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## Development and performance evaluation of inter-ply and intra-ply hybrid fabric reinforcements and their composites

Ashok Rajpurohit<sup>1,2\*</sup>, Vicky Singery<sup>1</sup>, Sébastien Joannès<sup>2</sup>, Philippe Sanial<sup>1</sup>, Lucien Laiarinandrasana<sup>2</sup>

<sup>1</sup>Chomarat Textile Industries, 39 avenue de chabannes, 07160 Le Cheylard, France

<sup>2</sup>MINES ParisTech, PSL - Research University, MAT - Centre des Matériaux, CNRS UMR 7633, BP 87, 91003 Evry Cedex, France

Fiber composites are characterized by high specific strength and modulus, fatigue resistance, damage tolerance and enhanced tailor-ability than metals, hence, these materials are extensively applied in high performance applications and make a major contribution to the light-weighting products. Composite designers are now looking towards newer unconventional applications for composites, these includes applications in all kinds of industries such as aerospace, transport, marine as well as in sectors of sports and leisure. For these newer applications such as skies or the spar caps in the wind blades, the requirement consists of several different properties in a complex loading condition with cost also being an important factor. Composites made from a single reinforcing material tends to be unsuitable as it cannot satisfy all the performance and cost conditionals simultaneously. Hence the idea of using hybrid reinforcements for such applications has been mooted by several researchers since early 80's. By combining two or more fibers it's possible to club advantages of both the fibers while simultaneously mitigating their less desirable qualities.

Fiber hybrid composites are those composites where two or more types of fibers are embedded in a common matrix. This combination of fibers could be in the form of two or more high performance technical fibers such as carbon, glass or aramid; which is most popular format of fiber hybridization for newer industrial applications. Several studies that have been reported in literature tend to focus on improvement in failure strain; improvement in toughness and pseudo-ductility property and analysis of hybrid effect in hybrid composites [1-6]. This paper brings other focuses such as of reducing material costs and achieving better balance of mechanical property for a hybrid composite to suit wider applications. The differential of this work is that it explores for same reinforcements fibers, the hybrid effect in two configurations of hybridization, namely, intra-ply and inter-ply hybrids. Unlike most other studies in the field of hybrids, it deals with UD reinforcements with cross-ply layup in a robust composite process of RTM using epoxy resin.

In this work, reference and hybrid UD reinforcements are manufactured on the actual productions machines using stitched UD technology and composites are manufactured using RTM setup from ISOJET. The reference fabrics; A (100% carbon T700S) and F (100% glass 111A E-Glass) are used to manufacture reference composites and the hybrid composites in inter-ply configuration. The intra-ply hybrid composites are manufactured using hybrid fabrics C, D and E having different pattern of roving presence along the width as can be seen in Figure 1. The set of composites manufactured are as explained in Table 1. Determination of properties, such as volumetric percentage of the constituent phases and density has been performed. The laminates are subjected to uniaxial tensile, compression and three-point bending tests to obtain their mechanical properties and quantify the hybrid effect for the composites with various hybrid configurations. Additionally, the fracture behavior and failure mode analysis were performed using scanning electron microscopy. The aim is to better understand the balance of several mechanical properties in different configuration of hybrids and identify their suitability for newer unconventional applications.

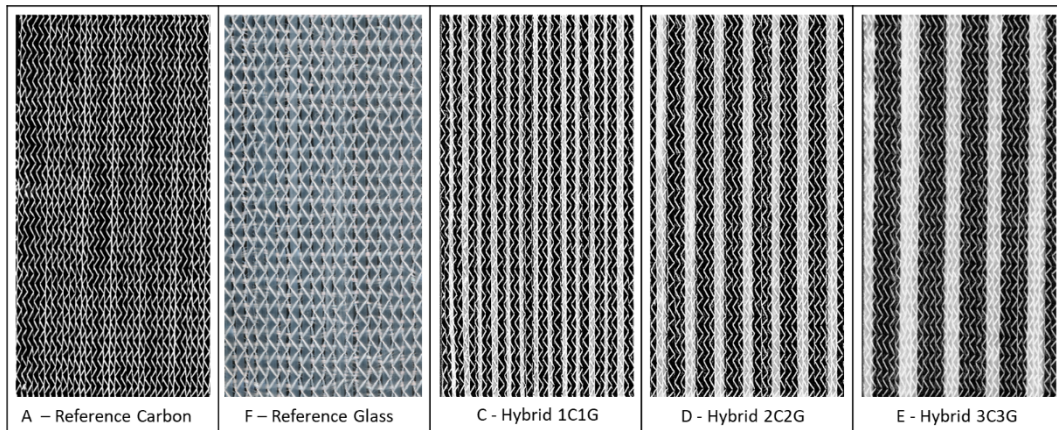


Figure 1: Developed reference and intra-ply hybrid reinforcements for the study.

Table1: Composites developed for the study and their physical properties

	Composite	Fabric used	Number of layers	Layup sequence	Thickness [mm]	Density [g/cc]	FVF [%]
Reference	R1	A (100% Carbon)	6	[0/90/0] <sub>s</sub>	1.88	1.52	49.36
	R2	F (100% Glass)	6	[0/90/0] <sub>s</sub>	1.22	1.80	47.08
Intra-ply Hybrids	H1	C (1C1G)	6	[0/90/0] <sub>s</sub>	2.60	1.66	51.28
	H2	D (2C2G)	6	[0/90/0] <sub>s</sub>	2.62	1.66	54.17
	H3	E (3C3G)	6	[0/90/0] <sub>s</sub>	2.61	1.66	51.82
Inter-ply hybrids	I1	A and F	12 (6+6)	[0 <sub>G</sub> /0 <sub>C</sub> /90 <sub>G</sub> /90 <sub>C</sub> /0 <sub>G</sub> /0 <sub>C</sub> ] <sub>s</sub>	3.13	1.66	50.04

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