4–11]. A high strength, high-modulus fiber primarily tends to increase the composite strength with nominal improvements in toughness. A low-modulus fiber can only be expected to improve toughness and ductility with limited improvement in composite strength. Combination of two or more types of fiber can produce a composite that is both strong and tough as compared to the mono-fabric type composite. Hybrid fiber reinforcement combinations can also be used in the manufacture of economically viable products by substituting economical fibers, such as polyethylene (PE) fibers, for more expensive alkali resistant (AR) glass fibers.

Xu et al. [4] reported that by using the concept of hybridization of glass, polypropylene, and polyvinyl alcohol (PVA) fibers, the resulting hybrid composite offered more attractive engineering properties than composites made with only one type of fiber. The hybrid system showed considerable improvements in ultimate tensile failure strain over the glass fiber composites. Similar conclusions were reported by Kobayashi and Cho [5] and Hasaba et al. [6] where steel and polyethylene hybrid combinations were studied. Kakemi et al. [7] evaluated the fracture of glass filaments in a hybrid polypropylene (PP)–glass composite. In the hybrid

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system, the fracture of the glass filaments was more evenly distributed than in the single glass composite, leading to greater strains at maximum stress of the hybrid composite. Mobasher et al. [8] found that the peak load of hybrid systems with carbon, aluminum and PP fibers increase as much as 75% over PP fiber composites or mortar. Perez-Pena and Mobasher [9] reported that the tensile ductility of cement composites containing polypropylene or glass mesh was significantly improved with various short fibers such as PP, AR glass, and nylon. Cyr et al. [10] reported that a hybrid composite with glass and PP fibers is stronger than a mono-PP fiber composite and tougher than a mono-glass fiber composite. Peled et al. [11] studied hybrid composites with combination of glass, PP and PVA microfibers. Combinations of 40:20:40 and 40:0:60 glass/PP/PVA (total of 5% vol. fiber reinforcement) were found to be similar in strength to 100% glass reinforcement but with a significant improvement in toughness.

In most cases discussed above, hybrid systems were studied with short fibers, randomly dispersed in the cement-based composite. In these cases there is a limitation in controlling the exact location of the fibers within the composite, which can be significantly important for many applications. The flexibility in fabric production enables several ways to combine two and more yarn materials within the fabric by controlling orientation and location of each material either in orthogonal or co-linear directions. One can utilize various yarn types at any direction within a fabric, or a combination of several fabric layers in a composite where each layer is made from different constituent materials. This approach provides full control of the exact location of each fabric and yarn, while their orientation in the composite during production allows for designing for specific characteristics as required by loading direction and magnitude. Therefore, the use of hybrid fiber reinforcement is particularly promising in fabric–cement composites.

In this study two types of hybrid composites were studied: (i) sandwich hybrid composites made with a combination of different layers of low-modulus fabrics of PE or PP and high-modulus AR glass fabric, and (ii) hybrid fabric composites combining PP and aramid yarns within a single fabric. All specimens were prepared by the pultrusion process [3,12]. The tensile behavior of the composites was studied using closed-loop uniaxial tension tests. The effect of various fabric types in suppressing the localization and crack bridging mechanisms as well as the microstructure were studied. Influence of the pultrusion direction on mechanical performance and microstructure was also evaluated.

2. Experimental program

2.1. Fabric types

2.1.1. Composite preparation

A pultrusion process [3,12], which allows production of laminated fabric–cement-based composites, was used. In this method the fabrics are passed through a slurry infiltration chamber, and then pulled through a set of rollers to squeeze the paste between the fabric openings while removing excessive paste. The fabric–cement composite laminate sheets are then formed on a plate shaped mandrel resulting in samples with width of 25 cm, length of 28 cm and thickness of about 1 cm. Two sets of specimens were prepared: (a) sandwich hybrid composites (made from fabrics of Set 1); and (b) composites with fabrics of Set 2, i.e., hybrid fabric (Tables 2 and 3).

Set 1. In the first system, two sets of cement board were prepared: (i) single (mono) fabric board made from eight layers of the single fabric type; and (ii) hybrid sandwich board where using four layers of AR glass fabric and four layers of either PE or PP-A. In order to study the effect of the pultrusion process, two types of mono-fabric composites were prepared: in the first the reinforcing yarns were along the pultrusion direction, and in the second the reinforcing yarns were perpendicular to the pultrusion process (Table 3).

Fig. 1 provides a schematic description of the sandwich hybrid composites, which were prepared as follows (Table 3):

(1) Two AR glass fabric layers were located at each surface of the composite (i.e., two layers at the bottom and two at the top) and four PE fabric layers were placed at the core of the board. These composites are referred to as G–PE–G.
(2) Same as the previous composite, except that PP-A fabrics were located at the core of the composite (G–PP–G).
(3) Two PE fabric layers were located at each surface of the composite and four AR glass fabric layers were placed at the middle of the board (PE–G–PE).
(4) Same as the previous composite, except that two PP-A fabric layers were located at each surface of the composite (PP–G–PP).

Table 1
Properties and geometry of yarns made up the fabrics.

Yarn type	Yarn nature	Tensile strength (MPa)	Modulus of elasticity (MPa)	Filament size (mm)	Bundle diameter (mm)	Number of filaments per bundle
AR glass	Bundle (coated)	1360	78,000	0.014	0.80	–
PE	Monofilament	260	1760	0.250	0.25	1
PP-A	Bundle	500	6900	0.016	0.12	158
PP-B	Bundle	220	7000	0.039	0.70	315
Aramid	Bundle	2370	55,000	0.012	0.38	1106

Table 2
Fabric composition and geometry.

Set #	Yarn type	Fabric structure	Yarn density per cm	
			Reinforcing yarns	Perpendicular yarns
1	AR glass	Bonded	4.0	4.0
	PE	Woven	22	6
	PP-A	Warp knitted	8.0	0.8
2	PP-B	Warp knitted	2.5	2.5
	Aramid	Warp knitted	2.5	2.5
	Hybrid: PP-B and aramid	Warp knitted	2.5	2.5