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# Characterization of Mechanical and Damping Properties of Nettle and Glass Fiber Reinforced Hybrid Composites

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**Abstract:** Growing environmental concerns are becoming significant challenges for large-scale applications in the automotive industry. Replacing and hybridizing glass fibers with natural fibers for non-structural applications is one effective way to address this challenge, while retaining the useful properties of both. This paper investigates the mechanical and damping performance of four types of compression-molded materials: polyester matrix (reference), nettle (6% by weight), hybrid 1 (6% glass and 6% nettle by weight), and hybrid 2 (12% glass and 6% nettle by weight), with polyester matrix at an ambient temperature. The tensile tests using digital image correlation (DIC) showed that by adding 6% by weight nettle fibers for polymer matrix tensile modulus increases by 21%. For the hybrid 1 two-layer composite (6% by weight glass and 6% by weight nettle) and the hybrid 2 three-layer composite (12% by weight glass and 6% by weight nettle), it increases by 80% and 101%, respectively. On the other hand, dynamic mechanical analysis (DMA) has been used to assess the damping properties of the materials. The results showed that the loss factor increased by 6~14% for nettle reinforced composite, by 8~25% for hybrid 1 glass-nettle reinforced composite and by 2~15% for hybrid 2 glass-nettle reinforced composite for frequencies around 1.0~2.0 Hz and around 12 Hz corresponding to vehicle body and suspension natural frequencies, respectively. These results showed that glass fibers can be replaced by nettle fibers without compromising performance.

**Keywords:** nettle fiber; mechanical properties; dynamic mechanical analysis (DMA); damping properties; hybrid composites

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## 1. Introduction

With increasing global energy crises and environmental hazards, plant-based fiber reinforced polymer composites have gained much interest due to their potential to serve as alternative reinforcements for synthetic materials [1]. The advantages of using natural fibers such as a reduced carbon footprint, lower cost, biodegradability, non-toxicity, a reduced health risk, and acceptable specific properties make them an attractive substitute to traditional fibers. Unfortunately, the main disadvantages of natural fibers, such as their sensitivity to moisture and high temperatures and the resulting degradation of their mechanical properties, can become a challenge to be accepted for application in the automotive industry [2]. A hybrid composite is a good alternative to compensate for these disadvantages by using conventional fibers combined with natural fibers to create hybrid composites such that the superior properties of one type of fiber complement those lacking in the other [2–6]. Several studies have proven that the combination of two or more types of reinforcement in the same matrix can enhance the mechanical and the thermal properties of the hybrid composite [7–9]. Samanta et al. [10] indicated that jute/glass hybrid displayed a higher reinforcement under a compressive load than bamboo/glass composites, while the opposite result was observed under a tensile load. Akil et al. [11] showed that the addition of glass fibers in a hybrid system of polyester composites reinforced with jute fibers resulted in an increase of the tensile and the flexural properties and a reduction of water absorption of the material.

Nettle fibers are mainly composed of cellulose, hemicellulose, lignin, and pectin with composition varying along the life of the plant, depending on the species and the growing conditions [12,13]. Nettle fibers possess excellent mechanical properties [12,14]. Different polymer matrices such as polypropylene [15,16], polyester [17,18], poly (lactic) acid (PLA) [15,19], and epoxy resin [20] were employed for the preparation of nettle fiber reinforced polymers for various applications [21].

Natural fiber reinforced polymers depend on a mechanical interaction between fibers and the matrix compared to chemical bonding with synthetic fibers, making them better able to damp vibrations [22–24]. Damping occurs through the properties of plant fiber structure involving entanglement, voids in the lumen, heterogeneity of the cell wall, and reversible hydrogen bonding in the cell wall [25,26]. The damping capacity of plant fiber composites is generally much higher than synthetic fiber composites. The damping range is also more widespread because of the wide variety of fibers and their hierarchical organization and complex composition [27].

Hybridization of low cost, sustainable nettle with glass fibers offers a more sustainable and economic alternative to glass fiber reinforced composites, with excellent damping properties. Furthermore, the hollow structure of the nettle fiber is expected to improve the specific stiffness and vibration absorption or damping ability of the hybrid composite material [17].

Currently, glass fiber reinforced composites are used for non-structural automotive applications. Although natural fibers, such as nettle fibers, have been used for reinforcing different types of composites [12,15,17–21], to the best of the authors' knowledge, no previous attempt has been performed at studying hybrid nettle/glass fiber composites. The aim of this study is to explore the potential of replacing glass fiber composites with nettle/glass fiber hybrid composites for non-structural automotive applications. In this study, compression-molded nettle/glass fiber hybrid composites were fabricated. To be used for non-structural applications, the material needs to maintain its elastic properties and to ameliorate its damping properties. The elastic modulus was determined through a tensile test using Digital Image Correlation (DIC) measurement setup and the damping behavior was determined in an experimental DMA test.

## 2. Materials and Methods

### *2.1. Materials*

Hybrid nettle/glass fiber composites are manufactured using polyester resin reinforced by nettle fibers and fiberglass mat. The unsaturated polyester resin was obtained from (SOLOPLAST-VOSSCHEMIE, Fontanil-Cornillon, France). Fiberglass mat is one of the most popular forms of reinforcement for non-structural applications. It is inexpensive and easy to use, and it can quickly build thickness into parts, molds, or even a repair. It was obtained from (Samaro, Beynost, France) with a surface density of 300 g/m$^2$. It features randomly oriented strands throughout that create an equal stiffness in all directions for parts [28,29]. Untreated nettle fibers were purchased from (FRD, Troyes, France). The diameter of the supplied fibers is between 30 µm and 90 µm.

### *2.2. Fabrication of Nettle Glass Fiber Hybrid Composites*

Fiber-reinforced polymer composites can be manufactured using several techniques, such as resin transfer molding (RTM), vacuum bagging, and compression molding. In this study, we used the conventional hand layup process followed by the compression molding method suitable for laboratory composite manufacturing since it consumes less capital investment and offers flexibility in materials design. An aluminum mold of size 200 × 200 × 3 mm was used for preparing the composites samples. Three types of compression-molded materials: resin (reference), nettle (6% by weight), hybrid 1 (6% glass and 6% nettle by weight), and hybrid 2 (12% glass and 6% nettle by weight) composites

(Table 1). Firstly, silicon spray is coated on the mold surface followed by positioning of a Teflon sheet to facilitate removal of the laminates. Polyester resin and a 2% weight of methyl ethyl ketone peroxide (MEKP) hardener were carefully mixed as prescribed by the supplier. The nettle fibers were placed on the mold and resin was spread over the surface of the fibers using a paintbrush, immediately followed by degassing of bubble using an aluminum bubble paddle roller. For the hybrid 1 composite, the same steps were followed by adding a fiberglass mat layer. For the hybrid 2 composite, glass/nettle/glass layers using the same steps were completely impregnated with polyester resin. Hybrid 2 was designed to protect nettle layer from harsh environmental conditions, such as humidity. It is well known that the major disadvantages of natural fibers are their susceptibility to moisture and humidity and a subsequent degradation in mechanical properties.

**Table 1.** Weight fraction of composites.

| | Glass | Nettle | Layers |
|---|---|---|---|
| Resin | 0% | 0% | - |
| Nettle | 0% | 6% | 1 Nettle |
| Hybrid 1 | 6% | 6% | 1 Nettle + 1 Glass |
| Hybrid 2 | 12% | 6% | 1 Glass + 1 Nettle + 1 Glass |

When impregnation was finished, the upper mold was closed and subjected to compression mold curing at an ambient temperature. All composites were compression molded to a final thickness of 3 mm. After 24 h, the curing process was completed, and composites were taken off the mold and cut for mechanical testing. Figure 1 presents the stepwise procedure followed to manufacture the hybrid composites.

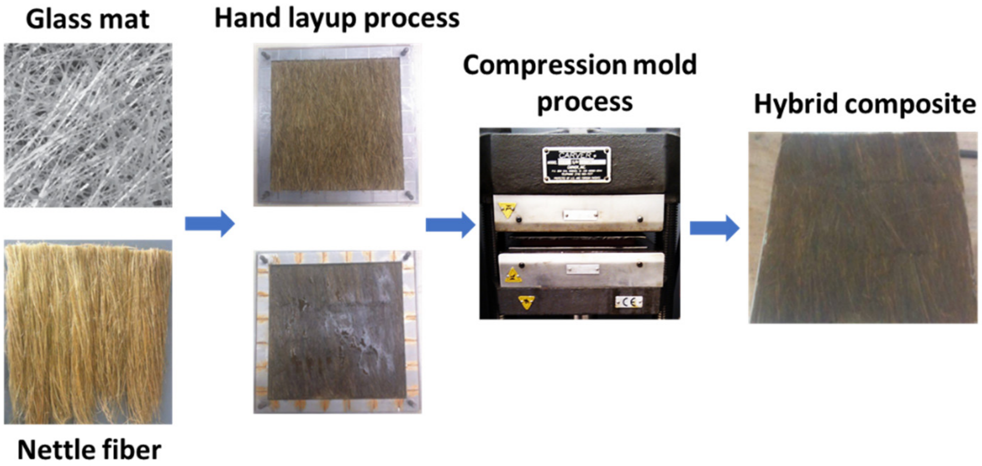

**Figure 1.** Hybrid composite manufacturing method.

### 2.3. Tensile Test

The tensile test was carried out to determine the tensile modulus of the composites. Five tensile test specimens were cut from composite sheets in accordance with the dimensions recommended by the international standard ISO 527-4 [30]. The specimens were cut from the composite plates in the direction of the fibers. The tensile test was performed in accordance with the same international standard at a rate of 10 mm/min under standard conditions (23 °C and 50% RH). The composite samples were stretched longitudinally. The tensile test was performed in a 50 kN loading cell capacity Instron 33R 4204 testing machine equipped with Digital Image Correlation (DIC) measurement setup. To record the deformation during the tensile tests, images were taken using two Charge-Coupled Device (CCD) cameras equipped with 35 mm focal length lenses. The region of interest used by the optical system was 10 mm × 100 mm. DIC works on the principle of correlation whereby a series of digitally acquired images are successively taken of a deforming sample surface throughout the test. Before testing, specimen surfaces were sprayed with a fine black colored acrylic resin-based spray, creating stochastic black and white contrast patterns for the subsequent DIC procedure. Sets of digital gray scale pictures of the surface contrast were taken every second during testing, and They served as input to calculate the displacement field using ARAMIS software [31].

### *2.4. Dynamic Mechanical Analysis (DMA)*

One of the most widely used techniques for damping characterization is Dynamic Mechanical Analysis (DMA). Dynamic Mechanical Analysis was carried out in a DMA Q800 (TA Instruments) using the dual cantilever bending mode, as shown in Figure 2. The composite laminates were cut into specimens, having dimensions of 35 × 12.5 × 3 mm and conditioned at 50% RH. The samples were subjected to a frequency sweep test of 1–45 Hz. The material response to increasing frequency was monitored at a constant strain amplitude and ambient temperature. The relationship between storage modulus ($E'$), loss modulus ($E''$), and loss factor (tan δ) with frequency was obtained.

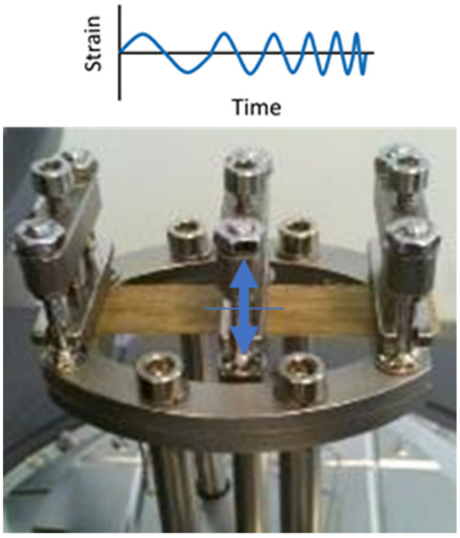

**Figure 2.** Frequency sweep at a constant strain amplitude in dual cantilever bending mode.

## 3. Results and Discussion

### *3.1. Tensile Test Results*

Typical tensile stress versus strain curves for the studied materials are shown in Figure 3. It is clear from the plots that tensile load-bearing capacity has improved for polyester fiber-reinforced composites. It is evident that polyester resin samples failed at low stress amongst the composites. This study focused especially on the tensile modulus of the hybrid reinforcement measured with DIC setup. Figure 4 shows images of a spray-coated sample with the evolution of the major strain at different loading stages for a hybrid 2 composite, showing strain localization prior to separation by cracking of the specimen [32].

With the incorporation of nettle fibers in polyester resin, tensile modulus increases as shown in Figure 5 and Table 2. Adding only 6% by weight, nettle fiber tensile modulus increases by 21%. For hybrid 1, a two-layer composite (6% by weight glass and 6% by weight nettle), and for hybrid 2, a three-layer composite (12% by weight glass and 6% by weight nettle), it increased by 80% and 101%, respectively. These results show the beneficial effect of the hybrid reinforcement on the tensile modulus. Increasing the volume of nettle fibers will result in a higher elastic modulus. However, under laboratory conditions with manual stratification, it was difficult to increase the amount of nettle fibers, while maintaining a good impregnation of the fibers. On an industrial scale, an approach similar to that developed in [23] would allow for a more optimized stratification.

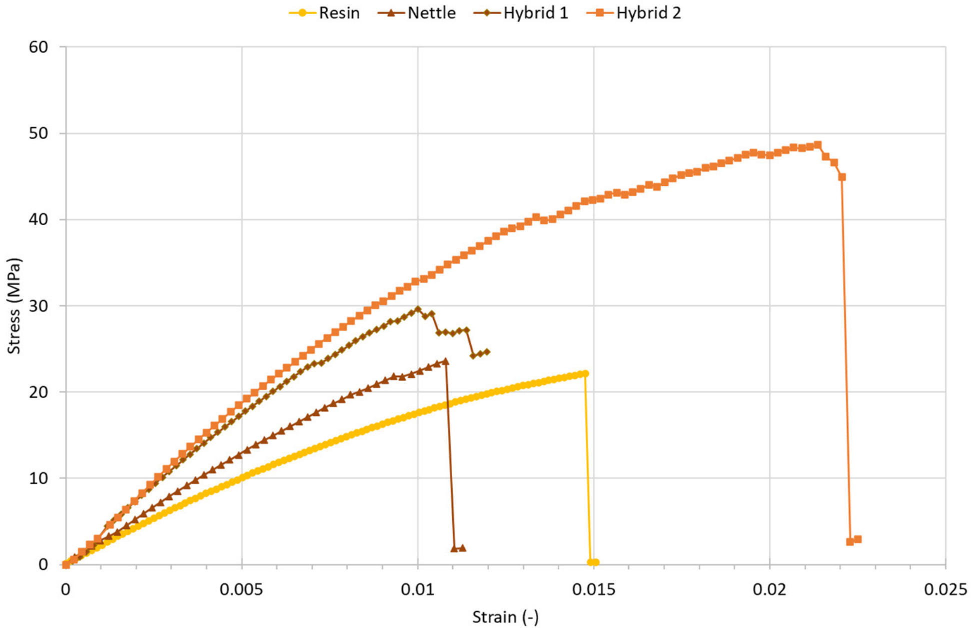

**Figure 3.** Typical tensile stress versus strain curves.

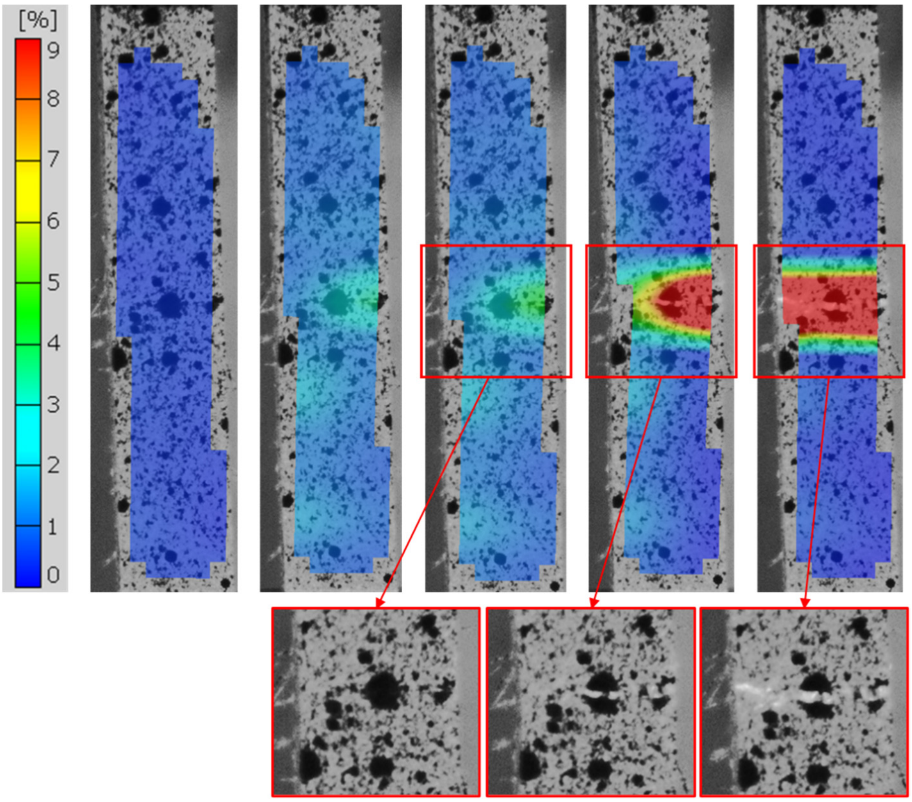

**Figure 4.** Images of major strain distribution at different loading stages for hybrid 2 composite.

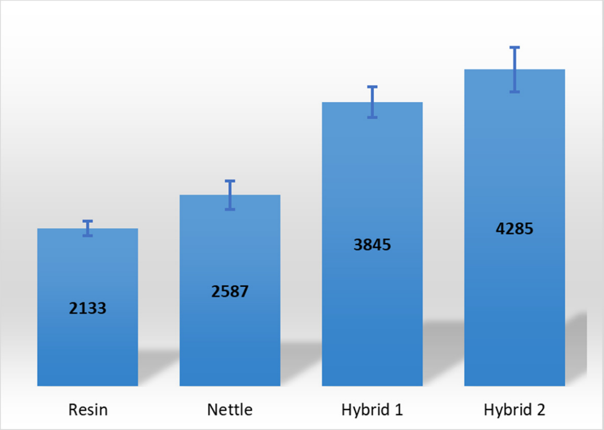

**Figure 5.** Tensile modulus in MPa.

**Table 2.** Tensile modulus for all samples.

| Sample | Resin | Nettle | Hybrid 1 | Hybrid 2 |
|---|---|---|---|---|
| 1 | 2375 | 2040 | 3955 | 3974 |
| 2 | 1901 | 2528 | 3574 | 4923 |
| 3 | 2116 | 2454 | 3433 | 3750 |
| 4 | 2141 | 2945 | 3781 | 4961 |
| 5 | 2130 | 2969 | 4483 | 3818 |
| **Mean** | **2133** | **2587** | **3845** | **4285** |
| **Standard Deviation** | **168** | **386** | **408** | **605** |

### 3.2. DMA Results

Loss modulus and loss factor are important indicators of viscoelastic damping materials; however, loss modulus and loss factor are variable, especially with temperature and frequency. In this study, the DMA test method was used to study the effect frequency ($f$) on the storage modulus ($E'$), loss modulus ($E''$), and loss factor (tan δ) of the fabricated materials. The storage modulus reveals the material's ability to store and return energy, while the loss modulus reveals its propensity for viscous energy loss. The mechanical damping factor or loss factor (tan δ) is the ratio of the loss modulus to the storage modulus. At an ambient temperature, four fabricated materials were tested at a sweeping frequency of 1–45 Hz, and the evolution of storage modulus, loss modulus, and loss factor with frequency was obtained, as shown in Figures 6–8, respectively.

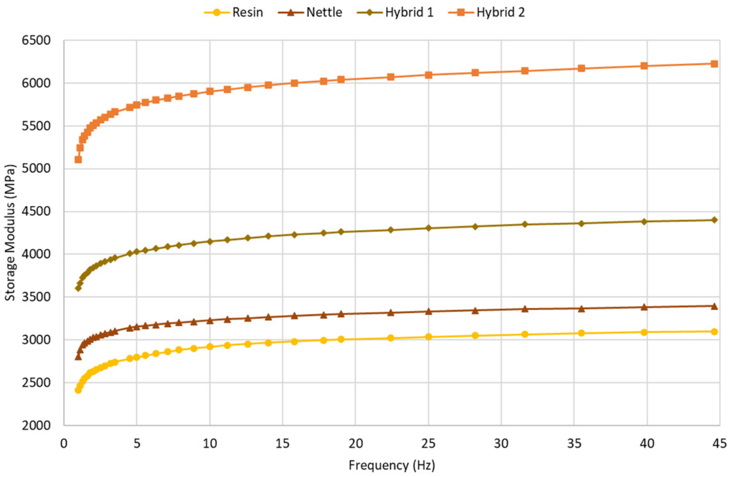

**Figure 6.** Variation of storage modulus with frequency.

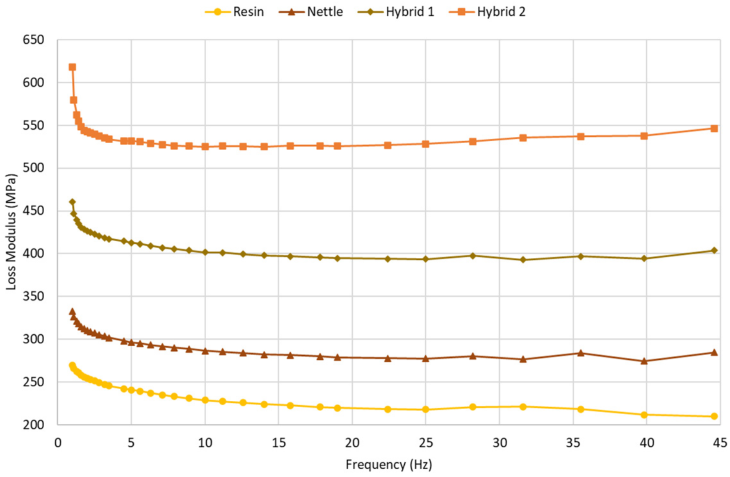

**Figure 7.** Variation of loss modulus with frequency.

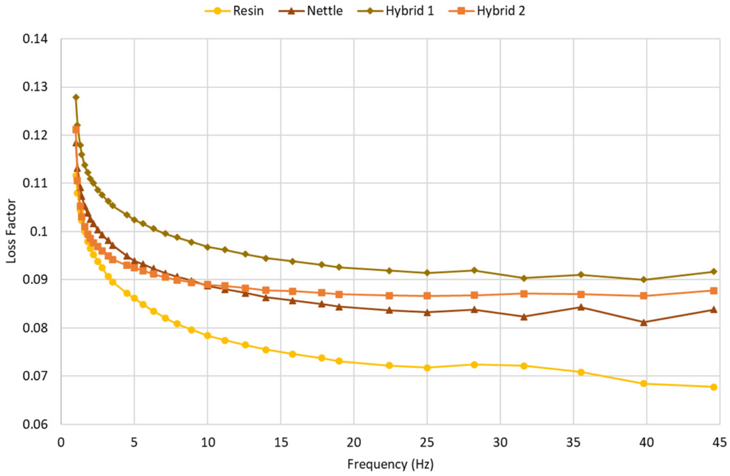

**Figure 8.** Variation of loss factor with frequency.

It is clear from Figures 6–8 that at an ambient temperature, the storage modulus increases with the increase of frequency, while the loss modulus and loss factor decrease with the increase of frequency. The storage modulus is often associated with the "stiffness" of a material, and it is related to the elastic modulus. By comparing four fabricated materials, Figure 6 shows the same trends observed for tensile modulus, where the resin storage modulus is the lowest one, followed by the nettle reinforced composite, the hybrid 1 composite, and finally the hybrid 2 composite storage modulus is the highest. A similar comparison can be done with Figure 7, where the loss modulus is often associated with "internal friction", and it depends on different types of molecular motions, relaxation processes, transitions, morphology, etc. [33]. The enhancement of storage and loss moduli is due to the restriction in the polymer chain mobility [34]. Low frequency data predicts material behavior over longer timescales, and high frequency data predicts material behavior at short timescales (high-speed impact, mechanical vibrations, and acoustics). Damping is an important parameter of the dynamic behavior of fiber reinforced composite structures; it plays an important role on resonance phenomenon. Materials with high damping ability have a high damping loss factor. As shown in Figure 8, addition of nettle fibers to polyester resin increases the loss factor (tan $\delta$). Indeed, natural fibers reinforced composites (NFRP) rely on mechanical interaction between fibers and matrix making them better able to damp vibrations [22]. Damping in NFRP is induced by the properties of plant fibers, including voids in the lumen, entanglement, heterogeneity of the cell wall, and reversible hydrogen bonding in the cell wall [25,26].

Since hybrid composite materials are intended for non-structural automotive applications, we extracted from Figure 8 four loss factor values corresponding to two vehicle body natural damped frequencies around 1.0~2.0 Hz and two suspension damped frequencies around 12 Hz [35]. The results are summarized in Table 3. These results showed that the loss factor increased by 6~14% for nettle reinforced composite by 8~25% for hybrid 1 glass-nettle reinforced composite, and by 2~15% for hybrid 2 glass-nettle reinforced composite for frequencies around 1.0~2.0 Hz and around 12 Hz. The loss factor increases for the hybrid 2 glass-nettle reinforced composite, and it is lower than the hybrid 1 glass-nettle reinforced composite because the latter contains less fiberglass mat reinforcement.

**Table 3.** Loss factors for typical vehicle natural damped frequencies.

| | **Resin** | **Nettle** | **Hybrid 1** | **Hybrid 2** |
|---|---|---|---|---|
| 1 Hz | 0.112 | 0.118 | 0.128 | 0.121 |
| 2 Hz | 0.097 | 0.103 | 0.111 | 0.099 |
| 11.2 Hz | 0.077 | 0.088 | 0.096 | 0.089 |
| 12.6 Hz | 0.076 | 0.087 | 0.095 | 0.088 |

## 4. Conclusions

The aim of this study was to explore the suitability of the developed nettle/glass hybrid composite for non-structural automotive applications. One of the needs for non-structural automotive parts to operate under the terms of use is high damping. The findings of this study provide helpful information for designers relative to hybridizing nettle and glass fibers. Results are encouraging about the possible use of nettle/glass fiber hybrid composites as a sustainable passive solution to improve the damping properties, giving rise to an increase of the loss factor of the structure according to the design requirements for non-structural applications.

**Author Contributions:** Conceptualization, F.A. and B.A.; methodology, S.X.; validation, F.A., S.X. and B.A.; investigation, F.A. and S.X.; resources, B.A.; data curation, B.A.; writing—original draft preparation, B.A.; writing—review and editing, F.A.; supervision, B.A. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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