WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.1.170177
e-ISSN 2729-8906
67(1): 2022 170-177 pp.

Short notes

THE LOW-VELOCITY IMPACT RESPONSE OF BIO-COMPOSITES

MAHARSHI J. DAVE, TEJAS S. PANDYA, SUMAN BABU UKYAM
UNIVERSITY OF MISSISSIPPI
USA

JASON STREET
MISSISSIPPI STATE UNIVESITY
USA

(RECEIVED SEPTEMBER 2021)

ABSTRACT

In this paper, an experimental investigation on the low-velocity impact response of wood-based bio-composites is presented. This study is to map the suitability of plant-based materials instead of petroleum-based plastic as a constituent raw material in composites. Wood-based composites panels were made from southern yellow pine (SYP), corn starch (CS), and methylene diphenyl diisocyanate (MDI) using a Diefenbacher hot press. The impact performance of the specimens was evaluated in terms of energy absorption capacity. Five types of bio-composites were prepared with varying compositions with SYP: 4% MDI; 2% CS and 2% MDI; 2% CS and 4% MDI; 4% CS and 4% MDI. These samples were prepared at two different manufacturing pressures. The bio-composite produced with higher manufacturing pressure had the highest absorbed energy among five different types of bio-composites, this shows that material behavior at impact loading is strongly dependent on the manufacturing pressure during fabrication.

KEYWORDS: Corn starch, impact loading, southern yellow pine, wood-based bio-composites.

INTRODUCTION

Bio-composites are composites made from natural and biocompatible material. The increase in awareness of the damage caused by synthetic petroleum-based materials on the environment has led to the development of eco-friendly materials. Interest in natural composites is growing for many reasons including their potential to replace synthetic petroleum-based composites at lower cost with improved sustainability.

Wood-based composites have been frequently used for automobiles (Koronis et al. 2013), vibration damping and noise reduction applications (Mohanty and Fatima 2015), and the packaging of nuclear waste (Bragov and Lomunov 1997). Bio-composites have a wide range of structural and nonstructural applications (Riedel and Nickel 1999) due to their, high energy absorption capabilities (Dave et al. 2018), renewability, biodegradability, low cost, thermal conductivity, high strength-to-weight ratio, and excellent thermal and sound insulation properties (Dave et al. 2018, 2019, Li et al. 2018, Kang et al. 2012, Pandey at al. 2010). Hence, bio-composites are a valid alternative to replace man-made petroleum-based composites.

When bio-composites are used for mechanical applications, they may be exposed to various impacts during their service life. It is generally accepted that low-velocity impacts occur at velocities below 10 $m \cdot s^{-1}$ (Richardson et al. 1996), and can reduce the strength of the whole structure under quasi-static and dynamic loads due to the localized internal damage inside the composite structure (Sutherland 2018). Therefore, it is extremely important to study the low-velocity impact behavior of materials to select a potential bio-composite for a particular application.

Experimental results have indicated that the damage tolerance of a structure can be improved by using bio-composites, including wood-based materials (Ramakrishnan et al. 2017, Mahesh et al. 2019, Abdalslam 2013, Demircioğlu et al. 2018). Despite extensive investigations of the impact behavior and damage tolerance using wood based-materials, no studies have focused on bio-composites reinforced with corn starch (CS) under low velocity impact testing.

Motivated by the current trends towards natural-based composites, the Mechanical Engineering department at the University of Mississippi and the Department of Sustainable Bioproducts at Mississippi State University focused on the development of new wood-based bio-composite made from agricultural and plant-based material. By employing cornstarch (CS) with southern yellow pine (SYP), this study aimed to improve the low velocity impact response of this type of bio-composite. These materials were impacted at energy level of 85 kJ using a drop weight test, and comparisons were made concerning the force and energy displacement response, and the condition of the damaged specimens. The outcome of this research may provide some useful information on how effectively plant-based materials can be used as a substitute material for plastic designed for structural and non-structural applications.

MATERIAL AND METHODS

Bio-composite samples created for the analysis of the high strain rate test were made from southern yellow pine (SYP), corn starch (CS) and methylene diphenyl diisocyanate (MDI) resin with different mass fractions (Tab. 1). MDI is an aromatic diisocyanate and is an efficient binder that has been used in the production of composite wood products for over 30 years. Corn starch (CS) is the starch derived from the corn (maize) grain or wheat. SYP was first run through chipper and then through a hammer mill to produce particles up to required size of 2 mm to 3 mm. SYP particles were mixed with corn starch and MDI in exact mass fraction ratios to form the composite mass for creating panels. The amount of mass used to create the bio-composite panels was approximately 2.95 kg except for the Material 2 panel manufactured at a mat pressure of 10.5 MPa (with ram pressure of 27.58 MPa) where twice the amount of mass (5.9 kg) was used. The temperature used to form the panels was approximately 185°C. A Diefenbacher 915 × 915 mm hot press system located at the Sustainable Bioproducts Laboratory at Mississippi State University was used to create the bio-composite panels used in this study. This hot press with steam injection capability was coupled with the Alberta Research Council's Pressman operations and monitoring software. The Diefenbacher hot press was used to create all composite panels of equal thickness (6.35 mm) by compressing different materials at varying pressures as shown in Tab. 1. The various pressures required to form the panel to the appropriate thickness were based on the ability of the composite material in the mat to be compressed to the appropriate thickness.

Tab. 1: Types of bio-composites.

Designation of bio-composites	**Mass fraction (%) of raw material constituents**			**Approx. pressure (MPa)**	**Curing time (s)**	**Density kg·m^{-3}**
	SYP	**CS**	**MDI**			
Material 1	96	-	4	8.9	140	826
Material 2	96	-	4	10.5	140	1389
Material 3	96	2	2	8.7	140	855
Material 4	92	2	4	8.7	140	850
Material 5	92	4	4	8.4	140	946

Experimental technique

The low-velocity impact response of the bio-composites was studied using DYNATUP 8250 drop weight system (Fig. 1) according to the ASTM D3763 standard at the structure and Dynamics Laboratory at the University of Mississippi.

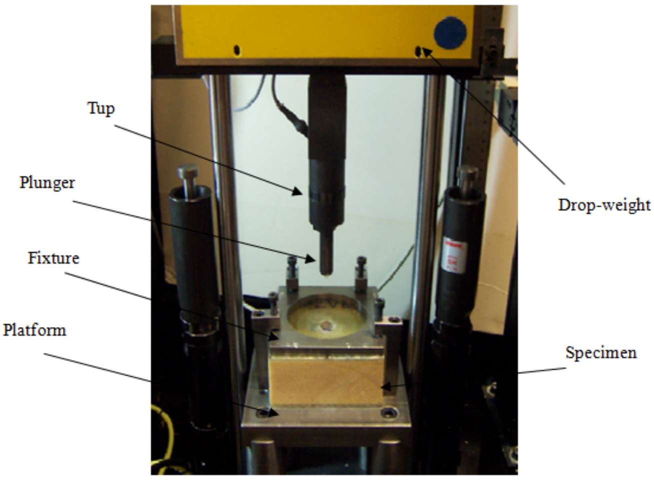

Fig. 1: Experimental setup of low velocity impact (Brahmananda and Mantena 2009).

The impact energy ranged from 84 J to 108 J and velocity ranged from 2.2 m·s^{-1} to 2.5 m·s^{-1}. The impactor assembly consisted of a hemispherical end with a diameter of 12.70 mm and a steel rod measuring 50.8 mm which impacted the center of each specimen. The pneumatically assisted specimen clamp assembly consisted of parallel rigid plates with a 76.2 mm diameter hole in the center of each. The low-velocity impact test using Dynatup 8250 was conducted as follows.

The bio-composite specimen dimensions were 101.6 × 101.6 × 6.35 mm, and the specimen was sandwiched between parallel rigid plates of the clamp. The impact drop height (0.25 m) and weight (23 kg) were determined such that velocity slowdown was less than 20% during the impact event. The applied impact energy was at least three times the energy absorbed by the specimen at peak load (ASTM D3763). The impact response of the specimens including velocity, displacement, load and absorbed energy were recorded and stored by a computer using the Dynatup impulse TM data acquisition system. The configuration provided 85 J of impact energy and 2.23 $m·s^{-1}$ of impact velocity for bio-composite Material 1 and Materials 3-5, and 108 J of impact energy and 2.5 $m·s^{-1}$ of impact velocity for bio-composite Material 2. Five specimens were tested for each bio-composite configuration and average data average values were considered for analysis.

RESULTS AND DISCUSSIONS

A load–displacement curve is the signature of a composite material's response to impact loading (Cesim and Dahsin 2008). Fig. 2 shows the force-displacement curves of five different types of bio-composites impacted in the range of 85 J to 108 J.

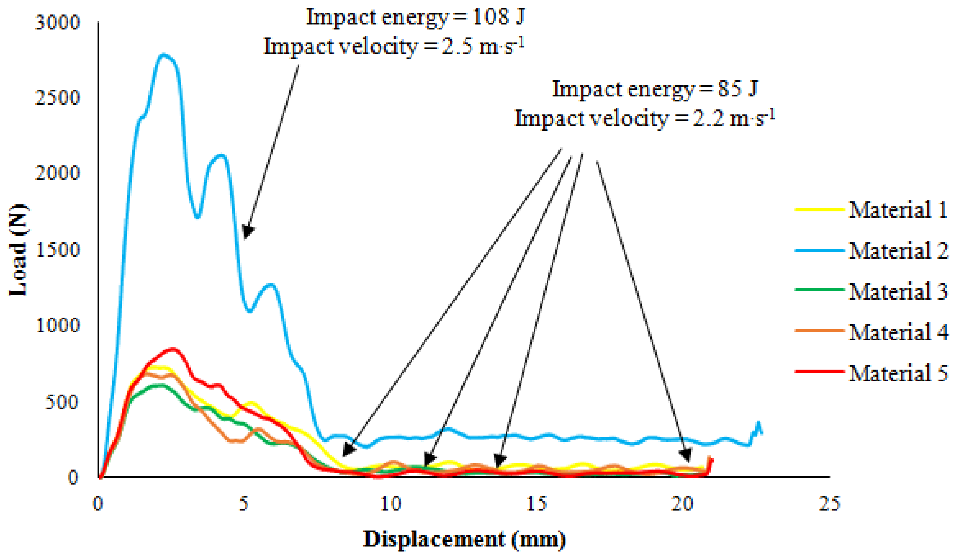

Fig. 2: Load-displacement curves of bio-composites.

A load-displacement curve consists of an ascending section of loading and a descending section combining loading and unloading. The ascending section of load-displacement may also be called the stiffening section as it represents the bending stiffness history of the composite material under impact loading (Cesim and Dahsin 2008). Depending on the level of impact energy, the descending section may have three different possibilities. This descending section may be a pure rebounding curve representing the rebounding of the impactor from the specimen. This descending section could also contain partial softening of the specimen and partial rebounding of the impactor. The descending section may even be a complete softening curve of the specimen. If the descending section is completely a softening curve, the load–displacement curve should be an open curve in that the impactor penetrates into the specimen or even perforates the specimen.

Fig. 2 shows that the bio-composite specimen material 2 had the highest peak load of 2800 N at impact energy of 108 J. This increment in damage resistance could be attributed to higher dynamic strength and density of the material. Moreover, analyzing the samples on the basis of similar manufacturing conditions, similar pressure and curing times, the specimen material 5 had the highest peak load and material 3 had the lowest peak among tested specimens at impact energy of 85 J. This increment in load bearing capacity of bio-composite sample material 5 could be attributed to the higher mass fraction of CS contained in this specimen.

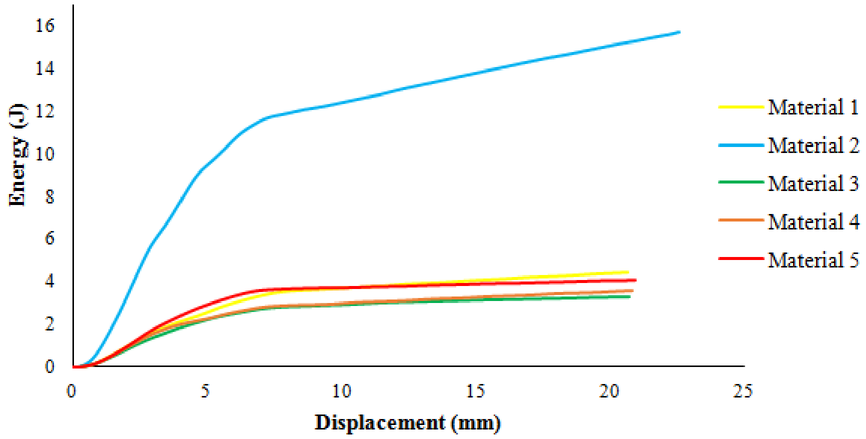

Fig. 3: Energy-displacement curves of bio-composites.

Fig. 3 represents energy-displacement diagrams of different bio-composites impacted in the range of 85 J to 108 J. It is evident that maximum energy is absorbed at peak load for all bio-composite specimens tested. A similar trend was observed during investigations of the low-velocity impact response of composites containing wood-based material (Demircioğlua et al. 2018, Mohammadabadi et al. 2018).

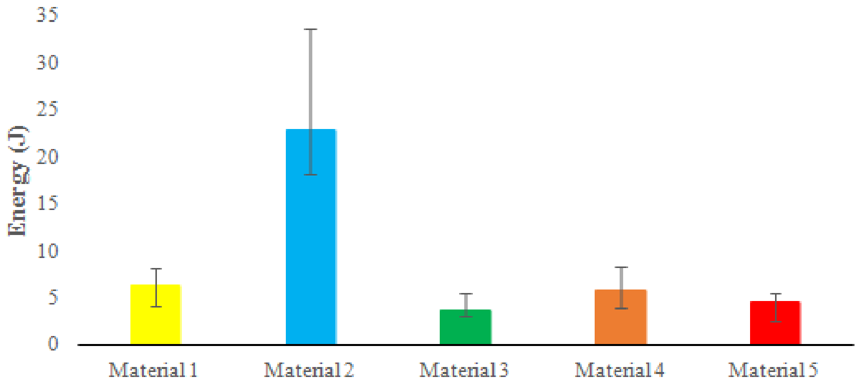

Fig. 4: Total absorbed energy during low velocity impact test of different bio-composites.

Fig. 4 reports the total energy absorption of different bio-composites under low velocity impact testing. The bio-composite specimen material 2 had the highest energy absorption and material 3 had lowest energy absorption among tested specimens. The CS adversely affected the energy absorption capacity of bio-composites among all bio-composites tested.

Fig. 5 shows the damage views of impacted specimens. All bio-composite specimens were penetrated during the impact event. Furthermore, it depicts that the radial growth of damage is least in specimen material 3, whereas more in the material 2.

Material 1 Material 2 Material 3

Material 4 Material 5

Fig. 5: Damage views of the impacted bio-composites.

CONCLUSIONS

Low-velocity impact responses of novel bio-composites were examined using a drop weight impact testing machine. From the impact response data and damage study, the following conclusions can be made. The composite created at the highest pressure (material 2) had the greatest stiffness among all the samples. This shows that improved damage resistance and energy absorption characteristics can be achieved when material is compressed at a higher pressure during the fabrication process. The applications of these bio-composites can be various including packaging and decking material.

REFERENCES

1. Abdalslam, S., 2013: Impact damage analysis of balsa wood sandwich composite materials. PhD diss. Detroit, Michigan: Wayne State University, Mechanical Engineering Department, Pp 74-75.
2. ASTM D3763-18, 2018: Standard test method for high speed puncture properties of plastics using load and displacement sensors.
3. Atas, C., Sevim, C., 2010: On the impact response of sandwich composites with cores of balsa wood and PVC foam. Composite Structures 93(1): 40-48.
4. Bragov, A., Lomunov, A., 1997: Dynamic properties of some wood species. Journal de

Physique IV 07(C3): 487–492.

5. Cesim, A. Dahsin L., 2008: Impact response of woven composites with small weaving angles. International Journal of Impact Engineering 35(2): 80-97.
6. Crupi, V., Epasto, G., Guglielmino, E., 2016: Internal damage investigation of composites subjected to low-velocity impact. Experimental Techniques 40: 555-568.
7. Dave, M.J., Pandya, T.S., Stoddard, D., Street, J., 2018: Dynamic characterization of biocomposites under high strain rate compression loading with split Hopkinson pressure bar and digital image correlation technique. International Wood Products Journal 9(3): 115-121.
8. Dave, M.J., Pandya, T.S., Stoddard, D., Street, J., Blake, C., Ly, P., 2018: Dynamic and damping properties of novel bio-composites using the hammer excitation vibration technique Wood Research 63(2): 215-226.
9. Demircioğlua, T.K., Balıkoğlua, F., İnala, O., Arslanb, N., Aya, İ., Ataş A., 2018: Experimental investigation on low-velocity impact response of wood skinned sandwich composites with different core configurations. Materials Today Communications 17: 31-39.
10. Kang, C., Oh, S., Lee, T., Kang, W., Matsumura, J., 2012: Sound absorption capability and mechanical properties of a composite rice hull and sawdust board. Journal of Wood Science 58: 273-278.
11. Koronis, G., Silva, A., Fontul, M., 2013: Green composites: A review of adequate materials for automotive applications. Composites Part B: Engineering 44(1): 120–127.
12. Li, T., Song, J., Xinpeng Zhao, X., Yang, Z., Pastel, G., Xu, S., Jia, C., Dai, J., Chen, C., Gong, A., Jiang, F., Yao, Y., Fan, T., Yang, B., Wågberg, L., Yang, R., Hu, L., 2018: Anisotropic, lightweight, strong, and super thermally insulating nanowood with naturally aligned nanocellulose. Science Advances 4(3).
13. Mahesh, V., Joladarashi, S., Satyabodh M., Kulkarni, S.M., 2019: An experimental investigation on low-velocity impact response of novel jute/rubber flexible bio-composite. Composite Structures 225: 111190.
14. Mohammadabadi, M., Yadama V, Yao, L., Bhattacharyya, D., 2018: Low-velocity impact response of wood-strand sandwich panels and their components. Holzforschung 72(8): 681 -689.
15. Mohanty, A., Fatima, S., 2015: Noise control using green materials. Sound and Vibration 49(2): 13-15.
16. Pramanik, B., Mantena, P.R., 2009: Punch-shear characteristics of nanoclay and graphite platelet reinforced vinyl ester plates, laminated face sheets and sandwich composites under low velocity impact. ASME Early Career Technical Journal 1.1-1.9.
17. Pandey, J.K., Ahn, S.H., Lee, C.S., Mohanty, A.K., Misra, M., 2010: Recent advances in the application of natural fiber-based composites. Macromolecular Materials and Engineering 295: 975–989.
18. Pandya, T.S., Dave, M.J., Street, J. Blake, C., Mitchell, B., 2019: High strain rate response of bio-composites using Split Hopkinson pressure bar and digital image correlation technique. International Wood Products Journal 9(3): 115-121.
19. Ramakrishnan, K.R., Corn, S., Moigne, N.L., Slangen, P., 2017: Low velocity impact damage assessment in natural Fibre biocomposites. ICCM21 - 21st International Conference

on Composite Materials, Xi'an, China.

20. Richardson, M.O.W., Wisheart, M.J., 1996: Review of low-velocity impact properties of composite materials. Composites Part A: Applied Science and Manufacturing 27(12): 1123-1131.
21. Riedel, U., Nickel, J., 1999: Natural fibre-reinforced biopolymers as construction materials. Die Angewandte Makromolekulare Chemie 272: 34-40.
22. Sutherland, L., 2018: A review of impact testing on marine composite materials. Part III-damage tolerance and durability. Composite Structures 188: 512-518.

MAHARSHI J. DAVE*, TEJAS S. PANDYA, SUMAN BABU UKYAM
MECHANICAL ENGINEERING DEPARTMENT
THE UNIVERSITY OF MISSISSIPPI
OXFORD, MS 38677
USA
*Corresponding author: mjdave@go.olemiss.edu

JASON STREET
DEPARTMENT OF SUSTAINABLE BIOPRODUCTS
MISSISSIPPI STATE UNIVERSITY
MISSISSIPPI STATE, MS 39762-9820
USA