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Pairing effect and tensile properties of laminated high-performance hybrid composites prepared using carbon/glass and carbon/aramid fibers

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ABSTRACT

Many attempts have been made to fabricate lightweight, high-performance, and low-cost polymeric composites. To improve the mechanical performance of the same material compared to conventional composites, paired hybrid materials were manufactured with different lamination structures. Each of six types of hybrid composite was designed by lamination pairing of carbon/aramid fabric and carbon/glass fabric using VARTM. The dependence of the mechanical properties of the samples on the pairing effects of the lamination structures was investigated. All pairing materials did not lead to a large increase of tensile strength due to the domination of carbon fiber, but the mechanical properties of specific laminates were clearly changed by the particular pairing sequence used. Using the limited material, the design of an effective structure was the central laminating condition with a good tensile and bending properties. Laminating position of the carbon fiber was found to play an important role in the stacking design of hybrid composites.

1. Introduction

With advances in technology, increasingly multifunctional and lightweight materials are required in ever-widening fields of industry. Following this trend, the demand for polymeric materials is expanding. Indeed, high-performance or high-functional fibers offer the benefits of high strength, high stiffness, heat resistance, abrasion resistance, and impact resistance [1]. The typical materials used are carbon fiber, aramid fiber, UHMWPE (ultrahigh molecular weight polyethylene) fiber, PPS (polyphenylene sulfide) fiber and PBO (polybenzoxazole) fiber. The demand for industrial high-performance fibers is increasing year by year, as is the global fiber market [2–4].

Carbon fiber has superior corrosion and bursting resistance than glass fiber or other polymer fibers at room temperature. Carbon fiber-reinforced composite materials have a number of attractive properties, notably their strength, stiffness, lightweight, and toughness. Carbon fiber composites are thereby promising materials whose range of applications has expanded to aerospace and automotive structures, wind power generation, sporting goods, industrial materials, civil engineering, and construction materials [5–8]. However, carbon composite materials suffer from low energy absorption rates and from degraded impact resistance, strength, and stiffness due to delamination. Metal sandwich structures have been advanced as a possible means to overcome these problems [9,10].

Due to their carbon-based organic composition, polymers readily combust leading to studies on flame retardant textiles. In particular, aramid material has drawn a lot of attention due to its heat resistance and high strength fibers. Aramid fiber has a large market share because of its relatively low price compared to other ultra-high strength fibers, as well as its high tensile strength of 2.8 GPa and modulus of elasticity of 109 GPa [11–14]. Functional aramid fibers have thereby found applications as industrial materials, bulletproof and protective shielding, marine fisheries parts, and civil construction structures.

Recently much research effort has been devoted to producing lightweight, high-performance, and low-cost polymeric composites. Thermosetting or thermoplastic composites can be used to improve performances through the incorporation and reaction of reinforcing fibers within the resin matrix [15,16]. Refs. [17–19] have been reported to optimize the tensile, impact and flexural strength properties. Interest has gradually been increasing for hybrid composite materials prepared by combining multiple fibers in conventional resins. Since composites reinforced by carbon fibers are susceptible to impacts, these hybrid composites aim mainly to improve the impact resistance of carbon-based laminates [20–22].

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Hybrid composites contain two or more different types of reinforcing fibers, which differ in terms of their (typically mechanical) properties. The hybrid effect is often described as a positive deviation of a certain property from the 'rule of mixtures' [23,24]. The performance of hybrid composites can be adjusted through various manufacturing factors, generally the type and fraction of fiber, fiber orientation, stacking sequence, laminating form, and manufacturing process. Composites with the same reinforcement fiber can have different properties depending on the choice of laminating structure. Such a laminating combination of fiber couple was named as 'pairing'.

Typical processing technologies such as autoclave, liquid composite molding, pultrusion, tape lay-up, filament winding, and sheet molding compound have been used to manufacture high performance composites suitable for industrial applications. Autoclave method produces high quality materials with good mechanical properties, but is expensive to set up and has low productivity. Vacuum assisted resin transfer molding (VARTM) is relatively simple and produces materials of a similar quality to autoclaved products. Recently, resin infusion processes such as VARTM, the Seemann composites resin infusion molding process (SCRIMP), and resin infusion under flexible tooling (RIFT) have been investigated in view of overcoming the high cost and low productivity of autoclaving in aerospace and renewable energy sectors. Indeed, in contrast with autoclaving, these resin infusion processes make the manufacture of integral products possible [25–28].

In this study therefore, a new type of composite material was prepared by hybridization of carbon fiber laminated with aramid and glass fiber, samples of which were investigated in terms of their mechanical properties. Another objective was to determine the correlation between these mechanical properties and the pairing effects of the lamination structures. In order to obtain high-quality composites, the specimens with different lamination structures were manufactured efficiently by VARTM. The pairing effect on the mechanical properties was investigated using tensile tests.

2. Experimental

2.1. Manufacture of hybrid composites

The composites were prepared using reinforcing carbon fabric (TC06P, AKSACA, Turkey), aramid fabric (Kevlar T49, DuPont, USA), glass fabric (K618, Hankuk Fiber, Korea), and epoxy resin as the matrix material. A woven reinforcement was used with plain weaving at 0° and 90°, whose specific features are given in Table 1. The characteristics of the epoxy resin (HTC-667C, Jeil Hi-Tech, Korea) used for the matrix are shown in Table 2.

Table 1
Specification of carbon, glass and aramid plain woven fabric.

Fiber	Carbon	Aramid	Glass
Style	TC-06-P	TA-05-P	TG-04-P
Weight (g/m^2)	200	165	197
Warp primary fiber	3K	158Tex	134Tex
Thickness (mm)	0.27 ± 0.025	0.33 ± 0.025	0.18 ± 0.025

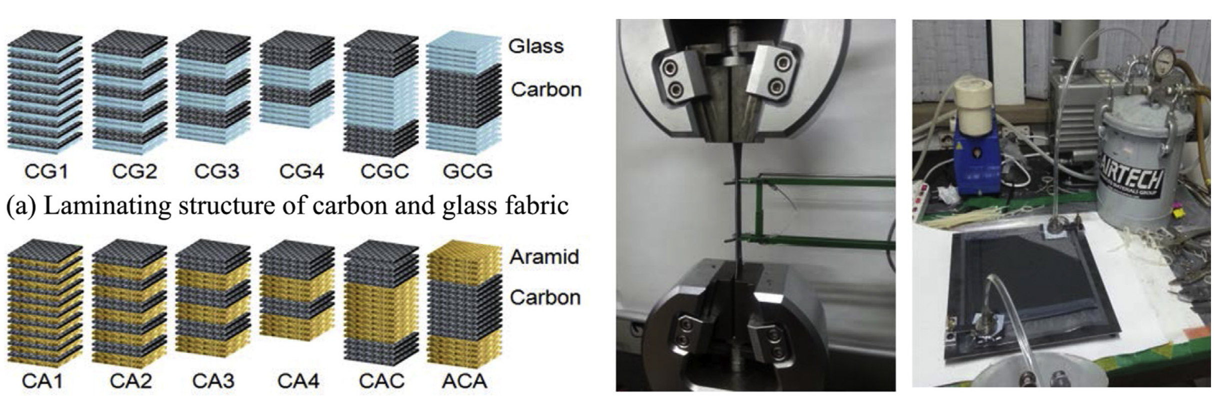
Table 2
Properties of epoxy resin (HTC-667C).

Specific gravity at 25 °C	1.16 ± 0.02
Viscosity at 25 °C (cps)	1200 ± 500
Hardener	Modified aliphatic amine
Tensile strength (MPa)	63.7
Compressive strength (MPa)	88.2
Flexural strength (MPa)	81.3

Pairing composites were prepared as sheets with multiple internal layers using VARTM. First, reinforcing fibers were uniformly cut into 245 × 285 mm pieces. Six types of paired specimens were prepared with different laminations. Details of the specimens and the associated stacking sequences are shown in Fig. 1. Both carbon/glass fiber (CG-type) and carbon/aramid fiber (CA-type) hybrid pairing composites were prepared, in which glass or aramid fibers were added to the carbon fiber. Using newly designed processing equipment for simpler and faster treatment, the laminating fabrics, release fabric, and flow media were added sequentially into a vacuum bag. This was then sealed tight and the inlet and outlet ports were connected to a vacuum hose. Epoxy resin was uniformly mixed with a curing agent and evaporated for 30 min in a vacuum chamber. A vacuum pump was connected to the outlet port and the resin was injected from the inlet port using a vacuum pressure of about 80 kPa. After complete injection, the material was hardened in an oven at 65 °C for 120 min.

2.2. Specimens and tensile tests

The plate-shaped composite material produced by VARTM was machined to produce standardized specimens using a water-jet system, as shown in Fig. 2. Dumbbell-shaped tensile specimens were cut to the size designated in the ASTM D638 standard [29–32]. Specimens of CFRP (carbon fiber reinforced plastic), AFRP (aramid FRP), GFRP (glass FRP), and carbon/aramid (CA-type) and carbon/glass (CG-type) hybrid composites were prepared. To study the changes in mechanical properties caused by the pairing effect for the different laminating structures, each six samples was prepared for both types of hybrid composite.



(b) Laminating structure of carbon and aramid fabric (c) Tensile test (d) VARTM process

Fig. 1. Laminating structure of hybrid composites by fabric pairing and VARTM process.