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The Use of Pineapple Fiber Composites for Automotive Applications: A Short Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author JS collected literature. Author TSMK focused the collection of data. Author CS revised the work and refined the writing. Authors MC, KS and SS provided supervision to the work's structure and offered feedback. All authors read and approved the final manuscript.

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ABSTRACT

Pineapple leaf fibers (PALF), as the part of a large productive system, based on the availability of fruits for the food industry, offer a large amount of possibilities in term of use of the fibers, which are almost exclusively dedicated to the field of materials, as the reinforcement of polymer matrices, either traditional oil-based ones or biodegradable ones. Pineapple fibers, due to their suitability to textile use, can be introduced into composites not only in the form of short fiber, although the latter remains the most frequent case. As the consequence of this, they are also of interest of the

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automotive industry, an interest, which is steadily and rapidly growing especially in the last few years. This review tries to elucidate what are the characteristics of pineapple fibers that are particularly important for the automotive industry together with trying to clarify which could be the possibilities in the next future for their wider introduction in this sector.

Keywords: Pineapple leaf fibers; automotive composites; biodegradable matrices.

1. INTRODUCTION

Pineapple (*Ananas comosus*), a perennial plant, is a member of Bromeliaceae family. It is mainly cultivated for their fruits, a production that is deemed to reach 31 million tones worldwide by 2028 with an average increase of 1.9% [1]. Pineapple leaf fibers (PALF) are normally separated by stripping and decortication, taking care of maintaining them as straight as possible. More recently, as far as short fibers are concerned, also milling methods were considered to increase the yield of these fibers, which appear still underused so far [2]. Following this process, they are soaked in water like flax and hemp for the retting process. Pineapple leaf is normally considered as a waste in horticulture and is not used for any purpose: only recently, characterization of leaves from various cultivars has been carried out [3]. Large amounts of pineapple leaf strands are being created, however only small market segments are being utilized in the field of feedstock and energy creation. Therefore, the extension of use of biocomposites has suggested enhanced mechanical use of fibers such as PALF, to elucidate the potential outcomes of this procedure [4]. The limit for application of PALF in composites with traditional non- biodegradable polymer matrices is their high cellulose content, which was measured to be in the region of 81%, the remainder being mainly formed by hemicellulose, which is dissolved by alkali bleaching, with no more that 3% lignin [5]. This indicates that PALF needs to be treated to provide a sound interface with polymer matrices, especially with oil-synthesized ones. Treatments providing an adequate coverage and protection of fibers, such as the one with silanes, were revealed to reduce further their hydrophilic characteristics with respect to alkali removal of loose matter and unstable hemicellulose [6].

Thinking of applying PALF as the reinforcement of polymer composites, it is of paramount importance to consider the most widespread matrices for use in that sector, alongside with the fabrication techniques that are employed for composite manufacturing. In automotive interior parts, but also in some parts of the body, such as bumpers, polypropylene (PP) matrices have been used for decades. Some recent works tend to consider also the possibility to use natural fibers, such as non-woven flax, hemp or kenaf, as the reinforcement for PP, also in view of obtaining more dampened structures [7]. The application of other natural fibers has also been attempted in combination with polypropylene on automotive composites, which are obtained as a by-product from the food sector, such as blue agave bagasse [8]. As it is common in the combination of PP with natural fibers, the matrix has been grafted with maleic anhydride, a matrix-specific procedure to improve compatibility with ligno-cellulosic materials, also in the automotive sector e.g., for coir-PP composites [9].

However, also in the case of automotive composites, while the use of PP as the matrix appears the most common solution, other ways have been experimented. In particular, on the two extremes, the use of traditional thermosetting matrices and the use of biodegradable ones have been experimented in combination with natural fibers.

In the case of thermosetting matrices, which are typically used for some components in the automobile, such as armrest, the number of species of natural fibers available is so wide that also method to try to automatize their selection has also been experimented [10]. More recently, the introduction of biodegradable matrices also produces appreciable results in combination with natural fibers. This applied particularly applicable in the so called semi-structural parts, such as dashboard panels, which are not deemed to survive to a serious car accident, but only to provide a safe mode of fracture without any sharp elements: in [11] for this aim a nettle-poly (lactic acid) composite was proposed.

The above considerations suggest that there is space for more reviews on use of natural fiber composites in the automotive field, updating data and information already shown by some classical work, such as [12], where the emphasis is put on the possibility to obtain Class A finishing also using natural fibers. This need for more updated reviews is especially true for the overwhelming development of this sector in the last decade or so. In particular, there are fibers, such as pineapple leaf ones, which have been underused so far and that on the other side were indicated already to possess a considerable potential, on which this work concentrates.

2. PINEAPPLE FIBER (PALF) COMPOSITES

For this review, hybrid composites of pineapple fibers with other natural or glass fibers are purposely only mentioned, since the main idea is related to the possible use of bare PALF composites in the automotive sector. However, some works on hybrids are of particular interest, especially because they aim to increase the global amount of reinforcement introduced in the polymer matrix. This is especially true for the ternary hybrid between glass, jute and pineapple fibers presented in [13]. Here, a considerable increase of flexural performance was obtained by increasing the global amount of fibers, in equal proportion between the three reinforcements, up to 42 vol.%. Another typical coupling of pineapple fibers is the already mentioned with kenaf fibers, on which also global studies involving other than thermal and dynamical mechanical properties also flammability assessment have been performed [14]. Other combinations, being limited always by the typical arrangement of PALF as short fibers, are for example with coir, with the idea of exploiting their respectively high lignin, for coir, and cellulose, for PALF, to obtain an intermediate effect [15]. Even more specific and somehow unusual uses have been proposed, in the view of introducing different natural waste in the composite, such as the one of PALF with chopstick refuse, in a biodegradable poly(butylsuccinate) (PBS) matrix [16].

To concentrate further on data of interest for the issue, as in every situation that involves the introduction of new filler in composites, it can be observed that the initial studies concentrated on assessing the maximum amount of filler that produces a beneficial effect on the matrix performance. As for other natural fibers, also for pineapple the possibility of investigating hybridization with glass fibers was considered. In particular, intimate mixing between short glass (50 mm) and pineapple fibers (30 mm) in polyester composites, based on a global content of 30% by volume of fibers, provided evidence of a wide variability of results [17]. Normally, the first indication provided from composites in mechanical terms, comes from tensile testing. In Table 1 comparative tensile data from different PALF reinforced composites are reported [17-21]. When in the same study different values have been obtained for various PALF amounts, those yielding the highest tensile strength are solely reported. Different matrices have been used and another significant factor also linked is the length of fibers possibly obtained.

Other properties, which are particularly noteworthy in the case of possible automotive applications, are flexural and impact properties. Flexural performance decreased with water uptake in poly(ethylene)-PALF composites with up to 30 wt. fibers, considering also that water absorption is higher for increasing amounts of fibers, while a lower, yet still significant, negative effect is reported from ultraviolet (UV) light [22]. A considerable improvement has been observed in terms of flexural stiffness, which has been evaluated to 2.3 times the pure polyester matrix for a 30 wt.% of pineapple fibers [23]: the same study evidenced that work of fracture under impact of the same composite was 24 kJ/m^2. This is even superior to what observed in a typical fiberglass with polypropylene matrix for automotive use, again with 30 wt.% fibers, where a value of 17.1 kJ/m^2 for unnotched Charpy impact work of fracture has been reported [24].

Table 1. Tensile tests results

Matrix	Amount of PALF fibers	Tensile strength (MPa)	Tensile modulus (MPa)	Ref.
Polyester	30% vol.	65	2732	[17]
Polypropylene	10.8% vol.	37.3	687	[18]
Soy flour	30 wt% (compatibilised)	33	5000	[19]
Poly(hydroxybutyrate-co-valerate (PHBV)	30 wt.%	55.83	2255	[20]
Polycarbonate	20 wt.% bleached	68	1900	[21]

3. USE OF PINEAPPLE LEAF FIBER (PALF) COMPOSITES IN THE AUTOMOTIVE SECTOR

As discussed above, the application of PALF composites in the automotive sector can be promising. Advantages can be their high cellulose content, therefore relatively high compatibility with biodegradable matrices, but also with maleic-anhydride grafted PP, and their sufficient mechanical and impact performance. On the other side, PALF are normally used as short fibers, while textile products are not easily available, which reduces globally the amount of reinforcement possibly introduced in the composite. In general terms, they need to adapt to the manufacturing processes applied in the automotive industry, also as regards thickness regularity and joining to the other parts of the automobile [25].

The process for extraction of pineapple fibers from the leaf is very well consolidated. This is obtained by three-roll scrapping followed by retting in urea or diammonium phosphate (DAP) solutions, then thorough washing and subsequent drying [26]. Alkali treatment can allow obtaining relatively high length of fibers (186 mm) and getting of their introduction in amount of up to 40 wt.% in the composite with increased tensile strength and stiffness [27]. After this, in terms of yarns for textiles, their preparation with methods applied for jute proved possible, despite the different diameter of pineapple fibers [28]. In particular, yarns of 90 tex linear density with around 0.35 mm diameters were obtained, though with a very low fiber yield after retting, not reaching 3%. The limited yield issue can be overturn though by the presence of large amounts of by products, such as pulp, fertilizers, etc. [29].

In automotive composites, in the last few years, in view of the low cost and high environmental friendliness of natural fibers, these are increasingly proposed with a rapid yet intense momentum [30]. In particular, the use of PALF has been proposed and prototyped in a number of pieces, starting from the more typical ones, in particular dashboards, seat backs, door panels, spare tire and boot linings [31]. After this, other products have been proposed, which always belong to the semi-structural sector, spreading also from paneling to the engine insulation and cover, oil filter housing and to the electrical protection parts, and even to bumpers, where impact-resistance requirements are very significant: a complete list is offered in [32]. Even more importantly, trying to obtain information on the possible structural application of PALF composites e.g., for bumpers, also modeling of failure modes has been attempted at different impact velocities [33]. Data relative to the location of maximum displacement in the bumper are reported in Fig. 1, while this is compared against velocity in Fig. 2. Another study focused

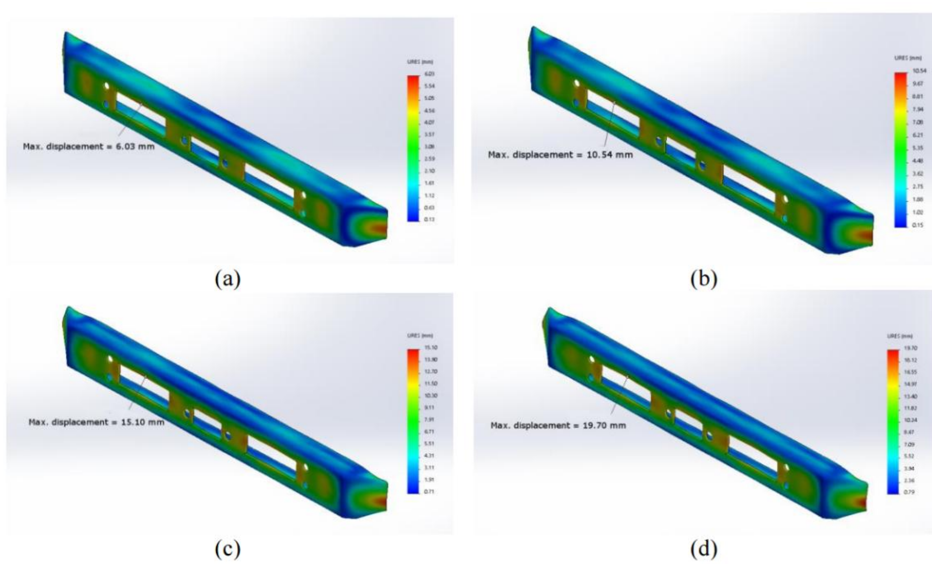

Fig. 1. The location of max. displacements of a bumper in PALF reinforced composite at a) 40 km/h, b) 70 km/h, c) 100 km/h, and d) 130 km/h [33]

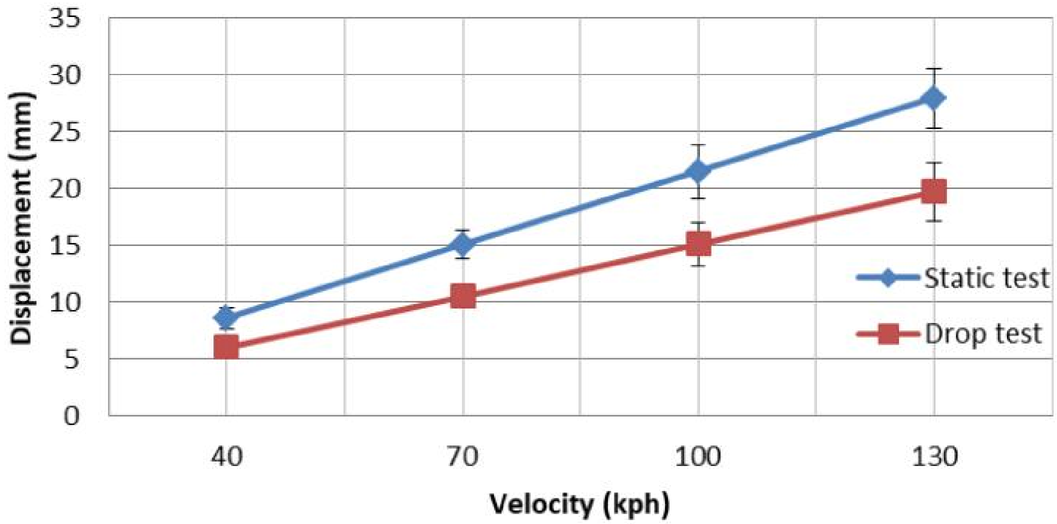

Fig. 2. Maximum displacement vs. velocity in the PALF reinforced composite bumper [33]

on comparing friction properties of Kevlar with PALF thermosetting composites, in the view of non-asbestos materials for automotive industry, obtaining comparable results with 5 wt.% of either fiber [34].

Despite this interest, it is very important to try to compare the different possible options as for natural fibers, as it is suggested that they can be possibly used in the same element of the automobile in different situations e.g., due to price variations, seasonality, factory location, etc. This originated the need for automatized selection based on the different values for mechanical and impact performance of side intrusion beam in composites manufactured with different natural fibers [35].

4. CONCLUSIONS

Pineapple leaf fiber (PALF) is a by-product of a large food-based productive system. Their high cellulose content, very low cost and relatively lightweight, with a density around 1.4-1.5, is increasingly suggesting application in composites. The automotive sector, on the other side, is trying to replace traditional reinforcements, such as particularly glass, with natural fibers. PALF is an obvious candidate, which can be also shaped into yarns and potentially in textile products for composites. The short review here exposed tries to summarize the rapidly growing interest for pineapple fibers in this field, suggesting that this can be predicted to be much larger in the years to come.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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