Composites: Part B 52 (2013) 217–223

Contents lists available at SciVerse ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Effect of fiber type and combinations on the mechanical, physical and thermal stability properties of polyester hybrid composites

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ARTICLE INFO

Article history:
Received 29 July 2012
Received in revised form 19 February 2013
Accepted 7 April 2013
Available online 17 April 2013

Keywords:
A. Fibers
A. Hybrid
B. Mechanical properties
E. Lay-up
Unsaturated polyester

ABSTRACT

The effect of fiber types and their combinations on the properties of unsaturated polyester composite was studied experimentally in this work. Monolithic and hybrid composite samples were produced using hand lay-up method followed by compression and the samples were tested according to ASTM (American Society for Testing and Materials) standards. The results showed that the Kevlar reinforced composite (KFRP) had the highest tensile strength among the monolithic composites and hand woven nylon fiber reinforced composite (LNFRP) with the least value. The combination of fibers (hybridization), Kevlar and glass fibers composite (KGFRP) and Kevlar–glass–nylon fibers composite (KGNFRP) resulted in tensile strength and specific tensile strength improvement over the monolithic glass fiber composite (GFRP). The combination of fibers also improved the thermal stability of the hybrid composites. Positive effects of hybridization were also observed for density and water absorptivity.

1. Introduction

Composite materials are known to have high specific modulus, high specific strength, high resistance to corrosion, low weight and can be tailored to meet specific purpose, which give them advantage over traditional materials such as metals and ceramics [1–5]. They have wide range of applications in aerospace, marine, automotive, biomedical, defense, offshore drilling, leisure goods and low pressure pipes [6–11].

The properties of composite materials are influenced by the nature of the fiber, type of matrix, the interface properties, the construction and geometry of the material [1,12–16]. Morye et al. [12] reported that aramid fiber, in 50:50 mixtures of phenol formaldehyde and polyvinyl butyral (PVB) resin had higher tensile strength and modulus than nylon 66 in the same matrix. Epoxy mix 57 used as matrix for E-glass fiber was reported to have better mechanical property than phenolic resin with 10% PVB also performed better than pure phenolic or epoxy resin [16]. Therefore, the design of composite structures is an integrated process involving material selection, process specification, optimization of laminate configuration and the design of the structural components [17].

Most of the earlier published works were on monolithic composites. However, recent publications have experimentally shown the superiority of multi-fiber composites and/or matrix modification in terms of cost saving and an improvement in composites performance. Saha et al. [6] reported that hybridization of glass fiber and polyethylene fiber (PEF) resulted in a linear increase in stiffness, with relative increase in proportion of PEF. Mishra et al. [18] hybridized glass fiber and biofiber in polyester and reported that addition of relatively small amounts of glass fiber enhanced the mechanical properties of the hybrid composites. Work on hybrid of E-glass fiber/Kevlar 29 fiber in polyester resin showed that the hybrid composite performed better at high impact velocity than the monolithic glass fiber composite [3]. In another work, Hosur et al. [19] reported the hybridization of S2 glass fiber with carbon fiber and the hybrid performed better under low impact velocity than the monolithic carbon fiber composite. In another development, Kim et al. [20] observed that stacking sequence played an important role in the properties of composites and that laminates with asymmetric stacking sequences tend to outperform those with symmetric stacking sequence. They further noted that when brittle fibers are placed in the front of the laminates and flexible ones at the back surface it offered better resistance to impact and composites exhibit higher flexural modulus [20,21].

Matrix modification has been reported as one more factor which tends to improve the properties of composites; Arbelaiz et al. [22] reported that matrix modification led to better mechanical performance than fiber modification in flax fiber/polypropylene composites. Specifically, the modification of unsaturated polyester resin has been reported to improve the impact property,

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http://dx.doi.org/10.1016/j.compositesb.2013.04.018

thermal stability and elongation at break but produces marginal difference in other mechanical properties when Dioctyl phthalate (DOP) was used as a modifier [23–25].

Nylon fibers are known for their high elongation at break. Kevlar possesses high strength and modulus but it is relatively expensive. On the other hand, glass fibers that are quite cheap with strength and modulus higher than nylon fibers are relatively heavy. Therefore, this work focuses on the effect of different fibers that are commonly available at lower cost in comparison to Kevlar and their combinations, on the mechanical, physical and thermal stability of the polyester reinforced composites. The work also studied the hybridization of the three relatively high strain rate to failure fibers. The matrix employed in this investigation is unsaturated polyester resin modified with 5 wt% DOP [24].

2. Experimental

2.1. Materials

The materials employed in this investigation were general purpose polyester resin manufactured by ADD resins and chemicals (pty) Ltd., South Africa. The glass fiber was woven roving E-glass fiber of denier 10,820, tightness of weave 7.65 cm^2, manufactured by Jiaxing Sunlong Industrial and Trading Co., Ltd., China. The Kevlar 49 fiber was a plain weave mat with denier 1500, tightness of weave 46.24 cm^2, manufactured by Carr Reinforcement Limited, UK. The nylon fiber was plain weave with denier 1320, tightness of weave 183.40 cm^2, manufactured by Tar Erh, Co., Ltd., China. The hand woven nylon fiber had denier 2360, tightness of weave 117.81 cm^2. Dioctyl phthalate (DOP) was manufactured by Zhenzhou p and b Chemical Co., Ltd., China.

2.2. Production of composite materials

The polyester mix was prepared by measuring 150 ml of general purpose unsaturated polyester resin into a plastic cup and 5 wt% of DOP was added and mixed for 10 min after which, 2 wt% of catalyst (methyl ethyl ketone) was added mixed for 3 min and 2 wt% cobalt accelerator added and mixed for another 2 min.

Hand lay-up method followed by compression was used to produce the composites in a metallic mold using 1 in. pure bristles brush to apply the polyester mix as prepared. Nine layers of the fibers each was used to produce the plain composites (monolithic) glass fiber reinforced polyester (GFRP), Kevlar composite (KFRP), nylon composite (NFRP) and locally woven nylon composite (LNFRP). Similarly, the asymmetric stacking sequence [20] was used to produce hybrid samples of Kevlar and glass composite (KGFRP), glass and nylon composite (GNFRP) and glass and local nylon composite (GLNFRP) using 5 layers of glass with 4 layers of the other fiber respectively. Also, ter hybrid composites of the fibers were produced using asymmetric stacking sequence with 3 layers each of the fibers. Fig. 1 shows sample schematic diagrams of produced composite laminates.

Fig. 1A serves as a sample for GFRP, NFRP, KFRP and LNFRP, Fig. 1B serves as sample for GNFRP and GLNFRP but with the 5 layers of glass fiber on top of the 4 layers of nylon fiber and local nylon fiber respectively and Fig. 1C serves as a sample for the KGLNFRP.

All the composites were produced at a pressure of 1013.40 kN/m^2 [26] using a Carver laboratory hydraulic press (model M, serial number, 23505-208). The mold was removed from the press after 6 h and was left to cure for another 18 h after which the content was removed and post cured in the oven at 60 °C for 3 h. The compositions of the composites are shown in Table 1.

2.3. Characterization

Three test samples each were cut from the produced composite materials and analyzed based on ASTM standard.

2.3.1. Tensile property test

ASTM D3039 was adopted for the tensile test. Axial torsion systems universal testing machine was used to carry out the test at a strain rate of 10 mm/min. Test data were collected and the tensile strength, tensile modulus, elongation at break and energy to failure evaluated.

2.3.2. Flexural property test

This test was performed with an axial torsion system universal testing machine using ASTM D790M at a test speed of 5 mm/min

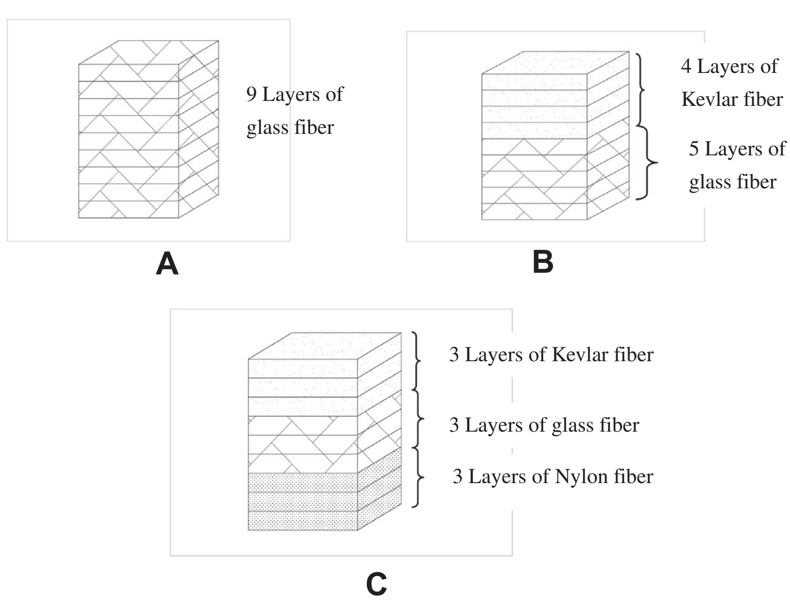

Fig. 1. Sample diagrams of composite laminates: (A) laminate of 9 layers of glass fiber, (B) hybrid laminate of 4 layers of Kevlar fibers and 5 layers of glass fiber and (C) ter hybrid of 3 layers each of Kevlar, glass and nylon fibers.