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Impact behaviour of hybrid basalt/flax twill laminates

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ABSTRACT

The purpose of hybridization is to obtain a new material preserving advantages from all of its constituents. Hybridization offers intermediate properties respect to the original materials, by creating a balance effect within the fibres incorporated in the composite materials and leading to a composite with more tailored behaviour The increasing need to mitigate the environmental impact of synthetic fibres and polymers is promoting the use and application of natural materials orienting the research toward the development of biodegradable systems.

In this framework, hybrid reinforced laminates with flax and basalt twill layers alternatively stacked, were manufactured by resin infusion fabrication technology and impacted at low velocity to investigate their dynamic behaviour, in an attempt to couple the impact resistance of basalt fibres with the environmentally friendly nature of flax fibres. For comparison purposes, the same experimental characterization has been performed on laminates reinforced with only basalt or flax fibres. The experimental results confirmed the positive role played by fibre hybridization in terms of damage.

The Electronic Speckle Pattern Interferometry technique was adopted to analyze the internal damage and to provide information on the shape and the extent of the delamination, that was found concentrated under the impactor-material contact point for the basalt and flax/basalt laminates.

1. Introduction

During their service life, composites are subjected to various loading conditions of which low velocity impact is one of the most critical, especially for aerospace composite structures [1–6]. Due to their high specific stiffness and strength, carbon fibre reinforced polymer composite is the preferred material in aerospace industry. However, the toughness of carbon fibre is quite low and the resulting damage resistance is poor. In this regard, several approaches have been successfully exploited to enhance the impact damage resistance of composite laminates. One approach is known as hybridization, usually with high strain to failure fibres to improve the damage resistance of composites to both low velocity and instrumented Charpy impact [7–9] and to lower the materials costs.

The purpose of hybridization is to obtain a new material preserving advantages from all of its constituents. Composites are themselves hybrid materials, but the term "hybrid composites" relates to composites including more than one type of fiber into one single matrix with a mixing level being on a small scale (fibers, tows) or on a large scale (layers). Thus, there are several types of hybrid composites. In line with Kretsis [10], hybrid composites include: sandwich structures, where one material is sandwiched between two layers of another; interply (layer-by-layer) hybrids, in which layers of two (or more) fibers are stacked alternately in a regular manner; intraply (yarn-by-yarn) hybrids, where tows of two (or more) fiber types are mixed in a regular or random manner, intimately (fiber-by-fiber) mixed hybrids, in which the constituent fibers are mixed as randomly as possible [11].

Hybridization offers intermediate or better properties respect to the original materials, by creating a balance effect within the fibres incorporated in the composite materials [12,13] and taking advantages from the different properties of different stacked fibres and leading to a composite with more tailored behaviour in order to meet the requirements of the final structure. Moreover, it is possible to lower the costs since some reinforcements are more expensive than others [14–16].

The increasing need to mitigate the environmental impact of synthetic fibres and polymers is promoting the use and application of natural materials orienting the research toward the development of biodegradable systems.

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The inherent low resistance to low velocity impacts of natural fibre reinforced composites is still limiting their applications in semi-structural applications, as impact damage is well known to reduce significantly the mechanical properties of composite laminates [17]. The impact behaviour of these materials depends on many factors the most important of which are the stacking sequence and the architecture along with the thickness [17,18]. In the field of fibrous reinforcement, basalt fibres have gained an increasing attention in recent years as possible replacement of the conventional glass fibres [19] due to their advantages in terms of environmental cost and chemical–physical properties [20].

The mechanical properties of basalt fibre reinforced composite laminates have been thoroughly investigated for both thermoset [21,22] and thermoplastic matrices [24–27], but only limited attention has been devoted to the low-velocity impact behaviour of these class of composites [28–32]. Lopresto et al. [27] provided a thorough investigation of the mechanical properties of basalt/epoxy composites, studying also the impact resistance. A more detailed investigation of the effect of hybridization of basalt fibres on low velocity impact response of glass fabric reinforced epoxy composites was performed in Refs. [23,33].

Recently research has been also performed on hybrid composites made of basalt and organic and ductile fibres [13,29,31,34–37]. In particular, bio-sourced materials reinforced with vegetal fibres, such as flax, hemp, jute and sisal have gained popularity due to sustainable development requirements and cost-effectiveness [38]. Yan et al. [38] suggested that, when considering mechanical performance, cost and yield, flax, hemp and jute are the most promising bio-fibres that can be used instead of glass fibres in composite materials. Recent studies [34] have also confirmed the high potential of vegetal fibre reinforced composites. Flax fiber reinforced composites exhibited the highest impact energy absorption among natural fiber reinforced composites. In addition, some authors [13,37] have shown that the combination of a flax reinforcement with basalt fibers lowers the brittleness of the basalt and has a significant effect on the propagation of damage during the impact. Recently, two very interesting papers [37,51] were published about the impact behaviour of basalt/flax hybrid composite laminates immersed in vinylester resin. In particular, Fragassa et al. [37] demonstrated an improvement of impact performance by composites having a flax core between basalt fibre skins and evidenced the requirement to explore more complex stacking sequences with intercalation of flax and basalt layers inside the laminate.

Thus, to explore their mutual influence on the impact behaviour, in this study flax and basalt fiber reinforcements in the twill form have been hybridized and intercalated: core of flax thick four layers and two external layers of basalt fibre instead of eight basalt and flax layers alternatively stacked here. However, similar results were obtained about the shape of the load curves as hereafter will be highlighted. In addition to these papers, beside the different resin, in the present research morphological investigations as well as a deep analysis and comparison on the different laminates investigated of the main impact parameters involved in the dynamic response of the laminates (laminate thickness, maximum load, impact, absorbed and penetration energy), were done. And most important, it was demonstrated the efficiency of an innovative NDT, ESPI, to investigate the onset and propagation of the damage where the most common US technique was revealed not able to highlight the internal damage since the signal absorption by flax fibers. The latter technique was not applied before on composite laminates.

In particular, hybrid laminates, reinforced with flax and basalt twill layers alternatively stacked, were manufactured by vacuum resin infusion and impacted at low velocity to investigate their dynamic behaviour in an attempt to couple the impact resistance of basalt fibres with the environmentally friendly nature of flax fibres. For comparison purposes, the same experimental characterization has been performed on laminates reinforced with the single type fibers, i.e. only basalt or flax fibres. The experimental results confirmed the positive role played by fibre hybridization. In fact, the hybrid flax composites showed an intermediate behaviour the single basalt and flax composites, resulting more resistant to impact than flax laminate and more capable than the basalt laminate to absorb the impact energy through not elastic mode and the deflect the impact progression.

Table 1
Characteristics of the reinforcements.

Reinforcement	Flax	Basalt
Density (g/cm^3)	1,27	2,67
Specific surface weight (g/m^2)	222,1	220
Weave type	Twill 2/2	Twill 2/2
Thickness (mm)	0,225	0,13

2. Materials and experimental methods

Basalt twill woven fabric with fibre areal weight of 220 g/m^2 (BAS220,1270,T), supplied by Basaltex NV and a flax twill woven fabric (FlaxPly BL200) with fibre areal weight of 200 g/m^2 supplied by Lineo, were used as reinforcements. Table 1 shows the characteristics of both reinforcement as reprted by the datasheet. The investigated reinforcements have been impregnated by the two-component commercial resin epoxy PRIME™ 20LV (100:26 resin/hardener weight ratio) formulated for infusion system by Gurit. PRIME™ 20LV has reduced viscosity (600–640 cP) and longer working time, which makes it ideal to impregnate very large parts with complex reinforcements in one-shot operation. It maintains the exceptionally low exothermic characteristic, which allows thick sections to be manufactured without risk of premature gelation due to the heat of exothermic reaction.

Three different laminates, reinforced with basalt, flax and hybrid basalt/flax fabric, have been manufactured by stacking 16 plies of reinforcement. In particular, the hybrid one was realized by alternating 8 basalt and 8 flax fabric layers according with a symmetric and balanced configuration and placing externally the basalt layers in order to ensure higher impact resistance. The final stacking sequence was $[B, F]_{8,s}$ for the hybrid laminate.

All composite panels have been produced by vacuum infusion process that basically involves three steps [39]: lay up of a fiber preform, vacuum application and fiber impregnation by a thermoset resin, cure of the resin. The reinforcement is placed between one-sided rigid mold and a formable vacuum bag material. The resin is injected from an input channel. Vacuum is applied through a single or multiple vents in order to remove the air from the fiber preform and to drive the fiber impregnation by resin. A resin distribution net medium is placed onto the reinforcement to promote the resin flow allowing the complete wet-out of the preform and eliminating voids and dry spots. After infusion, the panels were cured for 16 h at 50 °C according with the technical datasheet. The manufactured composite panels showed different characteristics in terms of thickness and fiber volume fraction as reported in Table 2.

The different thickness is due to the different resin absorption. In low velocity impact phenomenon the content of resin does not influence the response of the laminates. On the other hand, in literature it is largely reported that the fibre content is the fundamental parameter governing the impact behaviour. Thus, the investigated laminates were

Table 2
Characteristics of the manufactured composites.

Property	Basalt	Flax	Flax/Basalt
Thickness, mm	2.7	8.1	5.7
Fiber volume fraction	0.69	0.47	0.61
Density, g/cm^3	1.87	1.05	1.34