MECHANICAL PROPERTIES OF JUTE/PLA SANDWICH COMPOSITES WITH CORRUGATED BOARD AS A CORE LAYER

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Abstract

The mechanical characteristics of jute/PLA sandwich composites with corrugated board as a core layer are discussed in the current study. The core layer composites were made with corrugated board and polylactic acid. The core layer composites were then stacked with jute fabrics and PLA films on the top and bottom surfaces to fabricate sandwich composites.

Two composites (corrugated board reinforced PLA composites and jute fabric/PLA sandwich composites with the corrugated board as a core layer) were developed in the current study. For the manufacturing of corrugated board reinforced PLA composite core layer, a dipping bath was used to impregnate the corrugated boards with melting PLA solution. For sandwich composites, resin film method and hot press with mold were used to produce the jute fabric/PLA sandwich composites with the corrugated board as a core layer. A material test system (MTS810) was used to study the tensile, compressive, bending properties of the composites. Furthermore, an IZOD impacting instrument was used to examine the impacting characteristics of the composites.

1. Introduction

Sandwich composites are widely used due to their high specific stiffness and strength, noise reduction, thermal insulation, lightweight, and impact energy absorption characteristics. In general, high stiffness, high strength, and thin composites are used for face skin to resist the in-plane and lateral loads, while light but low-strength materials such as foam materials, honeycomb, and balsa wood are used for cores [1]. Thus, sandwich structures are used in many industrial fields required the lightweight character such as aerospace, automobiles, machine tools, sport goods and robot structures [2–4]. Corrugated boards, which commonly used in box and packaging materials, are also lightweight materials. The board can be considered as a sandwich structure. The usage amount of corrugated boards has been increasing since last century in the world. Nowadays, the amount is over one hundred million tons ever year. The huge usage of corrugated board impacts our living environment. How to treat the corrugated board after used and how to extend the life of corrugated board is a challenge. So, we try to solve these problems and extend the application of corrugated board after used. In this study, sandwich panels consisting of jute fabric/PLA face sheets and recycled corrugated board core layer were developed. The tension, compression, bending, and impacting forces were yielded to evaluate the mechanical characteristic of the sandwich composites.

2. Experimental

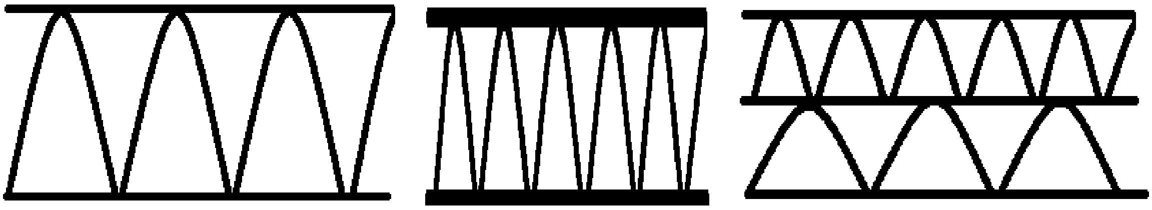


Figure 1. Configuration of various types of corrugated boards: (a) U-type (b) V-type and (c) UV-type.

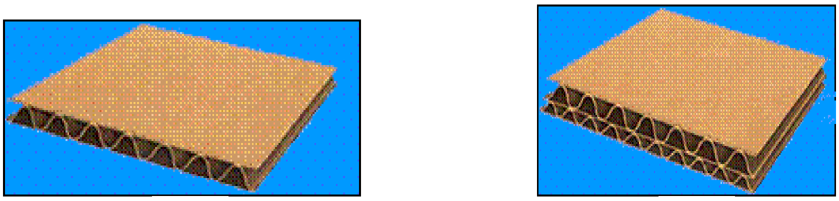


Figure 2. Photos of U-type and UV-type of corrugated boards.

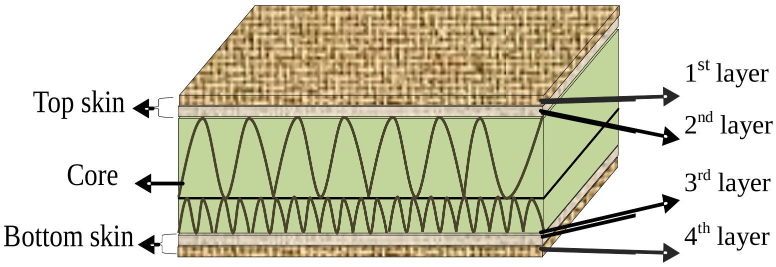


Figure 3. Schematic of sandwich .composite with a core layer of corrugated board and skins of jute/PLA.

Corrugated boards have light weight and good flatwise compression strength due to their corrugated structure. Figure 1 demonstrates the U-type, V-type, and UV-type of common corrugated configuration and Figure 2 shows the U-type, and UV-type corrugated boards. Two sandwich composites were made in the current study. One is corrugated board impregnated with melting PLA solution which named PA sandwich composites. The other is jute fabric and corrugated board reinforced PLA which named JPA sandwich composites. The JPA sandwich composites have top and bottom skin which made by jute fabric reinforced PLA composite. The core layer of JPA sandwich composite is corrugated board reinforced PLA composite that is PA sandwich composite. The configuration of JPA sandwich composites is illustrated in Figure 3. The recycled corrugated boards with UV-type were used to make PA and JPA sandwich composites. The PLA (NCP0004, Wei Mon Industrial Co., Taiwan) chips were used as matrix materials.

The laminating sequence of PA sandwich composites is shown in Figure 4 (a). Forty grams of PLA chips were hot pressed to film under 190℃ for 3 min. Prior to the manufacturing of PA sandwich composites, the PLA films and corrugated boards should be released moisture in an oven under 80℃ for 4 hours. After the moisture release process, one corrugated board and two PLA films which stacked as Figure 4(a) were set on a hot press machine with a mold at 190℃ for one min. The mold is special design which has top and bottom steel panels with 297mm in length, 210 mm in width, and 10 mm in thickness, and two L-type steel panels. All the steel panels were treated with Teflon coating to easy remolding. The L-type steel panels are inserted between the top and bottom steel panels. The L-type panels are used to control the thickness of sandwich composites and to avoid the crush failure of core layer of sandwich composites which made by a hot-press machine. The product

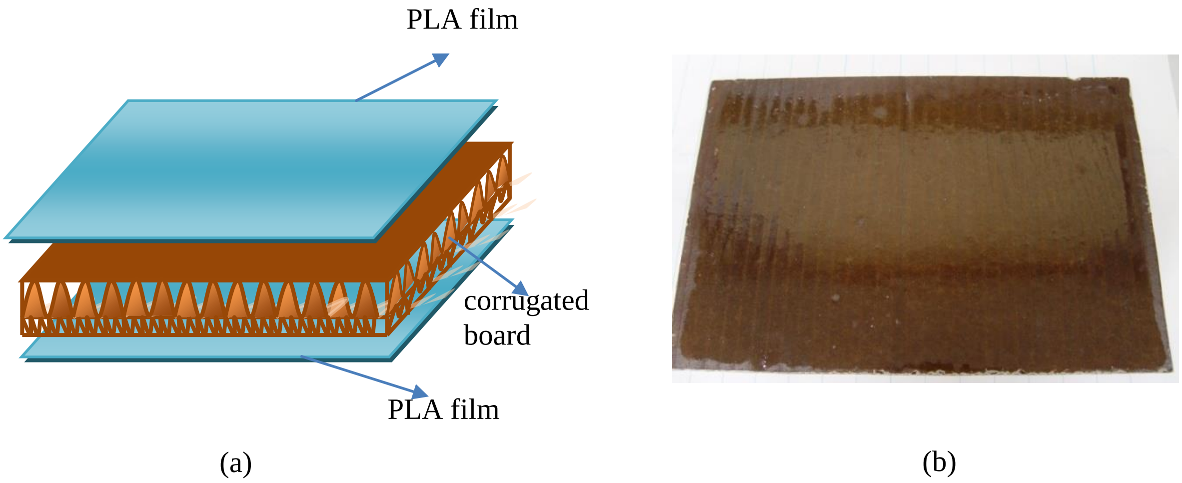


Figure 4. Configuration scheme of PA structure (a) and composite (b).

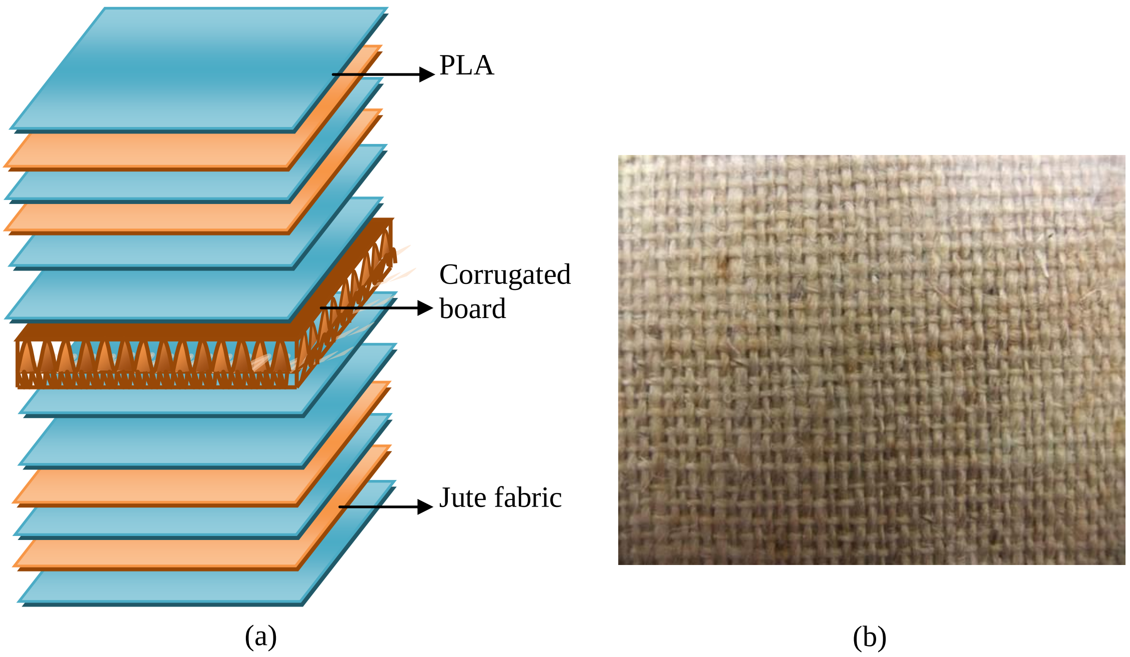


Figure 5. Configuration scheme of JPA structure (a) and composite (b).

of PA sandwich composite is shown in Figure 4(b). For the manufacturing of JPA sandwich composites, the laminating sequence of jute fabrics, PLA films, and corrugated board is demonstrated in Figure 5(a). As shown in Figure 5(a) one corrugated board, four jute fabrics, and eight PLA films were used to make JPA sandwich composite. The jute fabric is plain construction. The JPA sandwich composites were, also, made on a hot-press machine under 190℃ for 5 min. The mentioned mold was, also, used to make the JPA sandwich composites. However, the thickness of L-type panels is thicker than that of used to make PA sandwich composites. The JPA sandwich composites are shown in Figure 5(b). Table one list the constituent, fiber weight contents, and PLA weight contents of sandwich composite specimens. The number in the specimen's name indicates the total fiber weight content of sandwich composites. For example, 32PA is corrugated board/PLA sandwich composite with 32% of fiber weight content, and 40JPL is jute fabric/corrugated board/PLA sandwich composite with 40% of fiber weight content.

Materials / Specimen	Fiber Weight Contents (%)			PLA Weight Content (%)	Composite Weight (g/m^2)
	Jute	Corrugated paper	Total		
P	0	100	100	0	866
J	100	0	0	0	344
32PA	0	32	32	68	3133
55PA	0	55	55	45	1566
65PA	0	65	65	35	1333
26JPA	16	10	26	74	8333
33JPA	20	13	33	67	6666
40JPA	24	16	40	60	5366

P: corrugated board
J: jute plain fabric
PA: corrugated board/PLA composite
JPA: corrugated board/jute plain fabric/PLA composite.

Table 1. The nomenclature and fiber weight content of the specimens

The tensile, compressive, and bending properties followed by ASTM standards D3039, D3410, and D790-03 are evaluated on a materials testing system (MTS 810). The impact energy is carried on an IZOD machine. The loading directions and the string's orientations of corrugated medium are illustrated in Figure 6 where (a) the strings of corrugated board are perpendicular to the direction of tension force marked as "T", (b) the strings of corrugated board are parallel to the direction of tension force marked as "L", (c) flatwise compression, (d) longitudinal compression, (e) the strings of corrugated board are perpendicular to the span of bending, (f) the strings of corrugated board are parallel to the span of bending, (g) the strings of corrugated board are parallel to the direction of impact force, (h) the strings of corrugated board are perpendicular to the direction of tension force, (i) the side view of (g) specimen, and (j) the side view of (h) specimen.

3. Result and Discussion

3.1 Tension and Compression

The tension results are listed in Table 2. The corrugated board has good peak stress, modulus, and energy to break while tension direction is parallels to the orientation of string (L tension). Adding PLA into corrugated board can enhance the tensile modulus and peak stress about 200~400%. However, the adding PLA into corrugated board decreased the break strain. For JPA sandwich composites in tension, the sample in L-tension is better than in T-tension. The tensile strength of JPA sandwich composites is 4 ~ 8 times of PA sandwich composites. It appeared that the jute fabric can enhance the PA sandwich composite. The 26JPA sandwich composites are good in tension under the synergy assessment of composite's weight, strength, and break energy. For flatwise compression results, JPA sandwich composites are much better than PA sandwich composites and pure corrugated board both in peak stress (Figure 7 (a)) and modulus (Figure 7(b)). For PA sandwich composites, adding PLA into corrugated board seems not to increase the flatwise compressive modulus and strength while fiber weight content higher than 32%.

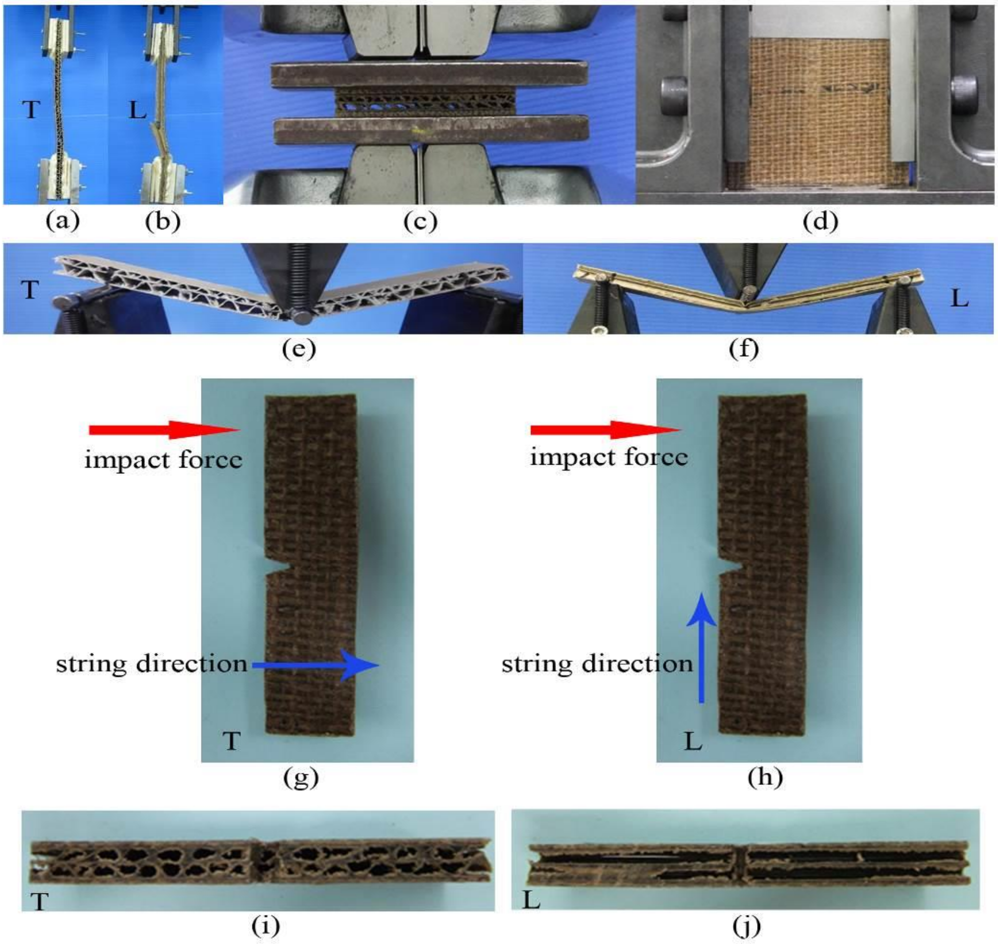


Figure 6. Loading and string direction for the composites under various tests.

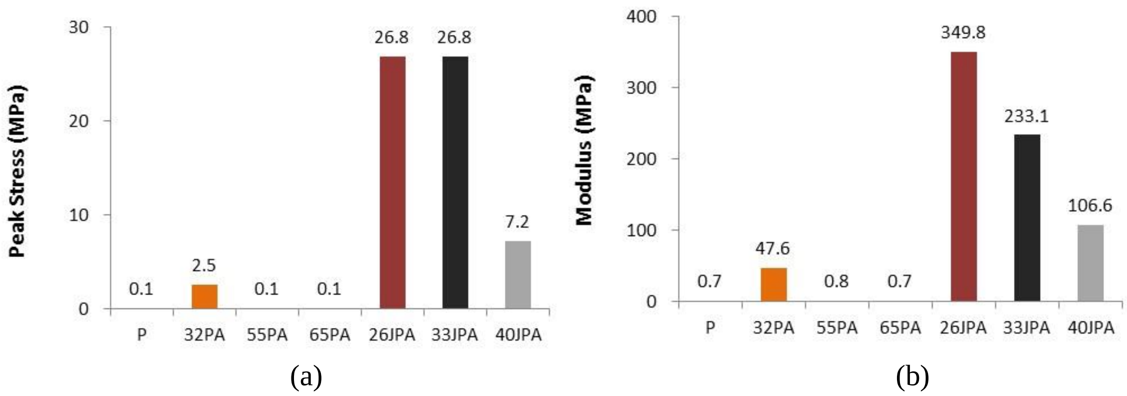
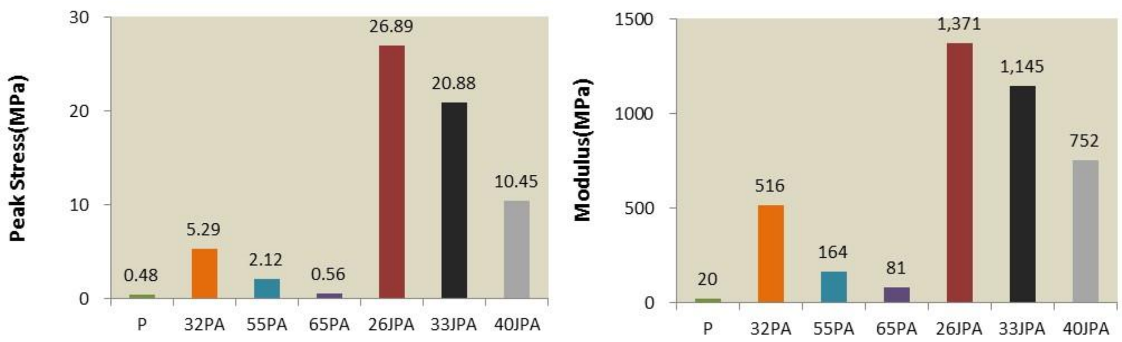


Figure 7. Peak stress (a) and Modulus (b) of PA and JPA composites under flatwise compression.

On the other hand, both PA and JPA sandwich composites have higher longitudinal compressive strength and modulus than that of raw corrugated board. As shown in Figure 8, more fiber weight content decreases the longitudinal compressive properties for PA and JPA sandwich composites. The longitudinal compressive strengths of 26JPA and 32PA are 5600% and 1100% higher than that of corrugated board, respectively. The longitudinal compressive modulus of the JPA and PA sandwich composites are about 12 and 54 times in average of corrugated board, respectively. The string's orientation of corrugated board is parallels to the longitudinal compressive direction, and then the string enhanced the resistance ability to against the longitudinal compressive force. So, proper design for the string's orientation of corrugated board can improve longitudinal compression properties.

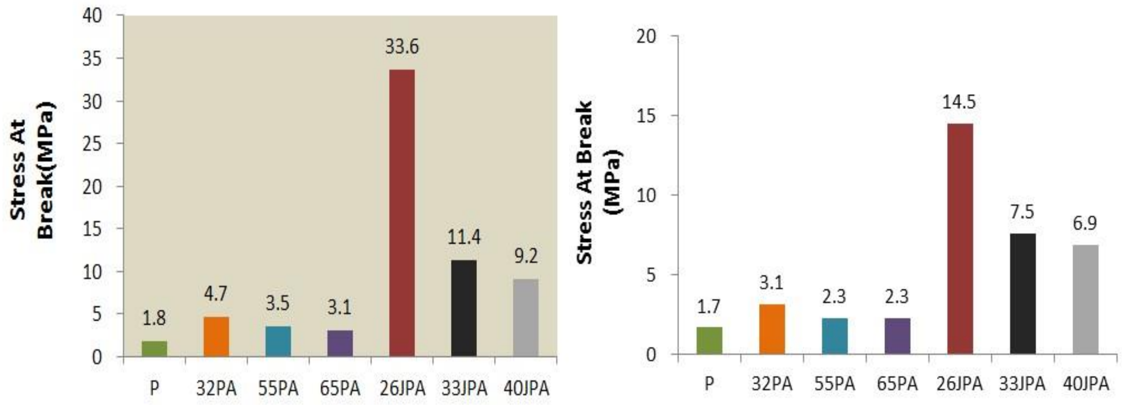


(b) (b)

Figure 8. Peak stress (a) and Modulus (b) of PA and JPA composites under longitudinal compression.

3.2 Bending and Impacting

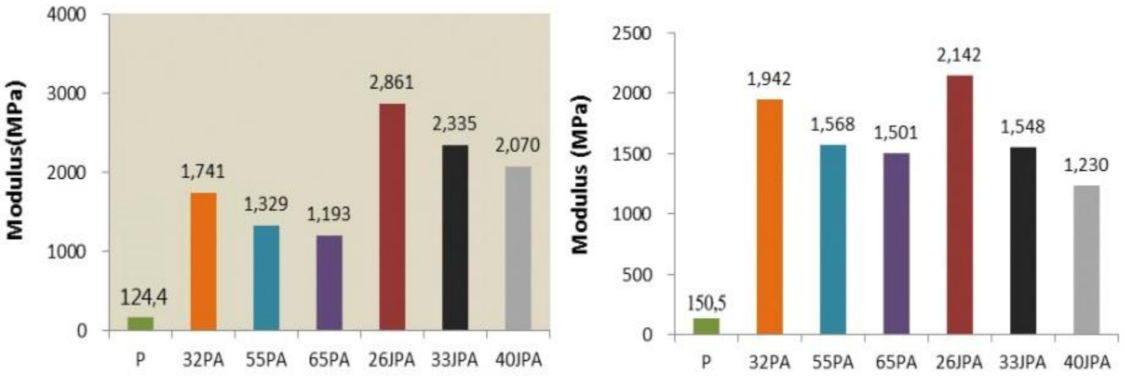
Bending strengths of sandwich composites are shown in Figure 9. Figure 9 (a) is the stresses at break of specimens under 3-point bending while the strings of corrugated board are parallel to the span of bending (L-bending). Figure 9 (b) is different bending position; the strings of corrugated board are perpendicular to the span of bending (T-bending).



(a) (b)

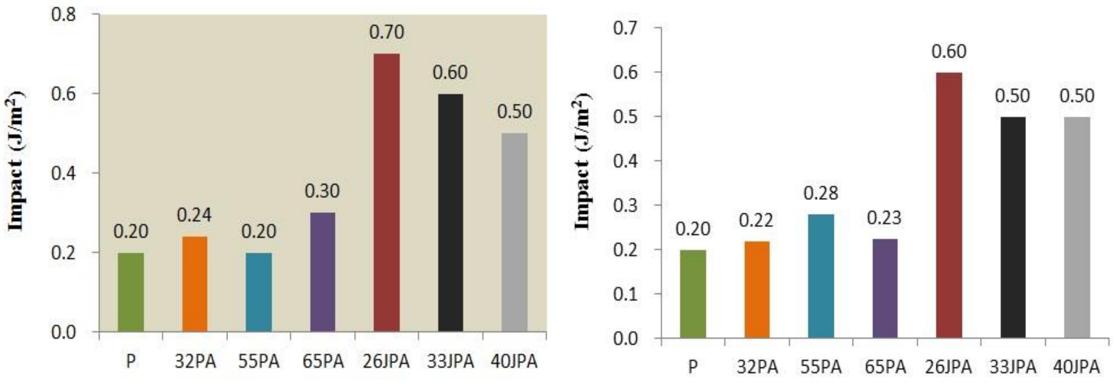
Figure 9. Bending peak stress of PA and JPA composites. (a) L-bending: the strings of corrugated board are parallel to the span of bending and (b) T-bending: the strings of corrugated board are perpendicular to the span of bending

The PA specimens are better than P specimen (raw corrugated board). The JPA specimens are stronger than PA specimen and raw corrugated board both in L-bending and T-bending conditions. In addition, all the specimens in L-bending condition are better than those in T-bending condition. This means that the strings of corrugated board parallel to bending span provided resistant to bending force. The 26JPA specimen appeared good strength both in L-bending and T-bending conditions. The bending modulus in L-bending and T-bending condition can be found in Figure 10 (a) and Figure 10 (b), respectively. It also can be found that jute fabric enhanced the bending properties even though in various fiber contents. Finally, Figure 11 indicates that PA specimens have less improved efficiency in IZOD impacting energy. Furthermore, the JPA specimens have much enhanced efficiency in the same impacting.



(a) (b)

Figure 10. Bending Modulus of PA and JPA composites. (a) L-bending: and (b) T-bending: specimen.



(a) (b)

Figure 11. Impact energy of PA and JPA composites. (a): L-impacting, and (b): T-impacting.

Properties / Specimen	Modulus (MPa)		Strain at break (%)		Energy to break N*mm		Peak stress (MPa)	
Tensile direction	T	L	T	L	T	L	T	L
P	53.71	74.27	2.68	3.87	653.74	743.86	1.41	1.52
32PA	204.21	194.41	2.66	1.94	903.74	949.40	2.78	3.98
55PA	121.05	123.78	2.38	1.72	887.19	808.64	2.34	2.06
65PA	110.72	114.50	1.69	1.54	843.86	619.86	2.13	1.82
26JPA	208.23	219.2	13.42	15.57	9369.41	14339.02	17.80	23.70
33JPA	237.74	228.18	11.44	13.59	8360.69	9591.08	14.06	18.54
40JPA	257.23	311.6	10.06	12.35	6236.05	7579.89	9.91	12.31

Table 2. Tensile properties of corrugated board/PLA composites.

4. Conclusions

Experimental results revealed that both the corrugated board reinforced PLA composites (PA sandwich composites), and jute fabric/corrugated board/PLA sandwich composites (JPA) have well reinforced efficient. The tensile and compressive modulus of the corrugated board reinforced PLA composites were 200% and 1200% higher than that of the pure corrugated board, respectively. For the core layer composites, the proper fiber content of the corrugated board was 32%. The tensile and compressive moduli of jute fabric/corrugated board/PLA sandwich composites were 150% and 430% higher than that of the corrugated board reinforced PLA composites, respectively. The proper content of fiber and board for the JPA sandwich composite was 26%. Both the corrugated board reinforced PLA sandwich composites and the jute fabric/corrugated board/PLA sandwich composites increase the energy absorption capacity while impacting test.

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