



COLLAPSE MODES AND CRUSHING CHARACTERISTICS OF POLYMER COMPOSITE SANDWICH PANELS-A REVIEW

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ABSTRACT

Shrubs are an ideal choice to exploit the natural fibers to be used as reinforcement for polymer based composites. The use of polymer based natural fiber composites are gaining popularity in automotive and aerospace industries over the last few decades due to its weight to strength ratio. This paper reviews the open literatures and journals which have researched the physical, mechanical properties of composites, collapse modes and crushing characteristics of composites. The literatures have shown the different methods and techniques that have been undertaken to experimentally examine the collapse modes and crushing characteristics of composites. The flexural properties, collapse modes and crushing characteristic of various types of composite sandwich panels were investigated in a series of three point bending tests that were performed in accordance with ASTM standard D790. The flexural behavior of new generation composite sandwich panels was subjected to 4-point bending to determine strength and failure mechanisms in flatwise and edgewise. Most studies have shown the superior potential of using ductile material in place of brittle core material for those critical-applications that undergo flexural loading; and also core structures like honeycomb, foldcore structures have shown an increase in the flexural stiffness of sandwich composite panels.

Keywords: Collapse Modes, Crushing, Impact Load, Fold Core, Honeycomb.

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1. INTRODUCTION

Fiber-reinforced composite materials have been significantly explored in different industrial applications like automotive and aerospace over the last decade. Since composites possess high specific mechanical properties compared to metallic alloys, these contemporary composite materials are being used as an alternative choice to metallic alloys. Researchers and industries are shifting their attention on composite materials because of the benefits offered and the combined properties obtained by the composites are better than the discrete material properties. Composite materials are three types based on the matrix materials used 1) metal matrix 2) polymer matrix 3) ceramics, the polymer based composites have gained more attention owing to weight to strength ratio. One of the most widespread reinforcement used is glass fibers and carbon fibers seeing as they are acquire better mechanical properties as comparable. Regardless of the virtuous mechanical properties, glass fiber also includes a negative impact on environment as they can raise a health issues and these are very expensive. Natural fiber are low density and high specific strength and stiffness of natural fibers are good enough for various applications .The natural fiber are capable of absorbing CO₂ which is helpful for human beings due to release of oxygen. The production cost of natural fiber is minimum compared to synthetic fiber and the processing technique for natural fiber is less hazardous.

Natural fiber are gaining attention in the composites although they have some disadvantages such as , low durability compared to synthetic fiber, high moisture absorption (which result swelling) etc. The best characteristic of natural fiber over synthetic is less weight to better strength .This property helps to use natural fiber composites in both automotive and aerospace application which influence in fuel efficiency. The ability of natural fiber–reinforced composites to be reprocessed without any prominent deterioration in the mechanical properties/strength but due to moisture absorption the adhesion between matrix and fiber may not good enough to exhibit mechanical properties, it is necessary to modify the fiber prior to the manufacturing of composites and this process of modification is called fiber treatment. There are several treatment are available to improve the adhesion property which is directly proportional to mechanical strength. Chemical treatment and applying of coupling agent are the best technique. Recently there has been growing interest in the case of hybrid chemical treatment technique which can improve the strength of material. There is hybrid composite concept, which is formed by combining two or more types of reinforcements with in single matrix [10].

This can be classified into three types:

- Synthetic /synthetic
- Natural /synthetic
- Natural /natural

Intensive research works has been done in various literatures regarding the characteristics of natural fibers and its polymer based composites. It is vital to study the modes of collapse by the NFC's for different loading condition, combination of tensile, compressive, shear, Impact and flexural loading as well, this loads are the parts of automotive and aerospace application.

2. COLLAPSE MODES

Natural fiber polymer composites are used in automobile industries for various parts like front and rear bumpers and also for leaf springs, which intern subjected to impact and flexural loading. Due to flexural loading and impact load these parts may leads to collapse under

crushing. After extensive literature review the following modes of collapse are observed in the series of flexural tests of the composite sandwich panels [1-5].

- Mode-I: unstable sandwich collapse with shearing of core.
- Mode-II: stable progressive collapse with local indentation and fracture of face plates.
- Mode-III: face micro buckling.
- Mode-IV: face wrinkling.

These are the frequently occurring collapse modes of sandwich panels in three point and four point bending test, Whereas the last two modes were not observed in the series of flexural tests described here, as the conditions of occurrence of these last two modes were not fulfilled by the mechanical properties of the sandwich specimen constructed materials and the sandwich panels geometry feature [1]. But the frequency of occurrence of first two modes is 50% where Mode-1 is in case of PMI and PUR core conversely Mode-2 is in case of PVC for both the face plates [1].

Collapse mode-1

Core shear failure collapse mode occurs only in the case of sandwich panel's structures which is using a brittle type of rigid core foam like PMI and PUR. As these two foam materials are considered as major group of plastics which can undergo permanent deformation [1]

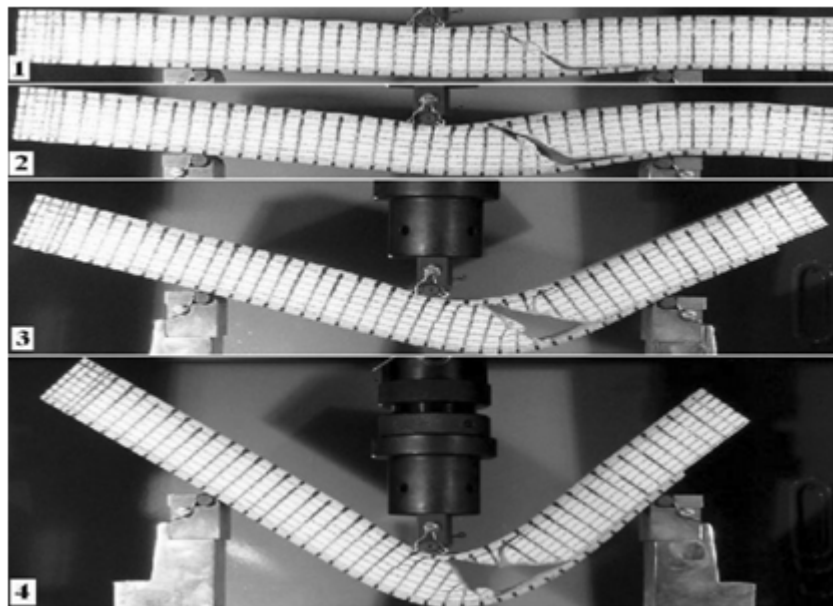


Fig.-1 Collapse mode I: core shear failure/testing of sandwich specimen FT-MSS7 specimen [1]

The following were the most important characteristics of the 1st mode of collapse.

- Non uniform and unsymmetrical bending of the sandwich panel.
- Extensive de-bonding between face plate and core structure.
- Extensive brittleness in the core material.
- Permanent deformation in the FRP faces plates.
- Very low absorption of deformation and crash energy.

Collapse mode-2

This stable mode of collapse will occur in the case of sandwich panels using PVC as a core materials, which are considered as elastic in accordance with the classification made by **Gibson and Ashby [3]**.

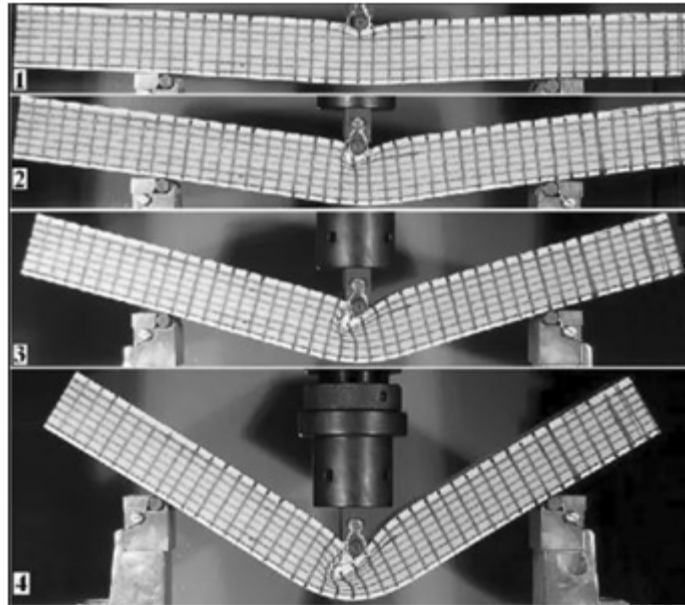


Fig.-2 Collapse mode II: Local Indentation/Testing of sandwich specimen FT-MSS2 specimen [1]

The following were the most important characteristics of the collapse modes.

- Uniform and symmetrical bending of the sandwich panel.
- Bending without de-bonding between face plate and core structure.
- Stable local indentation and flexural damage of FRP
- Elastic and local plastic deformation of core
- Extensive brittleness in the core material.
- Significant absorption of deformation and crash energy.

3. FACTORS EFFECTING ENERGY ABSORPTION CAPABILITY DURING COLLAPSE MODES

Matrix

The important part of any fiber based composites is matrix which provides a barrier against unpleasant environment protects the fiber surface from mechanical abrasion and damage and also Matrix transfer the load to fiber which is reinforced. Both thermoplastic and thermosets polymers are used for matrix with natural fiber to produce natural fiber composite. Matrix selection is based on temperature of working at it can lead to fiber degrade, most of the natural fiber used in polymer matrix are unstable at temperature above 200⁰C although it is possible to process under high temperature with certain circumstances for short period of time, due to this reason the thermoplastics like polystyrene, polypropylene, polyolefine, polyvinylchloride and polystyrene and some thermosets like polyester, epoxy Resin, phenol formaldehyde and VE resins [11] etc. are used. Thermoplastic have capability of both solidifying and liquidifying during cooling and heating respectively and the major advantages of thermoplastics is potential to recycle. After reviewing various literatures it is understand

that there are different types of matrix materials used in polymer based composites which is tabulated below.

Table-1 different types of matrix materials used in polymer composites

Thermoplastics	Thermosets
Nylon	Phenolic
Cellulose acetate	Epoxy
Polystyrene (PS)	Polyester
Polypropylene (PP)	Polymide
Polyethylene (PE)	Polyurethane
Polycarbonate (PC)	
Polyvinyl chloride (PVC)	
Polyether-ether ketone (PEEK)	
Acrylonitrile-butadiene-styrene (ABS)	

Thermoplastic matrix materials

Among various thermoplastic polymers, polypropylene is perhaps one of the most widely used because of its moderate to good mechanical properties. Hence, it is an obvious choice as the matrix material in the preparation of natural fiber-reinforced composites. These materials possess moderate dimensional stability, high temperature of thermal deformation and flame resistance. The recyclability of these materials is an advantage which will reduce disposable waste and therefore economical. The recovered polypropylene showed higher density, lower porosity and water absorption property with a high dimensional stability relative to the composites and native polypropylene, which also showed excellent mechanical properties such as strength and tensile strength [14-17]. These composite materials based on polypropylene showed higher flexural strength when compared with other matrix materials. Mechanical properties such as tensile strength, tensile modulus and impact strength of the unidirectional composites based on polypropylene as matrix material. The advantages of using PE as the thermoplastic matrix was studied by fabricating the PE –maize fiber composites. This material presented the reasonable thermal and mechanical properties [18].

Table 2 material properties of different thermoplastics matrix.

Thermoplastics	Density (g/cm ³)	Tensile modulus (GPa)	Tensile strength (Mpa)	Melting temperature (°C)
Polypropylene (PP)	0.90–0.91	1.1–1.6	20–40	175
Polyethylene (PE)	0.91–0.95	0.3–0.5	25–45	115
Polyvinylchloride(PVC)	1.38	3.0	53	212
Polystyrene (PS)	1.04–1.05	2.5–3.5	35–60	240
High density PP	0.94–0.97	0.5–1.1	30–40	137

Thermosets polymer matrix material

Thermoset polymers are also used as a matrix material for most structural composite materials. The single biggest advantage of thermoset polymers is that they have a very low viscosity and can thus be introduced into fibers at low pressures. Thermosets are processed by simple processing techniques such as hand lay-up and spraying, compression, transfer, resin transfer, injection, compression injection, and pressure bag moulding operations. The use of a few other methods, such as cold press moulding, filament winding, pultrusion, reinforced

reaction injection moulding, and vacuum forming, is hardly reported in the case of composites [19].

Epoxy resins have excellent mechanical and chemical properties and corrosion resistance, good thermal and dimensional stability, and are widely used in lamination, adhesives, coatings, and advanced composite surfaces [20]. Researchers are working in this area to prepare the composite material with unique properties, cost effectiveness and environment friendly nature. For advanced composite materials, an epoxy resin is an obvious choice due to its good stiffness, dimensional stability and the characteristics of chemical resistance [21]. The epoxy composites of natural fibers of different materials are used for newer applications [22].

Table -3: material properties of different thermoplastics matrix.

Thermosets	Density (g/cm ³)	Tensile modulus (GPa)	Tensile strength (Mpa)	Elongation at break (%)	Compression strength (Mpa)
Polyester	1.0–1.5	2.0–4.5	40–90	< 2.6	90–250
Epoxy	1.1–1.6	3.0–6.0	28–100	1–6	100–200
Vinyl ester	1.2–1.4	3.1–3.8	69–86	4–7	86
Phenolic	1.29	2.8–4.8	35–62	1.5–2.0	210–360

Fiber selection

There are different types of fiber available which are classified according to its origin or from where it obtained, due to the environment aspects, natural fibers are the effectively, economically, ecologically suitable. There are several natural fiber's already tested for its tensile strength, young's modulus ,density are as shown in table 4. Geographical availability factor is also consider in the selection of natural fibers. The strength of the fiber is directly proportional to fiber callouses and its microfiber content and also the fiber alignment. The mechanical properties of natural fiber reinforced composites are also influenced by several factors such as adhesion characteristics of fiber, aspect ratio with respect to matrix direction or orientation of fiber in composites etc. Fiber composition in composites is directly proportional to mechanical strength up to the optimum level. The mechanical properties of different reinforcement materials are shown in table-4.

Table-4: mechanical properties of different fibers used for reinforcement materials [10].

Fiber	Tensile strength(MPa)	Tensile modulus (GPa)	Elongation (%)	Density (g/cm ³)
Flax	800-150	60-80	1.2-1.6	1.4
Hemp	55-90	70	1.6	1.48
Kenaf	930	53	1.6	1.4
Jute	410-780	26.5	1.9	1.48
Sisal	610-720	9-24	2-3	1.34
Cotton	287-80	5.5-12.6	3-10	1.5-1.6
Coir	95-230	2.8-6	15-51.4	1.15-1.46
Bamboo	140-800	11-32	2.5-3.7	0.6-1.1
Ramie	40-1000	24.5-128	1.2-4	1-1.155
Banana	500	12	1.5-9	1.35
E-glass	2000-3500	70	2.5	2.5
Carbon	4000	230-240	1.4-1.8	1.4
Aramid	3000-3150	63-67	3.3-3.7	1.4

Lignin content in the fiber (natural) is the main reason for moisture absorption which results in the reduced adhesion. This can be overcome by treating the fiber with different chemical treatments and also by adding coupling agent. The properties of fiber based composites from different literatures are very much necessary to consider the factor like temperature during testing, moisture content in composites during test and speed of impact and user skill, because the moisture content in composites are directly influencing the mechanical properties that is the strength will improve with moisture content and reduces with temperature. All mechanical properties from journal paper are not obtained for full cross section if fiber composites with different fiber bundles and orientations. Hydrophobic matrixes are not suitable as they are highly influence with reduction of strength with increase in fiber content and Strength of composite will increase with 40-55% of fiber content and increase stiffness with 55-65% of the fiber content and the volume fraction of fiber should not be exceed 50-60% of composite volume[24]. Tensile strength of the composite is depends on the fiber length of reinforcement the aspect ratio should be an important parameter for fiber length selection and it is an important parameter that effect the mechanical properties of composites. If the length of fiber is short then the load is transferred to fiber through matrix just by shearing at the interface (fiber matrix). Tensile stresses are maximum along the length but zero at the ends.

Fiber content and length

The mathematical models of tensile, flexural and impact properties were developed and optimized using statistical package to find the optimum fiber parameters for maximum mechanical properties. The results of many research has showed that the fiber content in weight percentage is playing major role than the fiber length on the improvement of tensile, flexural and impact strength which intern effect the collapse modes and crushing characteristics [7-8]. There are few fiber which is best suited for the matrix materials to exhibit better mechanical properties such combination of matrix-fiber for natural fiber are tabulated below[23].

Table -5 different matrix – fiber combination for polymer composites

Thermoplastics		Thermosets	
Polymer	Fibers	Resin	Fibers
PP	Curua, coconut husks, hemp, jute, sisal, sugarcane bagasse	Polyester	Bamboo, banana, coconut, flax, pineapple, hemp
PE	Banana, rice husk, sugarcane bagasse	Polyurethane	Coconut, banana, curcua, sisal
HDPE	Banana, curcua, sisal, wood	Epoxy	Cotton, flax, hemp, jute, sisal, pineapple
PS	Coconut husks, sisal, sugarcane bagasse	Phenolic	Flax, sisal, jute, banana
		Vinylester	Pineapple, sisal, jute, coconut, hemp

S Jayabal et. Al [7] has done a research on the fiber length optimization to improve mechanical properties which is showed results such as .like the coir-polyster composites exhibited maximum tensile strength of 16.1709MPa for the fiber length of 50mm. The increase of fiber length value above or below this does not affect the tensile properties alone.

The fiber length of 150mm exhibited maximum flexural and impact behavior of 38.4912MPa and 164.73 J/m for the fiber length of 150 mm and 136mm respectively. It is

absorbed that the maximum values of tensile, flexural and impact strength for long fiber reinforcements.

Fiber content and fiber loading is playing major role on the mechanical properties of coir-polyester composites. The maximum tensile properties of coir-polyester were obtained in the fiber loading of 19% whereas the flexural and impact properties were obtained in the natural fiber loading of 29% and 21% respectively [23]

Fiber treatment

To enhance flexural properties and bonding between fiber surface and matrix surface various types of chemical treatment and coupling agent can be are there, apart from chemical treatment physical treatments can also be applied to fiber. The various chemical treatments are tabulated by Mohit sood [24] in his research as shown below table-6.

Table 6 various types of chemical treatments for fiber to enhance mechanical properties.

Name of treatment	Chemical(s) used	Chemical Structure	Strength of chemical
Benzoylation Treatment	Benzoyl Chloride	C_7H_5ClO	–
Cyclohexane modification	Cyclohexane/Ethanol	C_6H_{12}/C_2H_6O	1:1 vol/vol
Alkali treatment	Sodium Hydroxide	NaOH	5%, 10%, 15%
Fluorocarbon treatment	Periguard UFC		50 g/L
Silicon treatment	Perisoft MSA		20 g/L
Isocyanate treatment	Carbon Tetrachloride and dibutyl tin dilaurate	CCl_4 and $C_{32}H_{64}O_4Sn$	–
Peroxide treatment	Benzoyl peroxide or Dicumyle	$C_{14}H_{10}O_4$ or	6% solution in acetone
Permanganate treatment	Peroxide Potassium Permanganate	$C_{18}H_{22}O_2$ $KMnO_4$	0.005% in acetone
Acetylation treatment	Siliane	SiH_4	5 wt% in methanol
Treatment with flexible epoxy resin	Flexible epoxy resin		1 g resin:200 ml acetone
Sulfuric acid treatment	Sulfuric acid	H_2SO_4	1.0% (wt/vol)
Etherification	Dodecane bromide, NaOH, Isopropanol	$C_{10}H_{21}Br$, C_3H_8O	12 ml Dodecane bromide into Isopropanol Solution
Modification with maleic anhydride	Maleic anhydride	$C_4H_2O_3$	20 wt% solution into acetone
Stearic acid treatment	Stearic acid	$C_{18}H_{36}O_2$	1% solution in ethyl alcohol.
Modification with Alkyl ketene dimer	Alkyl ketene dimer		3–5% Alkyl ketene dimer in n-hexane
Treatment with Ethylenediaminetetra acetic	EDTA	$C_{10}H_{16}N_2O_8$	Solution of 5 g/l

Laminated design

However, composite materials constituent phases and the laminated layup are crucial in energy absorption of composite structures as it effectively changes the mechanical properties of final product. Various reports have been extensively concentrated on the effects of laminate design on energy absorption. **Thornton and Edwards** showed, in a stable collapse a $[\pm 45/\pm 45]$ layup resulted into obtaining lower energy absorption value than $[0/90]$ lay-up. Furthermore the specific energy absorption generally increases in $[0/90]$ with increasing in orientation angle θ [6].

Core Structural and thickness

Fold cores are a not so common kind of sandwich core structures used in composite materials which plays a major role in flexural stiffness to overcome the collapse happened due to impact loads. It is observed that the laminated layers of core structures are very common among them, as this structural core is easy to fabricate but the intermediate shearing between the laminates will leads to failure under loading [25]. The fold core structures like honeycomb and fold cores which can absorb crushing energy due to minimum shearing in intermediate layers and also the strength to weight ratio can be increased [26]. Different fold core structures which can improve the flexural stiffness are as shown in fig-3.

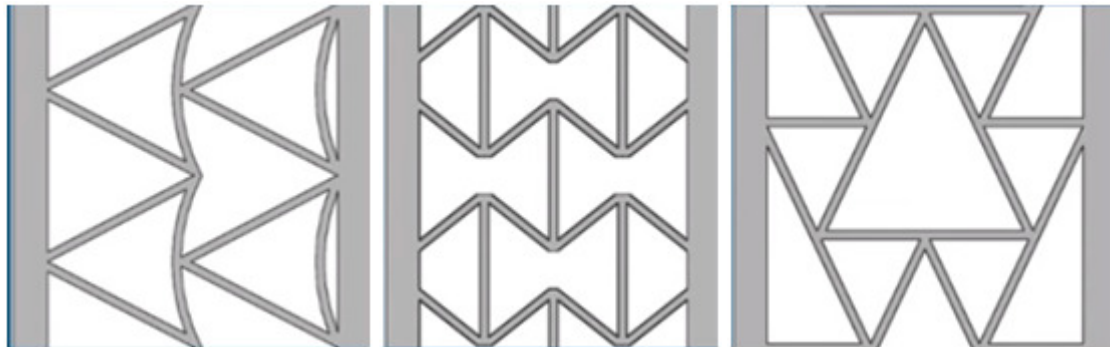


Fig-3: Different fold core structures 1) triangular 2) X-core 3) core triangular structures [7]

Sandwich structured composites are especially suitable for aeronautical and automobile application due low density, these sandwich panels consists of two thin, stiff, strong faces separated by a relatively thick layer of low density and stiff material [27]. The investigation on the effect of core thickness and intermediate layers on the mechanical properties of a polypropylene honeycomb core/fold core structures under three point bending. The results for the above investigation is clearly showing that the mechanical properties are increasing with the core thickness and the intermediate layers. The optimization of the core thickness is carried out and the effect of variation in core thickness from 10 to 40 mm and intermediate layers from single to quadruple on mechanical properties of a polypropylene honeycomb and fold core structures.

4. CONCLUSION

Summarizing the literature study, the collapse modes and crushing characteristics of a composite materials mainly depends on the matrix material which should have better binding characteristic and the fiber selection and its treatments to improve bonding between the fiber and matrix by improving surface roughness. The material used for core structures are plays a crucial role in energy absorption under flexural loading. The thickness of the core material has optimized for 10-40mm for better flexural stiffness which increased with core thickness. From the literature surveys, it has been observed that the research on the post treatment of composites have been undertaken to improvement of mechanical properties such as surface stiffness, surface hardness, wear resistance and other Tribological properties. However it has also been observed that the research has fallen short on the collapse modes and crushing characteristics studies of the composite sandwich panels using natural fibers as reinforcement in polymer matrix composites.

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