PERFORMANCE OF BAMBOO FIBER CORE BOARD AS SOFA CUSHION MATERIAL

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Abstract. Bamboo fiber is an environmentally friendly elastic material and its application in sofa upholstery material could minimize the environmental problems associated with traditional polyurethane foam. To explore the feasibility of bamboo fiber core board (BFCB) as a sofa cushion material, the indentation hardness, support factor, deformation recovery, and constant-load impact fatigue loss of two types of BFCBs were analyzed. The mechanical properties of BFCBs were compared with polyurethane foam commonly used as padding material for sofa upholstery. Yellow-BFCBs (Y-BFCBs) had better resilience, lower indentation hardness, better support performance, and less performance loss after fatigue than Moso bamboo. In addition, the thickness loss of Y-BFCB after fatigue treatment was greater than that of PU foam, while the loss of hardness was lower, and the loss of elasticity performance was the same as that of medium-soft foam. Moreover, the resilience of the Y-BFCB was the same as that of medium-soft sofa foam with a density of 35 kg/m^3. Y-BFCB has the potential to replace sofa polyurethane foam cushion material in practical applications. This study analyzed the mechanical properties of BFCBs and provided a theoretical basis for the application of bamboo fibers in sofa cushion materials.

Keywords: Bamboo fiber core board, compressive properties, resilience, fatigue loss.

INTRODUCTION

Sofas are an indispensable part of the living and socializing environment, and the type and combination of cushion material directly affect the mechanical properties and durability of the sofa. Polyurethane (PU) foam is the main raw material used in the production of sofa cushions due to its excellent mechanical properties and comfort (Chen et al 2017; Liu et al 2021). However, PU foam undergoes creep behavior under prolonged use, which leads to defects such as collapse and deformation of sofa cushions (Xu et al 2015). The main components of PU foam include polyols,

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isocyanates, foaming agents, and catalysts that can potentially release hazardous gases. While closed-loop recycling and biodegradation of PUs have been extensively researched, they are still unsolved (Liu et al 2023). Therefore, it is important to explore environmentally friendly materials with favorable properties to replace traditional PU foam for sofa padding.

Numerous studies have been conducted on the application of plant fiber materials such as jute, bamboo, straw, luffa, and latex as padding materials in upholstered furniture. The majority of plant fiber cushions require adhesives to bond the dispersed fibers, which gives the cushions a high degree of hardness, poor ventilation, and incorporation of harmful substances such as formaldehyde (Chen et al 2018a, 2018b; Richely et al 2022). The use of thermoplastics as adhesives in cushion production reduces the use of chemical adhesives. Bamboo fibers showed promise in combination with thermoplastics in polymer composites, resulting in superior mechanical and physical properties of bamboo fibers (Yeh and Yang 2020). In addition, China is rich in bamboo resources, with 6.42 million hectares of bamboo forests producing more than 150 million tons of bamboo timber annually (Xiong et al 2020). Bamboo fiber composites have seen applications in mattresses, vehicle interiors, decoration, textiles, and other fields (Rocky and Thompson 2020).

Bamboo fiber core board (BFCB) is a newly developed composite material produced from raw bamboo fiber and low-melting-point polyester staple fiber (4080) by thermal pressing. Raw bamboo fiber obtained by milling and separating bamboo material retains the structure of bamboo fiber and has excellent thermal, antibacterial, and moisture absorption properties (Chan et al 2023). Low-melting-point fibers have excellent melt bonding and thermal stability and can be recycled by melt regeneration. Numerous studies have advanced the development of bamboo-fiber-reinforced thermoplastic polymer composites to improve the properties of bamboo fiber materials (Mahmud et al 2021; Radzi et al 2022). Yu et al (2023) evaluated bamboo-based upholstery blended with Ethylene-propylene side by side fibers and found that the modulus of elasticity of the unit had a significant effect on the change in the static seating pressure distribution of the upholstery and the subjective comfort. Wang and Young (2022) examined the mechanical properties of woven bamboo fiber-reinforced polypropylene composites and found that the tensile strength of composites increased after alkali treatment of bamboo fibers, while moisture-heat aging reduced the mechanical properties of the composites. Jitkokkruad et al (2023) investigated the effect of bamboo leaf fiber content on foam structure, mechanical properties, cushioning properties, and biodegradability of eco-friendly foam mats made of bamboo leaf fiber and natural rubber latex. Variations in fiber content affected the bulk density, indentation hardness, deformation characteristics, compressive properties, and cushioning coefficient of the foam mat. Bamboo fiber composites have great potential for application as sofa padding materials. Most of the above studies were related to the preparation process and properties of bamboo fibers; however, feasibility studies on the application of bamboo fibers in sofa cushions are almost nonexistent. The objective of this work was to develop bamboo fiber cushions as an alternative to PU foam.

In this study, the mechanical properties of two types of BFCB were tested for resilience, indentation hardness, support factor (SF), deformation recovery, and constant-load impact fatigue loss compared with those of PU foam. The possibility of replacing PU foam with BFCB as a sofa cushion was analyzed. The preferred material parameters for BFCB application to sofa cushions were identified.

MATERIALS AND METHODS

Materials

BFCB made from Yellow BFCB (Y-BFCB) and Moso BFCB (M-BFCB), are commonly produced in the Chinese market (Fig 1). Moso bamboo fibers are slender and stiff, with small cavities thick walls, and smooth inner and outer walls (Fig 1; Lian et al 2021; Li et al 2023).

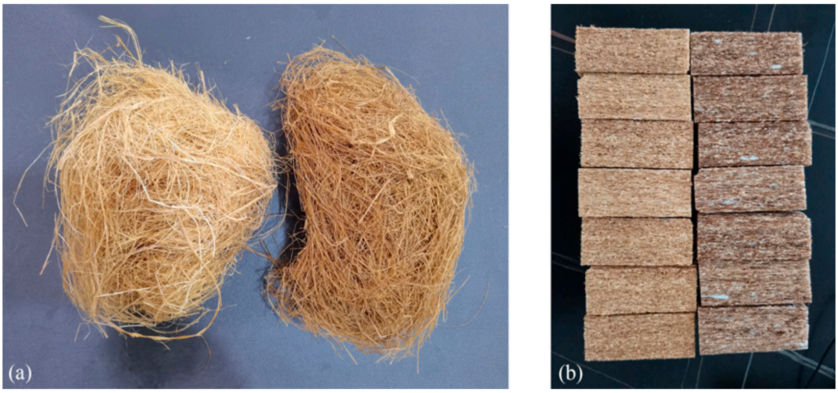

Figure 1. Examples of (a) yellow bamboo fiber (left); and Moso bamboo fiber (right).

BFCB and PU foam used for mechanical properties testing in this study were provided by Changsheng New Material Technology Co., Ltd. (Sichuan, China). BFCBs were prepared by hot pressing bamboo fibers and 4080 fibers at a 2:1 ratio. 4080 fiber is a low melting point fiber that mainly plays the role of bonding and curing bamboo fibers. This fiber can maintain the original network structure and physical and chemical properties of bamboo fibers. The fibers were uniformly blended, and the large clumps of fibers were loosened into smaller pieces. A carding machine was used to comb the small pieces of fiber into reticulated fiber layers. The fiber layers were evenly laid by a mesh-laying machine and repeatedly stacked to form a nonwoven blanket of a certain thickness. The nonwoven mats were thermoformed in a hot press at 180°C and 50 KPa for 5 min. The molded BFCBs were cut into pattern sizes for specific tests.

The densities and types of PU materials commonly used in the production of sofa padding layer materials in the enterprise were selected. Y-BFCBs and M-BFCBs with an apparent density of 80 kg/m^3 were selected. PU samples were selected as 35 kg/m^3 medium-soft foam (M-PU) and 37 kg/m^3 high-resilience foam (H-PU). According to the test standard GB/T 10807 (2006); the test specimen sizes were $100 \times 100 \times 50$ mm. All specimens were conditioned at 21-25°C and 45-55% RH before testing. Three blocks of each sample were tested, and each block was tested three times.

Experimental Design and Statistical Analysis

A one-way analysis of variance general linear model was used to analyze the mechanical properties of BFCBs. All significance levels were set at $p < 0.05$.

Load-Strain Curve and Indentation Hardness Test

Load-strain curves and indentation hardness of the materials were tested according to Chinese standard GB/T 10807 (2006) on a HD-F750A Foam Indentation Hardness Tester (Guangdong Province Dongguan Haida Instrument Co., Ltd., China). The specimen was positioned in the center of the support plate, aligned with the circular indenter above. The indenter descended on the upper surface of the specimen applying a force of 3-5 N. The preliminary thickness of the specimen was measured and recorded. The indenter continued to descend at a uniform speed of 100 mm/min.

The test concluded when the indentation thickness reached 95% of the original specimen thickness. The results were used to construct a load-displacement curve. Values were specifically recorded at 25%, 40%, and 65% of the original specimen thickness. The force value F_{40}, measured at 40% deformation was the indentation hardness index of the material. After unloading, the samples were allowed to recover in the experimental environment for 24 h. The SF and deformation recovery (ε) of the material were calculated by Eqs 1 and 2.

$$\mathrm{SF} = \mathrm{F}_{65}/\mathrm{F}_{25} \tag{1}$$

$$\varepsilon = (D_2 - D_1)/(D_0 - D_1) \times 100\% \tag{2}$$

where F_{25} is the value of the indentation force measured when the specimen is deformed by 25%; F_{65} is the value of the indentation force measured when the specimen is deformed by 65%; ε is the rate of shape recovery after 24 h; D_2 is the thickness of the specimen after 24 h of recovery from deformation (mm); D_1 is the thickness of the specimen after deformation (mm); and D_0 is the initial thickness of the specimen (mm).

Resilience Tests

The resilience test was conducted on a HD-F754 Foam Ball Rebound Tester (Dongguan Haida Instrument Co., Ltd.) by Chinese standard GB/T 6670 (2008). The test standard specifies that each sample is tested three times and the median is selected as the final resilience result for that sample. Three samples were evaluated for each material, and the mean value of the three samples was selected for statistical analysis. The specimen was positioned in the built-in groove of the Ball Rebound Tester to ensure that both the specimen and the instrument's transparent tube were placed horizontally. A 16 mm diameter steel ball (16.8 ± 1.5 g) was placed 500 mm vertically from the center of the test sample. The ball was released, and the value of the initial rebound height was recorded. The data were invalidated if the rebound hit the inner wall of the transparent tube. Resilience (R) was calculated by Eq 3.

$$R = \frac{H}{H_0} \times 100\% \tag{3}$$

where H is the bounce height of the ball (mm). H_0 is the height of the ball drop (mm).

Constant Load Impact Fatigue Test

Constant load impact fatigue of the sample material was determined by Chinese standard GB/T 18941 (2003). The sample was placed on the platform with ventilation holes of the HD-F750-1 Foam Fatigue Tester (Dongguan Haida Instrument Co., Ltd.). The vertical distance between the indenter and the upper surface of the specimen was adjusted to be the same as the thickness of the specimen. The indentation parameter was set at 750 ± 20 N. The specimen was subjected to impact testing at a rate of 70 cycles per minute. The test was terminated after 80,000 load cycles provided the sample remained centered on the circular indenter within the test period. The specimens were removed for 10 min of natural recovery under stress-free conditions. The test standard specifies that each sample is tested three times and the median is selected as the final resilience result for that sample. As the initial properties of the BFCB and PU foam materials differed widely, the absolute value of the performance reduction after testing also differed. The visual differences in fatigue loss were difficult to accurately measure. We compared the percentage of material fatigue loss. The fatigue loss rate for thickness, indentation hardness, and resilience were calculated from Eqs 4 to 6.

$$l = (L - L_0)/L \times 100\% \tag{4}$$

$$f = (F - F_0)/F \times 100\% \tag{5}$$

$$r = (R - R_0)/R \times 100\% \tag{6}$$

where l is the fatigue loss rate of the thickness of the sample; f is the fatigue loss rate of the hardness of the sample; r is the fatigue loss rate of the resilience of the sample; L is the initial thickness of the sample measured by vernier calipers(mm); L_0 is the thickness of the sample after constant load impact fatigue(mm); F is the initial indentation hardness value of the sample (N); F_0 is the indentation hardness value of the sample after constant load impact fatigue (N); R is the initial resilience of the sample (%); and R_0 is the resilience of the material after constant load impact fatigue (%).

RESULTS AND DISCUSSION

Load-Strain Curves

Figure 2(a) and (b) illustrate load-strain curves for the two types of BFCBs. Similar to latex and palm fiber mats, the stress-strain curve of BFCB displayed two stages (the plateau phase and the densification phase; Liu et al 2022). The stress-strain curves of Y-BFCB samples had a narrower range and more consistent compression characteristics. Load-strain curves of M-BFCBs tended to be dispersed, and the test results obtained from different samples varied considerably. M-BFCB will require further stabilization before utilization as an elastic padding material due to the poor stability of its compressive mechanical properties.

Indentation performance was more uniform for high-resilience foam compared with medium-soft foam (Fig 2[c]), and the trend of stress increase during compression was stronger for high-resilience foam (Fig 2[d]). In comparison with BFCBs, the stress-strain curve of PU foam displayed three phases (linear, plateau, and densification phases). Due to the softness of the two PUs in the study, the PU samples underwent low stress at the start of the compression phase. Compressive stress progressively increased after the sample reached the plateau stage. The results revealed that the stress-strain curves of the BFCBs exhibited patterns similar to those of the foam materials and that the degree of deformation was linearly correlated with the magnitude of the force. The pore space of the fibers shrank as the degree of deformation rose, and the material eventually moved into the densification phase. The internal fiber structure was destroyed as a result of the indentation deformation, which also caused a substantial rise in stress. M-BFCBs contain more and finer bamboo fibers than Y-BFCBs at the same density. M-BFCBs entered the densification stage early due to the greater resistance between the fibers during compression.

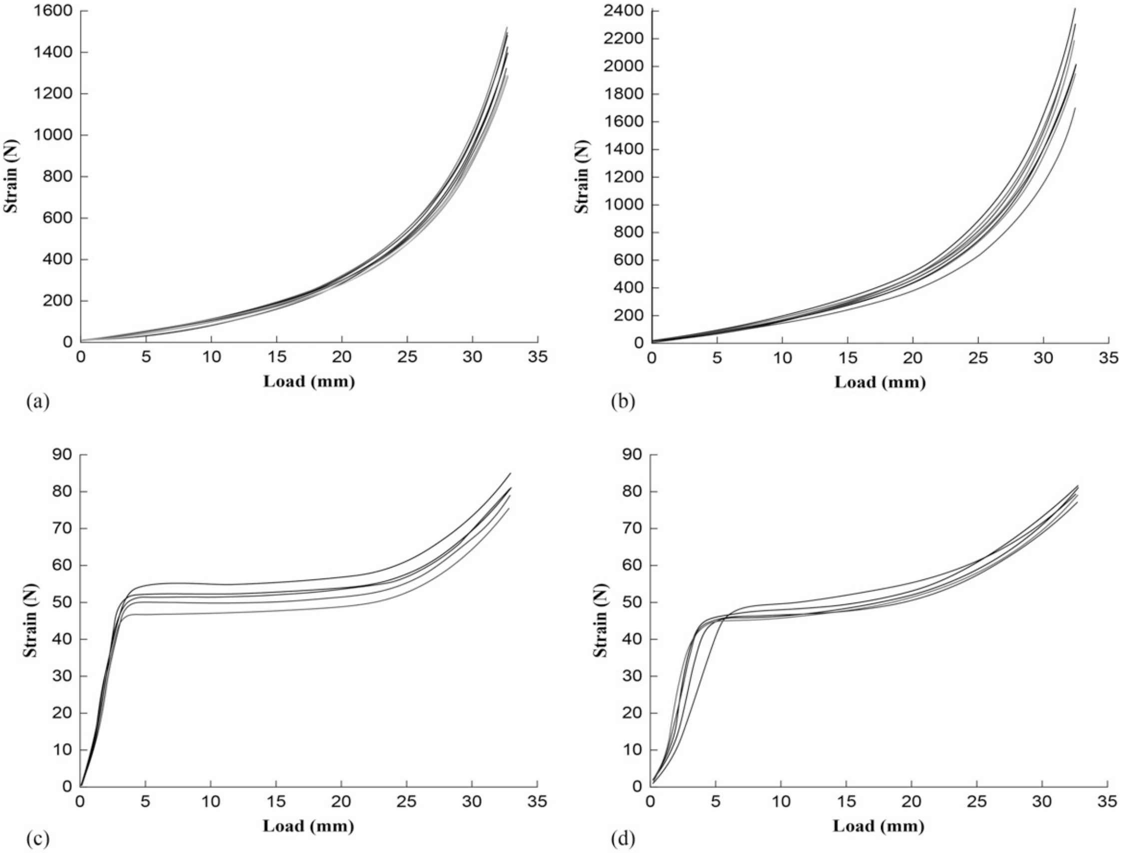

Figure 2. Stress-strain curves of (a) yellow bamboo fiber core boards, (b) Moso bamboo fiber core boards, (c) medium-soft foam, and (d) high-resilience foam.

Indentation Hardness

An independent samples t-test for the indentation hardness of the two types of BFCBs is shown in Table 1. The mean indentation hardness of Y-BFCBs was 229.14 N, and that of M-BFCBs was 322.17 N. The indentation hardness of M-BFCB was significantly higher than that of Y-BFCB (p-value < 0.001), and its mean indentation hardness value was 1.41 times higher than that of Y-BFCB. The type of raw bamboo material had a significant effect on the indentation hardness of BFCB. Yeh and Yang (2020) studied the effects of different bamboo-fiber-reinforced PP composites and also showed that bamboo species influenced the mechanical properties of composites and attributed the effects to differences in crystallinity and lignin content.

The average indentation hardness of the 35 kg/m^3 medium soft foam was 42.7 N, and that of the 37 kg/m^3 high resilience foam was only slightly lower at 41.2 N (Fig 3). The indentation hardness of both Y-BFCBs and M-BFCBs was higher than those of the two PU foam materials. M-BFCB had the highest indentation hardness, which was 7.61 times higher than that of medium-soft foam. The indentation hardness of the Y-BFCB was 5.20 times higher than the medium-soft foam. Indentation hardness is a visual reflection of the load-bearing properties and surface softness of flexible porous materials. Indentation hardness reflects the compactness and firmness of the buffer layer in compression. Gu et al (2016) used 25% and 65% indentation hardness and SFs to evaluate the mechanical properties of rattan cushions. The higher the indentation hardness value of the material, the higher the support capacity, but with less softness.

Table 1. The independent sample t-test results for indentation hardness and support factor of BFCB.

	Mean (SD)			
	M-BFCB ($N = 9$)	Y-BFCB ($N = 9$)	t-test	p-value
F_{40}	322.17 (32.67)	229.14 (12.98)	8.034	0.000**
SF	8.13 (0.72)	8.82 (0.62)	−2.594	0.018*

*$p < 0.05$.

**$p < 0.01$.

BFCB, bamboo fiber core board; M-BFCB, Moso-BFCB; Y-BFCB, yellow-BFCB.

Comparative analysis of BFCB and PU foam indicated that the indentation hardness of the two types of BFCBs was greater than PU foam, which was mainly due to the internal fiber structure of the BFCBs. The BFCB had higher indentation hardness and better load-bearing capacity than PU. The development of padding material for sofa cushions made of BFCB provides increased support capacity and meets the comfort needs of sofas for some populations. BFCBs need to be softened before application.

Support Factor

The SF gauges the ability of a material to support people using the furniture, which is directly proportional to the support force and the resistance against deformation. The SF of comfortable upholstery material is required to be greater than 2.8. As shown in Fig 3, the average SF values of M-BFCB, Y-BFCB, medium-soft foam, and high-resilience foam samples were 8.13, 8.82, 1.55, and 1.62, respectively. The average SF of the overall BFCB was 5.35 times higher than that of the PU foam. The mean SF of Y-BFCBs was significantly higher than that of M-BFCBs (Table 1). The SF of the BFCB was considerably higher than that of the foam material, which satisfied the support requirements of the sofa production standard for padding material. The BFCB was still in the linear phase when it was compressed to 25% of its thickness. The larger pores in the material were not completely compressed, with relatively minor values of F_{25}. The material entered the densification stage when the compression thickness of the BFCB reached 65%. The pores between the fibers were fully compressed, the force required for indentation increased dramatically, and the value of F_{65} far exceeded the value of F_{25}. Yu et al (2023) analyzed the hardness and supported the performance of the PU by using the indentation hardness and SF. The results showed that the PU samples were in the stabilization stage when compressed to 25% and 65% of their thickness. Due to the uniformity of PU materials, the difference between the values of F_{25} and F_{65} of PU samples was relatively minor, which made the SF values of the PU foam relatively small.

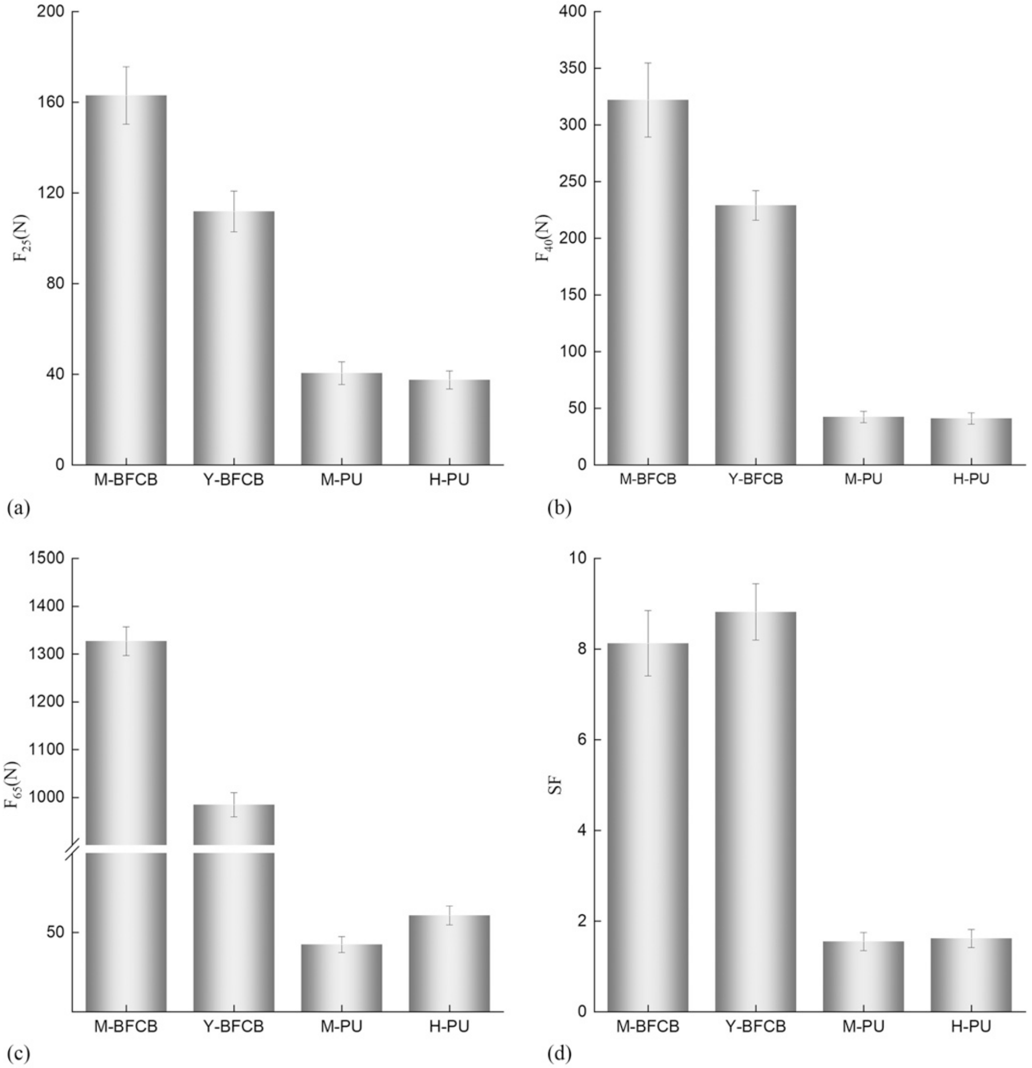

Figure 3. The mean F_{25}, F_{40}, and F_{65} values of BFCB and PU foam samples (a-c) and (d) mean SF of BFCB and PU foam samples. BFCB, bamboo fiber core board; H-PU, high-resilience foam; M-BFCB, Moso-BFCB; M-PU, medium-soft foam; PU, polyurethane; SF, support factor; Y-BFCB, yellow-BFCB.

Therefore, the support performance of BFCB was better than the medium-soft and high-resilience foam used in the test.

Deformation Recovery Rate

The deformation recovery rate reflects the ability of a material to regain its shape after use. The higher the deformation recovery rate, the better the ability of the sample to regain its shape after loading. The deformation recovery rates of different BFCBs and PU foam samples are shown in Fig 4(a). The mean deformation recovery rates of M-BFCB and Y-BFCBs were 29.6% and 40.5%, respectively. The mean deformation recovery rates of medium-soft PU foam and high-resilience PU foam were 56.2% and 63.2%, respectively. Table 2 summarizes the independent sample t-test results for the deformation recovery rate of BFCBs. Which showed significant

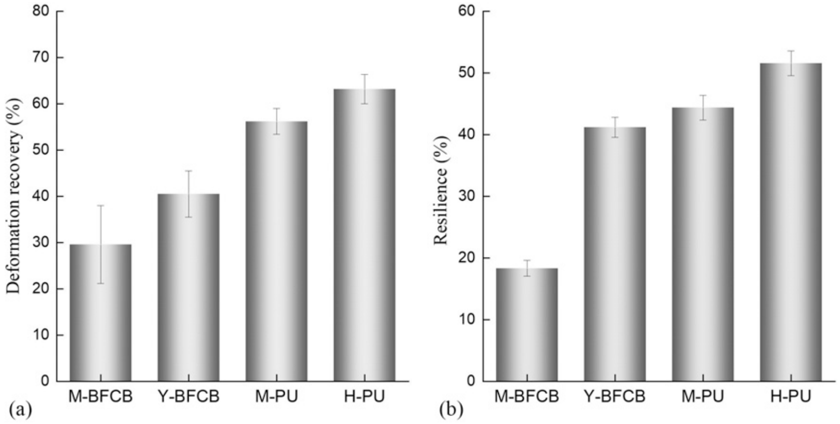

Figure 4. The mean (a) deformation recovery and (b) resilience of BFCB and PU foam samples. BFCB, bamboo fiber core board; H-PU, high-resilience foam; M-BFCB, Moso-BFCB; M-PU, medium-soft foam; PU, polyurethane; Y-BFCB, yellow-BFCB.

differences in the deformation recovery rates of the two types of BFCBs (p-value < 0.001). This is attributable to the fact that the BFCB had entered the densification stage; the pores between the fibers were compressed, and internal fiber deformation occurred when the sample was compressed to 65% of its thickness. After stress unloading, the bamboo fibers in compression slowly recovered from the deformation of the sample due to its internal stress. During the pressurization process, M-BFCBs were comparatively less able to recover from deformation due to the distortion of the fibers inside the boards. This was mainly due to the development of numerous microcracks as well as larger cracks appearing on the surface of fiber bundles and between fiber cells when bamboo fibers were compressed to the dense stage. These cracks would loosen the structure of bamboo fiber bundles (Chen et al 2017).

The lowest deformation recovery rate in the test samples was obtained from the M-BFCB, and the highest was obtained from the high-resilience PU foam. The average deformation recovery rate of medium-soft foam was 1.39 times higher than that of Y-BFCB and 1.90 times higher than that of M-BFCB. The overall deformation recovery rate of BFCB material was lower than that of PU foam, and the ability to return to shape after force was weaker than that of PU foam. The deformation recovery ability of BFCB was higher and closer to PU. Therefore, it has more potential to replace PU as cushion-filling material.

Resilience

The difference in the resilience of BFCB and PU foam was investigated in Fig 4(b). The average resilience of Y-BFCB, M-BFCB, medium-soft foam, and high-resilience foam was 41.2%, 18.6%,

Table 2. The independent sample t-test results for deformation recovery and resilience of BFCB.

	Mean (SD)			
	M-BFCB	Y-BFCB	t-test	p-value
Deformation recovery	29.60 (8.4)	40.50 (5.00)	−6.113	0.000**
Resilience	18.35 (1.30)	41.2 (1.61)	−33.073	0.000**

**$p < 0.01$.

BFCB, bamboo fiber core board; M-BFCB, Moso-BFCB; Y-BFCB, yellow-BFCB.

44.4%, and 51.6%, respectively. The resilience of M-BFCB with a density of 80 kg/m^3 was considerably lower than that of the other three materials. The content of 4080 fibers in M-BFCB was slightly higher than that in Y-BFCB. Compared with yellow bamboo, Moso bamboo had denser interfiber pores and a larger volume of individual pores. The interior of the large-volume pores was not supported by a fibrous structure. As a result, the Moso bamboo fibers were unable to provide sufficient resistance to the reaction force when impacted, and the M-BFCB was less resilient. Y-BFCB had a higher resilience, which was similar to that of medium-soft foam with a density of 35 kg/m^3, and the value was only 6.10% lower than that of medium-soft foam.

Table 2 shows the results of the independent sample t-tests for the resilience of BFCBs. The variety of raw materials used in BFCBs had a significant effect on resilience. The resilience of the Moso fiber core board was significantly lower than that of Y-BFCB (p-value < 0.001). According to Chinese industry standard QB/T 1952.1 2012 for the manufacture of upholstered furniture, the resilience performance of Grade A foam used in sofas should exceed 45%, that of Grade B foam should exceed 40%, and that of Grade C foam is supposed to exceed 35%. The resilience of Y-BFCB satisfied the standard of sofa padding, whereas the resilience of M-BFCB failed to reach the standard of sofa padding material. Y-BFCB was more applicable to upholstered sofa cushion material.

Constant-Load Impact Fatigue Loss

The mean loss of properties after constant load fatigue for the BFCB and PU foam samples are shown in Fig 5, while Table 3 illustrates the results of independent sample t-tests on the post-fatigue performance loss of BFCBs.

The rate of thickness reduction for M-BFCB was 4.0 times higher than that for medium-soft foam, while that for Y-BFCB was 4.6 times higher than that for medium-soft foam (Fig 5). The thickness reduction value of Y-BFCB was 1.2 times higher than that of M-BFCB, and the thickness reduction rate of medium soft foam was 1.4 times higher

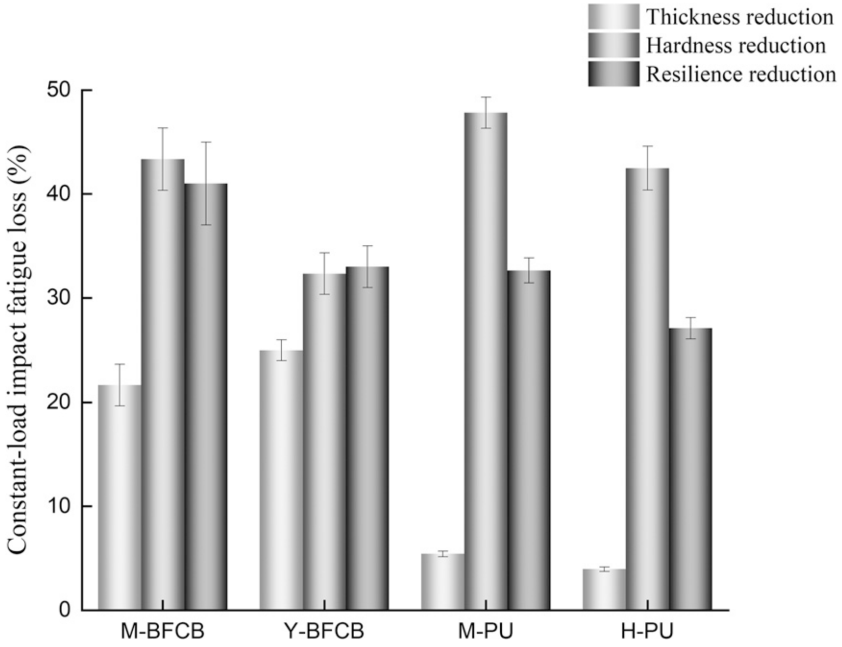

Figure 5. Mean constant load impact fatigue loss of BFCB and PU foam samples. BFCB, bamboo fiber core board; H-PU, high-resilience foam; M-BFCB, Moso-BFCB; M-PU, medium-soft foam; PU, polyurethane; Y-BFCB, yellow-BFCB.

Table 3. The independent sample t-test results for constant load impact fatigue loss of BFCB.

	Mean (SD)			
	M-BFCB	Y-BFCB	t-test	*p*-value
Thickness reduction	0.21 (0.02)	0.25 (0.01)	2.612	0.059
Indentation hardness reduction	0.43 (0.03)	0.32 (0.02)	4.928	0.008*
Resilience reduction	0.41 (0.04)	0.33 (0.02)	3.235	0.032*

$^*p < 0.05$.

than that of high-resilience foam. There were no significant differences in the postfatigue thickness reduction of the two types of BFCBs (Table 3). Thickness reduction after the fatigue of BFCB was greater than that of PU foam material. BFCB specimens entered the densification stage under the repeated extrusion of the instrument indenter and the internal fiber structure was severely damaged. The internal force direction of the fibers of BFCB was complicated, making it difficult to return to the initial form after testing.

Hardness reduction rates of M-BFCB, Y-BFCB, medium-soft foam, and high-resilience foam were 43.6%, 32.3%, 47.8%, and 42.5%, respectively (Fig 5). There were significant differences between the hardness reduction values of the two types of BFCBs (*p*-value = 0.008; Table 3). The hardness reduction value of M-BFCB was 1.34 times higher than that of Y-BFCB. The hardness reduction values were the highest for medium-soft foam while those for Y-BFCB were the lowest, which was 0.67 times the hardness reduction value of medium-soft foam. The analysis revealed that the Y-BFCBs had the least hardness loss and outperformed the other three materials.

Resilience reductions of M-BFCB, Y-BFCB, medium soft foam, and high resilience foam were 40.7%, 33.0%, 32.6%, and 27.1%, respectively. There were significant differences in postfatigue resilience reduction of the two types of BFCBs (*p*-value = 0.032; Table 3). Resilience loss after fatigue treatment of M-BFCB material was 1.23 times higher than the Y-BFCB while that for Y-BFCB was slightly higher than that of PU foam material, which was 1.01 times higher than that of medium-soft foam.

Y-BFCB performed better than the M-BFCB after being fatigued. The Y-BFCB had a slightly higher rate of thickness loss than the two types of PU foam that are frequently used in sofa cushions, a lower rate of hardness loss than the PU foam, and a resilience performance loss that was equivalent to the medium-soft foam. The deformation rate of BFCB was smaller than that of Moso bamboo fiber after long-term use. Y-BFCB represents a better choice than M-BFCB for the development of bamboo fiber cushions. The production process of BFCB should be improved to reduce the fatigue loss rate.

CONCLUSIONS

1. Resilience, indentation hardness, compression deformation characteristics, deformation recovery, and constant-load impact fatigue loss of BFCBs were significantly influenced by bamboo species. The mechanical properties of Y-BFCB were better than those of M-BFCB.
2. The indentation hardness and SF of Y- and M-BFCB were noticeably higher than those of the PU foam, indicating that the BFCBs had better support properties but lower surface softness.
3. The thickness loss rate of Y-BFCB after constant load impact fatigue was greater than that of PU foam commonly used for sofa filler layers, but the loss of hardness was less than that of the PU foam, and resilience loss was comparable to medium-soft PU. In addition, the resilience of Y-BFCB complied with the standards for cushion-filling materials in the sofa manufacturing industry and had the potential to be applied as a sofa cushion-filling material.
4. Deformation recovery of BFCBs was lower than PU foam. Further studies are needed to produce softer BFCBs and analyze the dynamic

cushioning properties of these upholstery materials to model pressure and human comfort.

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REFERENCES

Chan C-H, Wu K-J, Young W-B (2023) The effect of densification on bamboo fiber and bamboo fiber composites. Cellulose 30(7):4575-4585.

Chen Y, Su N, Zhang K, Zhu S, Zhao L, Fang F, Ren L, Guo Y (2017) In-depth analysis of the structure and properties of two varieties of natural luffa sponge fibers. Materials 10(5):479.

Chen Y, Yuan F, Guo Y, Hu D, Zhu Z, Zhang K, Zhu S (2018a) A novel mattress filling material comprising of luffa fibers and EVA resin. Ind Crops Prod 124:213-215.

Chen Y, Zhang K, Yuan F, Zhang T, Weng B, Wu S, Huang A, Su N, Guo Y (2018b) Properties of two-variety natural luffa sponge columns as potential mattress filling materials. Materials 11(4):541.

GB/T 6670 (2008) Flexible cellular polymeric materials—Determination of resilience by ball rebound. Standardization Administration of China, Beijing, China.

GB/T 10807 (2006) Flexible cellular polymeric materials—Determination of hardness (indentation technique). Standardization Administration of China, Beijing, China.

GB/T 18941 (2003) Flexible cellular polymeric materials—Determination of fatigue by constant-load pounding. Standardization Administration of China, Beijing, China.

Gu Y, Wu Z, Zhang J (2016) Load-deflection behavior of rattan chair seats. Wood Fiber Sci 48(1):13-24.

Jitkokkruad K, Jarukumjorn K, Raksakulpiwat C, Chaiwong S, Rattanakaran J, Trongsatitkul T (2023) Effects of bamboo leaf fiber content on cushion performance and biodegradability of natural rubber latex foam composites. Polymers (Basel) 15(3):654.

Li H, Xu W, Chen C, Yao L, Lorenzo R (2023) Temperature influence on the bending performance of laminated bamboo lumber. J Mater Civ Eng 35(5):04023072.

Lian C, Chen H, Zhang S, Liu R, Wu Z, Fei B (2021) Characterization of ground parenchyma cells in Moso bamboo (*Phyllostachys edulis*-Poaceae). IAWA J 43(1-2): 92-102.

Liu Q, Gu Y, Xu W, Lu T, Li W, Fan H (2022) Compressive properties of polyurethane fiber mattress filling material. Appl Sci 12(12):6139.

Liu B, Huang X, Wang S, Wang D, Guo H (2021) Performance of polyvinyl alcohol/bagasse fibre foamed composites as cushion packaging materials. Coatings 11(9):1094.

Liu B, Westman Z, Richardson K, Lim D, Stottlemyer AL, Farmer T, Gillis P, Vlcek V, Christopher P, Omar MMA (2023) Opportunities in closed-loop molecular recycling of end-of-life polyurethane. ACS Sustainable Chem Eng 11(16):6114-6128.

Mahmud S, Hasan KMF, Jahid MA, Mohiuddin K, Zhang R, Zhu J (2021) Comprehensive review on plant fiber-reinforced polymeric biocomposites. J Mater Sci 56(12): 7231-7264.

Radzi AM, Zaki SA, Hassan MZ, Ilyas RA, Jamaludin KR, Daud MYM, Aziz SA (2022) Bamboo-fiber-reinforced thermoset and thermoplastic polymer composites: A review of properties, fabrication, and potential applications. Polymers (Basel) 14(7):1387.

Richely E, Bourmaud A, Placet V, Guessasma S, Beaugrand J (2022) A critical review of the ultrastructure, mechanics and modelling of flax fibres and their defects. Prog Mater Sci 124:100851.

Rocky BP, Thompson AJ (2020) Production and modification of natural bamboo fibers from four bamboo species, and their prospects in textile manufacturing. Fibers Polym 21(12):2740-2752.

Wang B-J, Young W-B (2022) The natural fiber reinforced thermoplastic composite made of woven bamboo fiber and polypropylene. Fibers Polym 23(1):155-163.

Xiong X, Ma Q, Yuan Y, Wu Z, Zhang M (2020) Current situation and key manufacturing considerations of green furniture in China: A review. J Clean Prod 267: 121957.

Xu W, Wu Z, Zhang J (2015) Compressive creep and recovery behaviors of seat cushions in upholstered furniture. Wood Fiber Sci 47(4):431-444.

Yeh C-H, Yang T-C (2020) Utilization of waste bamboo fibers in thermoplastic composites: Influence of the chemical composition and thermal decomposition behavior. Polymers 12(3):636.

Yu Y, Zheng J, Pu H, Zhu C, Wu Q (2023) Preparation and evaluation of an elastic cushion with waste bamboo fiber based on sitting pressure distribution of the human body. Sustainability 15(9):7462.