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Mechanical properties of basalt fiber reinforced composites manufactured with different vacuum assisted impregnation techniques

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A B S T R A C T

This work describes an experimental mechanical characterisation campaign on composites made out of a quasi-unidirectional basalt fabric. In order to evaluate the ability of commercial basalt fabrics and their composites to meet the potentials of basalt fibers, the work has used raw materials from commercial catalogs with no further modification. Two common manufacturing techniques for medium performance composites have been adopted: vacuum assisted resin infusion, and hand-impregnated vacuum bagging. Two panels, one for each technique, have been fabricated, able to provide a sufficient number of samples for a comprehensive stiffness and strength characterization through Tensile, Flexural, In-Plane Shear, Short Beam Shear, Double Cantilever Beam and End-Notched Flexural tests. Results revealed a significant dependence of the mechanical properties on the manufacturing processes, due to their different ability to fully impregnate the dry fabric assembly, and on the quality of fiber/matrix adhesion. In general, hand-impregnation followed by vacuum bag curing was able to guarantee a better impregnation, which in particular yielded superior Interlaminar Shear Strength and Interlaminar Fracture Toughness performances.

1. Introduction

Basalt is a volcanic extrusive mineral obtained by a rapid cooling of the melted lava. Basalt rocks are widespread on the Earth's crust and, even if they can differ by chemical composition in dependence on the geographical site of formation, in general, they show good properties in terms of both chemical, physical stability and mechanical properties [1–3].

The procedure to extrude fibers by processing basalt rock is relatively old (first patent in 1923), and it took research work throughout all the second half of last century to obtain an optimized process and competitive final product [3]. Nowadays basalt fabrics for the composite manufacturing industry are available, obtained with processes similar to those employed for glass fabrics, but generally easier and with lower environmental impact. These achievements, together with the nominally superior stiffness and strength properties and good thermal and chemical stability, have proposed basalt fibers as an appealing alternative to glass fibers. Furthermore, despite the similarity in chemical composition with asbestos, basalt fibers do not cause health risks [4,5], and have been successfully used as reinforcement for thermosetting [6–8] and thermoplastic [9] matrix resin systems [10].

On the other hand, some weak points still persist. For instance, the costs and the properties of technical basalt fibers may change and may strongly depend on the quality and composition of the raw materials [11–14]. In addition, few works are still available about the evaluation of final mechanical performances, able to fully confirm that the benefits of the single fibers are reliably transferred to the final composite. This lack of comprehensive characterization is somewhat worsened by controversial findings in recent studies. In Refs. [15,16]the poor basalt-fiber/matrix adhesion is highlighted as an important issue, due to fiber surface defects left by the extrusion process, which can affect the ability of the composite to exploit the superior tensile properties of basalt over glass. Colombo et al. [1] evaluated the influence of the type of resin on the static and fatigue properties of quasi-isotropic BFRP laminates, manufactured with a vacuum infusion technique. The experimental results showed that epoxy resin provided better results than

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vinylester in terms of tensile strength and fracture toughness. The study also revealed that fiber-matrix adhesion problems may arise in using this kind of fibers.

A number of recent studies has instead concluded that basalt reinforced epoxy composites are competitive with their glass fiber counterpart [10,14,17]. Interestingly most characterization on the cited works have considered laminates made out of [0/90] commercial woven fabrics, while very little reference is found to a pure UD basalt reinforced laminate, which would provide more basic elastic/strength parameters for comparison. In the present work, an extended mechanical characterization is performed on two UD laminates, using the same commercial fabric and resin but two different manufacturing processes: Hand Lay-Up impregnation followed by Vacuum Bagging consolidation, and a Vacuum Assisted Resin Infusion. Both techniques have been widely used in several industrial sectors and in the marine industry in particular. The use of commercial raw materials and traditional manufacturing techniques is then aimed at investigating how mature is the development of technical basalt fibers for a generic replacement of their glass fiber counterpart.

The proposed characterization has investigated fiber-dominated properties (tensile and flexural behavior along the fiber direction) and matrix-dominated properties (tensile and flexural behavior in the fibers transverse direction, Interlaminar Shear Strength via Short Beam Shear and Three Rail Shear tests, mode I and mode II fracture toughness via Double Cantilever Beam and End Notched Flexure Test). The findings, in general, have evidenced two main sources of influence on mechanical properties: the grade of fiber impregnation, mainly related to the manufacturing process, and the fiber/matrix adhesion quality. Regarding the manufacturing techniques, the Vacuum Assisted Resin Infusion process (RI) exhibited a lower ability to fully and thoroughly impregnate the fabric lay-up, compared to hand-impregnation vacuum bagging (VB). This determined a higher fiber volume fraction for RI, which yielded higher stiffness values when these are referred to fiber dominated properties, but poorer matrix dominated behavior with respect to VB.

2. Materials and methods

2.1. Manufacturing

Two different manufacturing processes were considered for the production of the laminates (i.e. vacuum bagging and resin infusion techniques). In particular, vacuum bagging (hereinafter VB) is a conventional open mold technique consisting in staking a certain number of laminae under a vacuum bag. In this case, each lamina is previously impregnated by hand and the vacuum allows to extract the exceeding resin and enhance the quality of the composite by eliminating a portion of voids.

Otherwise, resin infusion (hereinafter RI) is a close mold technique where dry plies are placed and compacted by a vacuum bag. The dry layup contained in the mold is then impregnated by resin, which flows through, mainly driven by vacuum. In the case of this work, two flow mesh layers were placed between the lay-up assembly to facilitate and regulate the resin flow during infusion. Fig. 1 shows two images of the VB and RI setups. It is worth noting that the bags and the planar extension of the laminates had the same dimensions to ensure similar compacting conditions for the two panels. Moreover, the implemented resin infusion setup was able to produce an homogeneous resin flowing front (Fig. 1). In order to obtain a number of beam samples suitable for fracture toughness testing, an artificial delamination was introduced on one side of the panels by means of a thin release film (see Section 2.2). The presence of two flowing meshes on both sides of the lay-up ensured a correct impregnation of the two delaminated fronts, where the delamination film would otherwise act as a barrier for resin flowing only through the upper mesh. The laminates, were analyzed through macrography by using an SLR Camera with a resolution of 24.1 MPixel equipped with a 40 mm, f2.8 lens with the aim to evaluate the actual status of the composites.

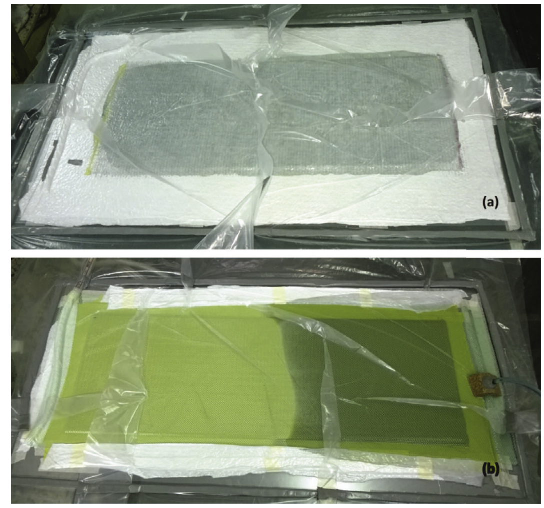

Fig. 1. Manufacturing Setups: (a) Vacuum Bagging; (b) Resin infusion.

2.2. Raw materials

A commercial Fabric under the trade name of BUF13-580-600-GBF103, manufactured by Zhejiang GBF Basalt Fiber Co. LTD, is employed. The fabric is made of continuous basalt fiber yarns, plain woven with low tex weft basalt ties. The resulting quasi-unidirectional cloth has an areal weight of 580 g/m^2, supplied in rolls of 600 mm width. The matrix system consisted of a low viscosity epoxy resin (SX8 EVO supplied by Mates Italiana s.r.l.) mixed with its own amine based M-type (medium reactivity) hardener (100:30 mix ratio by weight). Table 1 reports some data-sheets information provided by the suppliers about the properties of the used raw constituents. In particular, the low viscosity of the resin allows to manufacture composites through both VB and RI methods.

Panels with dimensions 700 × 300 mm^2 were manufactured by using 8 unidirectional basalt laminae for each composite. A non-stick thin film (i.e., Polytetrafluoroethylene - PTFE), with thickness of 13 μm, was embedded in correspondence of the mid-plane of the laminate to create an artificial pre-crack over a length of 65 mm as schematically shown in Fig. 2.

For each material (i.e. RI and VB) all characterisation samples were cut from one panel, to reduce uncertainties related to the manufacture. Each sample was cut with nominal areal dimensions in accordance with the type of test to carry out and the guidelines of standards. The fiber volume fraction for BFRPs has been evaluated

Table 1
Datasheet of the used basalt fibers fabric and epoxy resin.

Basalt fibers		SX8 EVO epoxy resin system	
Density [g/cm^3]	2.7	Density [g/cm^3]	1.2
Diameter [μm]	13	Viscosity at 25 °C [mPas]	550
Tensile modulus [GPa]	93	Gel time at 25 °C [h]	3
Tensile strength [MPa]	2130	Tensile modulus [GPa]	2.7
Maximum deformation [%]	2	Tensile strength [MPa]	60