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Flexural behaviour of indigenous natural rubber cored novel sandwich structure- An experimental approach

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Smart structures are very significant in several engineering applications because of their wide variety of applications, capability to withstand varying loads, escalations of elastic loading when compared to several other structures. One of those smart type structures is sandwich structures that are generally light in weight, having higher stiffness, and easy to manufacture. Also it is used in numerous applications, viz., aerospace, automobile, building construction, marine structures, bio-medics, etc. The present article studies with fabrication of sandwich beam having natural rubber (NR) as the core material, resulting development of a novel Natural Rubber Cored Sandwich Beam (NRCSB). Along with this, flexural performance of the developed sandwich panel (SwP) have been studied with the different thickness of AI5083-H112 skins. A maximum flexure stresses has been determined to be 20.566, 51.474 and 89.033 MPa for 1 mm, 3 mm and 5 mm, respectively. NRCSBs has also shown better elastic performance under three points loading condition and experimental results have been found in well agreement with theoretical one. The instant study has been concluded that the mechanical impersonating factor of NR leads to an improved overall behaviour of NRCSBs.

Keywords: Sandwich panel, Alloys, Indigenous natural rubber, Adhesive, Flexural bending

1 Introduction

The design and analyses of structures that are non-conventional, have become very prominent field of study in recent days. There is thrust in the application of such structures in various engineering practices, such as automotive, aerospace, medics, etc. The use of NR as a core material in sandwich panels is a relatively new and novel area of research. Natural rubber has a number of unique properties, including excellent energy absorption and damping characteristics that make it an attractive candidate for use in sandwich structures. There has been a massive insistence of structures that weighs less, and at the same time, exhibits excellent mechanical and physical properties. One of those unconventional structures is sandwich structures that are usually lightweight with good strength characteristics. A sandwich structure consists of three parts in it,namely, a core and two faces wrapping the core. The core material acts a pivotal function in the overall characteristics and performance of a SwP. The properties of individual materials conform to the overall property improvement of the structure, viz., the elastic property of core and skins combine to yield an improved overall elastic property of beam, revealed from the present study. Thus, structural study, for better performance, of these type of materials are essential for attaining an improved one, when compared to other virgin material structures, and applying those materials in a broaden engineering extremity. For the building up of a sustainable sandwich composite structure, [1] studied a sandwich structure that was of aluminium sheet skins and disposed of bottle caps as the core. The 3-point bend test method was considered in order to define bulk density, elastic modulus, flexural stiffness, equivalent core shear modulus, skin stress, etc. For calculation of the ultimate shear stress for core and skin, Eqs. 1 and 2 (ASTM C393 standard) was followed:

$$F_S^{uts} = \frac{P_{max}}{(d+c)b} \quad \ldots (1)$$

$$\sigma = \frac{P_{max}S}{2t(d+c)b} \quad \ldots (2)$$

For the 3-Point (3P) loading of sandwich panels, ASTM C393 standard was followed that provided a swift valuation of flexure strength and stiffness on a capacity of 100 kN test setup. In a finding [2], presented a structure named Layer Sandwiched Beam (LSB), to study its shear and flexural behaviours, with Glass Fibre Reinforced Polymer (GFRP) skin and Phenolic core joined together with a polymer epoxy, and failure

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modes were estimated based on interpretations from experimental and numerical investigations. Shi *et al.*[3], considered analysis of damaging properties of a GFRP-Balsa sandwich structure by a 4-point bending technique using an electro-hydraulic servo fatigue testing machine, considering various span length-to-depth ratio samples to find shear-failure in the core, followed by de-bonding of faces and core. Some investigations were done on non-metallic sandwich panels, which were built with corrugated plywood core bonded either to skin sheet of plywood or aluminium or fibre reinforced polymers[4–6] and a comparison was made to study bending behaviour for single layer and double layer cores. Some researchers[7] have studied the dynamic behaviour of composite sandwich beams and modelled 3D finite-element dynamic three-point bending-test simulation. The dynamic bending tests were also performed for the purpose of validation of the numerical model, where the numerical and experimental results in terms of contact-force, peak-force, energy absorbed, displacement of both face-sheets were found to be satisfactory.

Inthe current article, effort has been made to analyse a novel sandwich structure where an indigenous natural rubber (NR) is introduced as the core material to improve the performance of the sandwich structure. Properties of indigenous rubber materials have been studied for their applications to various engineering structures. Experimentation has also been conducted on the samples of sandwich panels to study the flexural characteristics upon variable loading conditions. Also, the results obtained experimentally have been validated with the theoretical results. Results obtained experimentally are in well parity with that of the theoretical results, with a maximum deviation of about 7% only. Our research is unique in that it is study to investigate the flexural behaviour of the indigenous prepared natural rubber cored sandwich structure/ beams. While there is little previous research on such topic where the core materials are either made of metals or non-metallic polymers, our study has the potential to make a significant contribution to the field by unleashing the potentials of using such indigenously prepared natural rubber core in engineering structures, as these rubbers are available easily.

2 Materials and Methods

2.1 Rubber cored sandwich beams

As discussed earlier, NR is introduced as the core material in order to enhance the performance of the sandwich structure.

2.2 Sandwich core material

An elastic material obtained from latex sap of trees, mainly those trees that belong to the genera Hevea brasiliensis. Presently, in Asia about 99% of NR is acquired from domesticated Hevea[8] trees. NRsare an elastomer or an elastic hydrocarbon polymer. The reason/general properties for which NR has been chosen as core material for the present study are their abundant availability, elastic property, high strength (tensile and tear), resistance to fatigue, ability to bond to itself and to other materials, renewable type of resources as NR is an agricultural product[9].

2.3 Theoretical strength of sandwich beams (SBs)

The SB has a high tensile strength to weight ratio when compared to an equivalent beam made with only core material or face material. The bending stiffness to weight ratio of the SB is high due to the high stiffness face material. The flexural stiffness is generally expressed below in Eq. 3:

$$D = \frac{2}{3}Et^3 + \frac{2}{3}E^*\left(\frac{c}{2}\right)^3 + Etc\left(t + \frac{c}{2}\right) \qquad \ldots (3)$$

In a study about the flexural performance of a glue-laminated fibre composite sandwiched beam structures, a four-point static bending method was involved[10]for an experimental investigation at two different positions of beam for evaluating their strength and stiffness properties, estimating the flexural stiffness of beam in two orientations, for flatwise and edgewise orientations.

3 Results and Discussion

3.1 Modelling, sample preparation and specifications of SB

In the instant study, the SB was prepared with two parts, the core bonded by a thin skin on both sides with graded structural epoxy adhesive.

The NR application for core material makes the overall beam a novel structure. The dimension of core material varies accordingly with the skin thickness. Figure 1 shows the basic geometry of the assembled NRCSB. The chemical composition and mechanical properties for the strength of aluminium found from tested results are detailed in Table 1 below. Thus, it could be concluded to be Al 5083-H112 alloy.

3.2 Novel sandwich panel sample preparation

Abiding by ASTM standards, a novel composite sandwich beam was constructed, considering face sheet as Al 5083 grade and indigenously available natural graded rubber. The reason for selection of the mentioned graded aluminium is the broad application

Table 1 — Chemical composition and mechanical properties of Al 5083 skin sheet.

Fe (Iron)	Mg (Magnesium)	Si (Silicon)	Cu (Copper)	Zn (Zinc)	Cr (Chromium)	Ti (Titanium)	Ni (Nickel)	Al (Aluminium)	Ultimate tensile strength (MPa)	Yield Strength (MPa)
0.24	4.55	0.12	0.01	0.003	0.085	0.01	0.0034	Balance	275	308

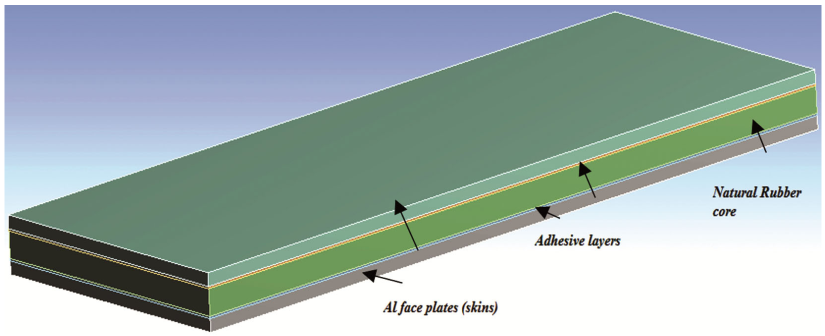

Fig. 1 — Modelled schematic view of the assembled novel SB.

of the grade in nearly all engineering fields. The motivation of choice of core material is first, because of the mechanical properties of NR and secondly, due to the availability in the locality, and lastly, of course, due to low cost and ease of manufacture. Both the skin sheets and the core (NR) have been bonded using a commercial, industrial adhesive resin, which is mixed with hardener from the same make, in proportion. The skin samples (Fig. 2) were prepared by following the dimensional specifications as stated in ASTM C393 standard detailed as considering a short beam of material Al5083, with 200 mm in length and 75 mm wide. The various thicknesses for the faces/skins were considered based on the literature study, and for the core, the material is shown in Fig. 3 (a). SwPs were prepared in order of Al skin-NR Core-Al skin. The aluminium plates/skin samples were considered with variable dimension as in three cases has been shown in Table 2.

The total thickness of SB, as in the table above, was calculated for the three cases using Eq. 4.

$$d = c + 2t + 2x \quad \dots (4)$$

The adhesive used or this study is Araldite made commercially available AW 106 resin and Hardener HV 953U epoxy adhesive (Hutsman Advanced Materials Americas Inc.)[11],[12] that is considered as multi-purpose, and are capable to bond a variety of materials, ranging from metals to non-metals. Samples' adherend surface was first cleaned with an industrial cleaner cum degreaser with cotton, with it soaked, cleaned in single passes length-wise of adherend surface (Fig 2) with no repetition with once cotton used and disposed. The samples were prepared

Fig. 2 — Aluminium sandwich face samples.

at room temperature, and sufficient time is given to dry up. The NR sheets were cut to required dimensions, and, adhesive with resin and hardener mixed together by weight (gms.), were applied on the rubber sheets on both sides (Fig 3a). A total of 9 (nine) number of samples were prepared, as shown in Fig. 4, for testing under conditions of the novel sandwich structure. The epoxy adhesive core placed on the one part of adherend face and other part put on other side of the glued core of 6 mm thickness shown in Fig. 5, applying uniform pressure. A curing time of 24 hours was considered to achieve good quality bonding. The NRCSBs after preparation was allowed to cure or dry for nearly 24 hours for the adhesive layer to have a good bonding with the substrates on either face.

The novel sandwich beams that are developed using the materials as mentioned above of face and core is shown in Fig. 3, using the commercial adhesive considering the proportion of resin and hardener by weight.

The layer of adhesive in the beam is considered to be 0.5 mm on both the sides in accordance to ASTM 1002 standard. Figure 5 shows the natural rubber sheet that was considered for the core material of the novel sandwich structure for the present study.

Table 2 — Parameters considered for sandwich beam construction.

CASE- I	CASE- II	CASE- III
c = 6 mm	c = 6 mm	c = 6 mm
t = 1 mm	t = 3 mm	t = 5 mm
d = 9±0.05mm	d = 13±0.05 mm	d = 17±0.05 mm

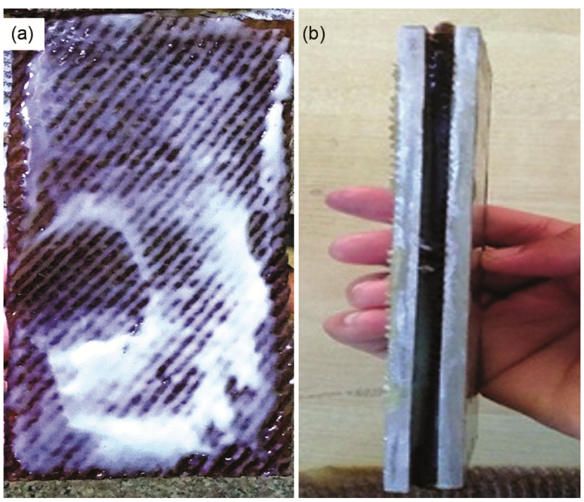

Fig. 3 — Preparation of sandwich beam samples (a) NR core, and (b) assembled beam.

3.3 Surface study of sandwich panel specimen

As discussed in the previous segment from literature studies, the surface study of adherends in adhesive joints significantly effects on the behaviour of bonded or sandwich structures. Therefore, study has been carried out considering the original surface conditions of the substrate specimens, and subsequently, a study for finding average surface roughness was done. The roughness parameters considered are average surface roughness (R_a) and the maximum surface roughness (maximum height of profile, R_z) to evaluate the quality of surface of the specimens. Surface roughness values, R_a and R_z were measured using a Taylor-Hobson's 3D Surface profile meter on the novel sandwich faces samples. The faces that were considered for bonding were first cleared using isopropyl alcohol and then placed for extracting values of R_a and R_Z, as mentioned. Some results of R_a obtained from the surface profilometer considering average R_a values at nine points/positions of the substrate. Table 3 shows the values of R_a and R_z for specimens of the different thickness substrate surfaces, and correspondingly, the graphical 3D presentations of the surface of the substrate specimens are showed in Fig. 6 (a-c) for clear understanding the nature of the surface.

Table 3 — Surface roughness values of substrate surfaces.

Substrate thickness (mm)	R_a (µm)	R_z (µm)
1 mm	0.231	1.47
3 mm	0.192	1.18
5 mm	0.259	1.36

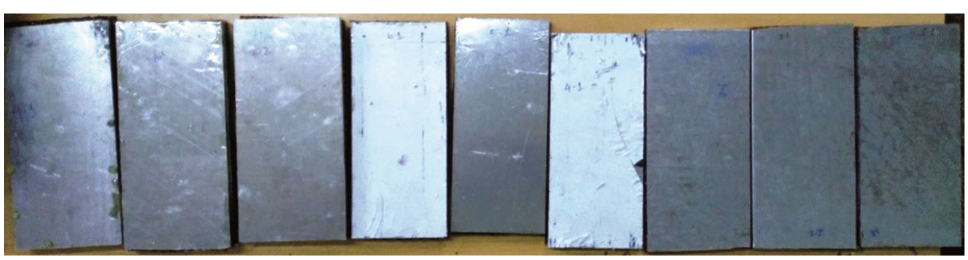

Fig. 4 — Assembled samples of sandwich beam.

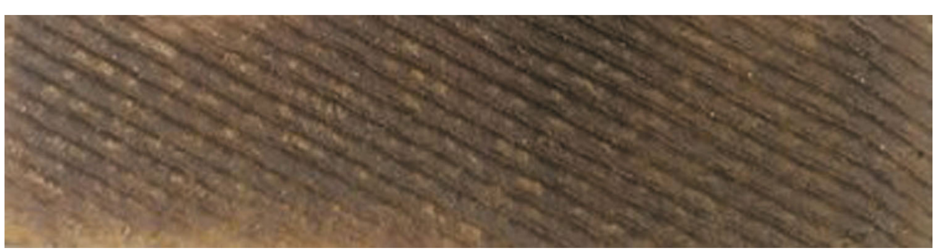

Fig. 5 — NR for core material.

Table 4 — Mechanical properties of NR.

	Tensile Strength (MPa)	Shore A Hardness	Elongation at break (%)	Mooney Viscosity	Compressive Strength (at 25% strain) (MPa)
ASTM standard	D412 Method A: 2016	D2240: 2015e1	D412 Method A: 2016	D1646-17	D575 Method A: 2012
	0.74	26.4	685.52	46.25	0.235

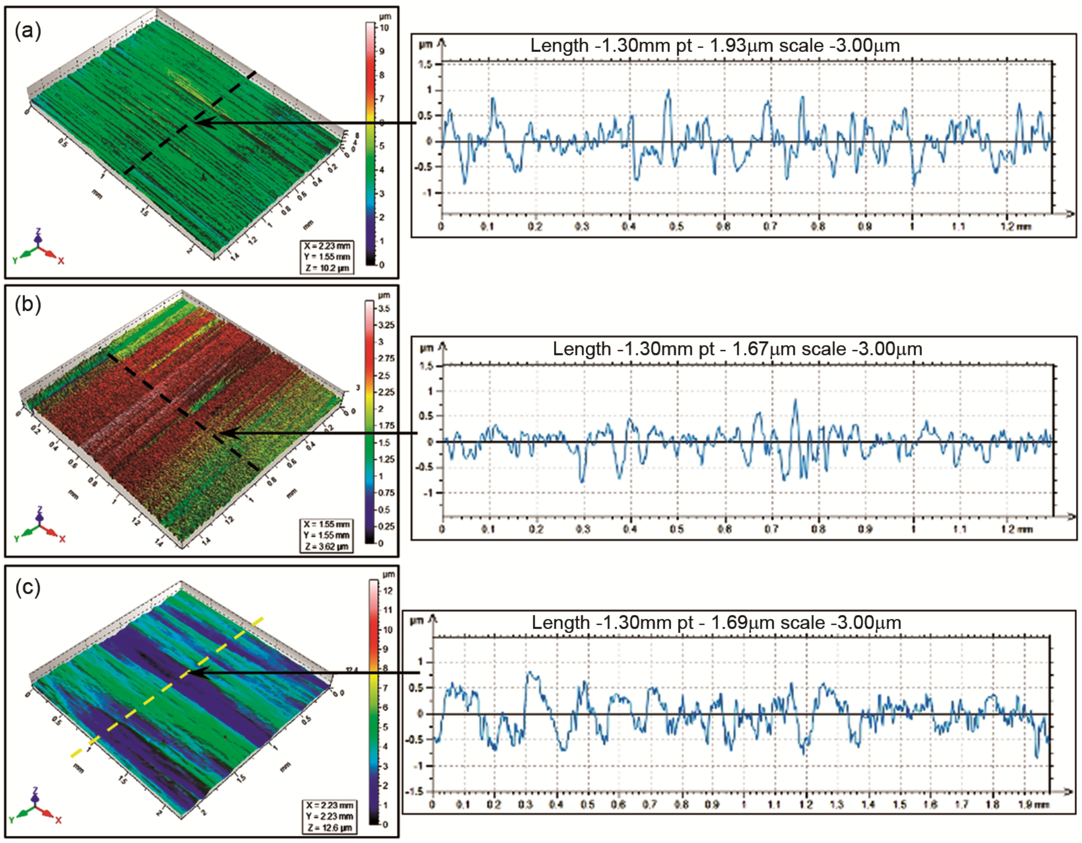

Fig. 6 — 3D and 2D surface roughness profile of (a) 1 mm, (b) 3mm, and (c) 5 mm thickness specimen.

The surface study played a significant role in understanding the quality of surface of the specimen on which adhesive has been applied for enhanced performance of the bonded surface to the core surface.

3.4 Characterization of natural rubber

3.4.1 Behavioural study of natural rubber

As indicated above, the natural rubber used is indigenous, and thus, the study of its mechanical has been an important regime for application of those in a structure and after that, for further performance study. Some mechanical tests were also conducted to identify the properties of NR. Following Table 4 illustrates the different properties of NR along with the ASTM standard followed for performing the tests, the samples and test-setups of those are shown subsequently in Figs 7 and 8.

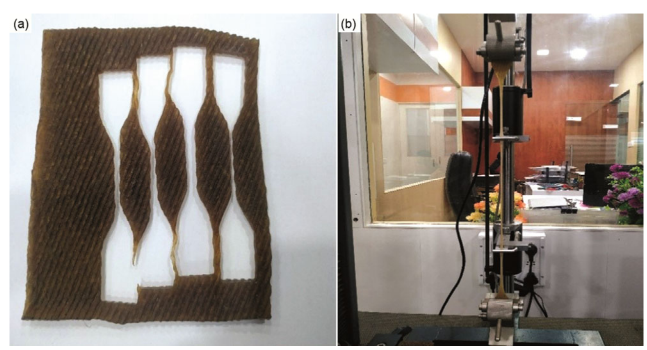

Fig. 7 — (a) Natural rubber sample preparation for tensile test, and (b) tensile test setup.

3.4.2 Thermogravimetric analysis

A thermal gravimetric analysis (TGA) was done to identify the constituents present in the NR used for manufacturing the SwP. TGA is the method of thermal analysis in which the changes in the mass of the rubber sample has been determined with the change in temperature with time. Thetest was carried out under ASTM standard D6370:1999 (Ra 2014), to find out the constituents present in the visco-elastic NR material (as given in Table 5) at a temperature of 23±2 °C and 50±5 % relative humidity up to a temperature of over 850 °C for more than 85 minutes.

The Difference Thermo Gravimetry (DTG) curve in Fig. 9 shows that the pyrolysis of NR taken place in two steps, the first step at about 360 °C as the peak shows in DTG curve, and the second step at 386.5 °C of the DTG curve. It has been found that NR sample pyrolyzed at the relatively low temperature of about 387 °C with 88.65% of polymer content, with an ash content of only 0.7% which may be neglected.

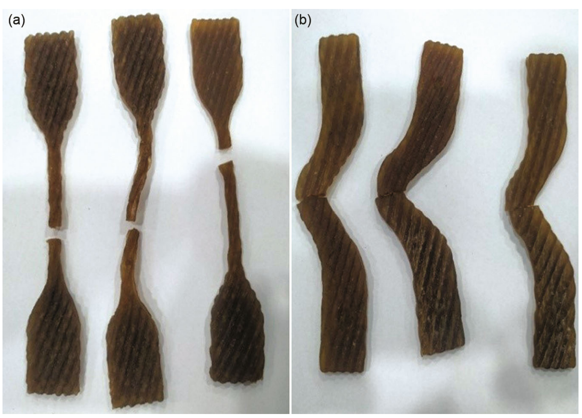

Fig. 8 — Natural rubber samples after tests.

3.4.3 Study of spectrometry

In an instance, NR was blended with nano-silica (SiO_2) in the latex state[13] for studying the mechanical behaviour with several filler contents, where the unvulcanised NR was blended to SiO_2 nano-silica filler, and that was characterized using Fourier Transform Infrared (FT-IR) Attenuated Total Reflectance (ATR) spectroscopy.

Thus, FT-IR is an important material analysis technique in order to identify and understand the chemical compounds present in the material. For the present study, the NR was tested with FT-IR (Shimadzu made) following the ASTM D3677: 2015 standard and the test confirmed the materials to be Natural rubber. The trace of the FT-IR spectroscopy in Fig. 10, shows the percentage transmittance in the ordinate and wavenumber in cm^{-1} in the abscissa. As the trace implies the largest peak to be 2922.16, which is in the first region between 4000 and 2500, thus, it corresponds to absorption affected by the presence of monomers or single bonds of N-H, C-H and O-H.

Secondly, in the fourth region of the IR spectrum which holds between ranges of 1500 to 400, which is also known to be fingerprint region of IR band, and trace reveals that this range includes many numbers of absorption peaks that implies the existence of a variety of single bonds, and lastly, the trends of the peaks were compared to previous studies[14], [15].

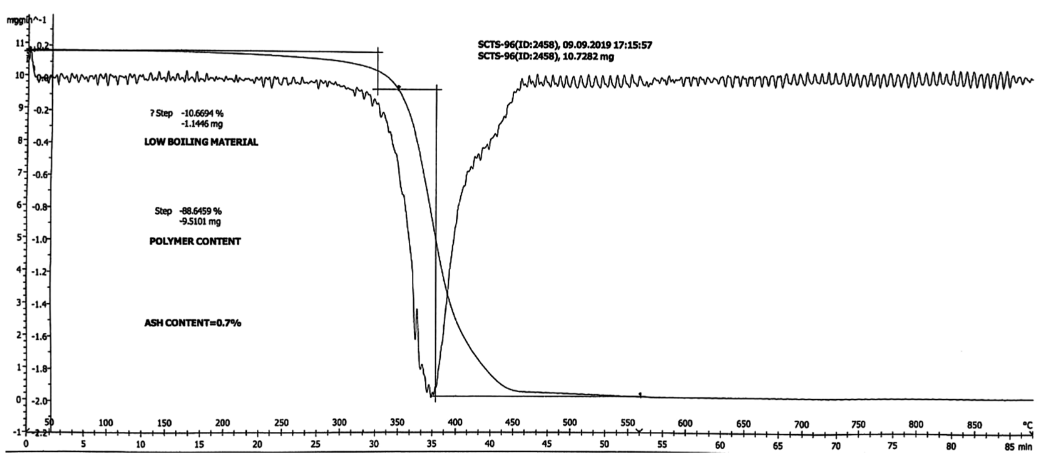

Fig. 9 — DTG curve for the DGA test.

Table 5 — Constituents present in NR by TGA method.

Step	Step height of TGA curve	Comments
Step 1	10.67 %	Low volatile compounds
Step 2	88.65 %	Main step of the Polymer pyrolysis, corresponding to peak maximum of DTG curve at 386.5 °C
Residue	0.7 %	Ash

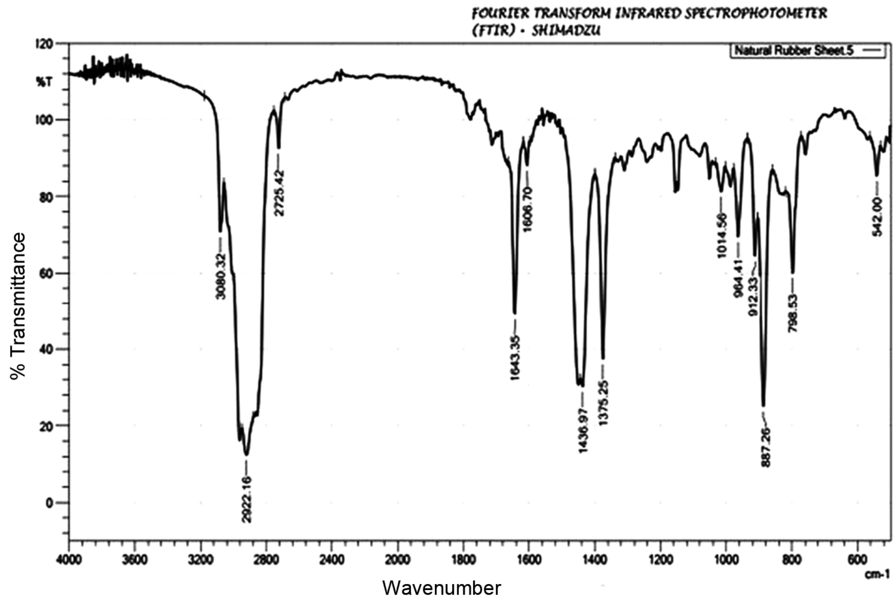

Fig. 10— FTIR trace of NR.

3.4.4 Morphological surface study

The study of surface behaviour of natural rubber in this instanthas been required because its indigenous property that is required to be revealed forfurther investigations. The microscopic behaviour of the rubber core in the NRCSB has also been studied after the beams have undergone flexural bending. Some investigations for the morphological characteristics of NR blended with kaolinite organoclay composites revealing about the improvement of NR with a blend of composites [16]. Some other morphological behaviour study of viscoelastic material [17–21]such as rubber and blending with different composites before and after vulcanization revealed several prospects of those rubbers with and without blends.

Figure 11 shows the FESEM image of the natural rubber which is the core material of NRCSB. Figure 11 (a-d) shows the unmodified/un-fractured condition of natural rubber. Figure 11 (b) shows the surface morphology of natural rubber at 1000x under un-fractured condition. It can be clearly seen that there is no breakage or trace of initial crack generation. While the Fig. 11 (e) and (f) is the surface morphology of natural rubber at 2KX and 4KX, which has undergone the tension and compression due to application of load to mid-span of SwP that resulted delamination of core. The Fig. 11 (e) clearly shows the generation of crack in natural rubber and delamination also take place. Fig. (f) is the magnified area of natural rubber and in this stretching and delamination of natural rubber is clearly visible.

Thus, the micrographs encapsulated for the samples of the novel sandwich panel considering conditions before and after the flexural test. The EDX analyses of NR also confirms the existence of nitrogen, carbon and oxygen in the natural rubber as depicted in Fig. 12 (a-b). Figure 12 (a) shows the spectrum of natural rubber and (Table 6) its weight percentage and atomic percentage and Fig. 12 (b) shows the elemental mapping of natural rubber which shows the distribution of elements in natural rubber.

The importance of micrographs in this case is to be comprehended, first, for the skin material's surface on which the adhesive has been applied on. Secondly, the interfacial layer between the skin and natural rubber core. The study of surface morphology has also been carried out in the present investigation, which is an important behavioural aspect of interfacial layers of sandwich beams before binding NR core to Al alloy face sheets. Fig. 13 (a) shows the bonded sandwich panel before the flexural loading with distinctly visible evenly distributed adhesive layer in the NR-Al skin interfacial layer, whereas, on the other hand, in Fig. 13 (b) shows a minor gap in the interface between the skin and the core though at a point away from the deformed zone where the load on the beam had been applied. The micrograph for the NR that had been applied in the NRCSB is demonstrated in Fig. 14 (a and b).

The fibres at the interface between NR core and Al skin material shown in Fig. 14 (b) indicates that there is not much delamination between the interfacial

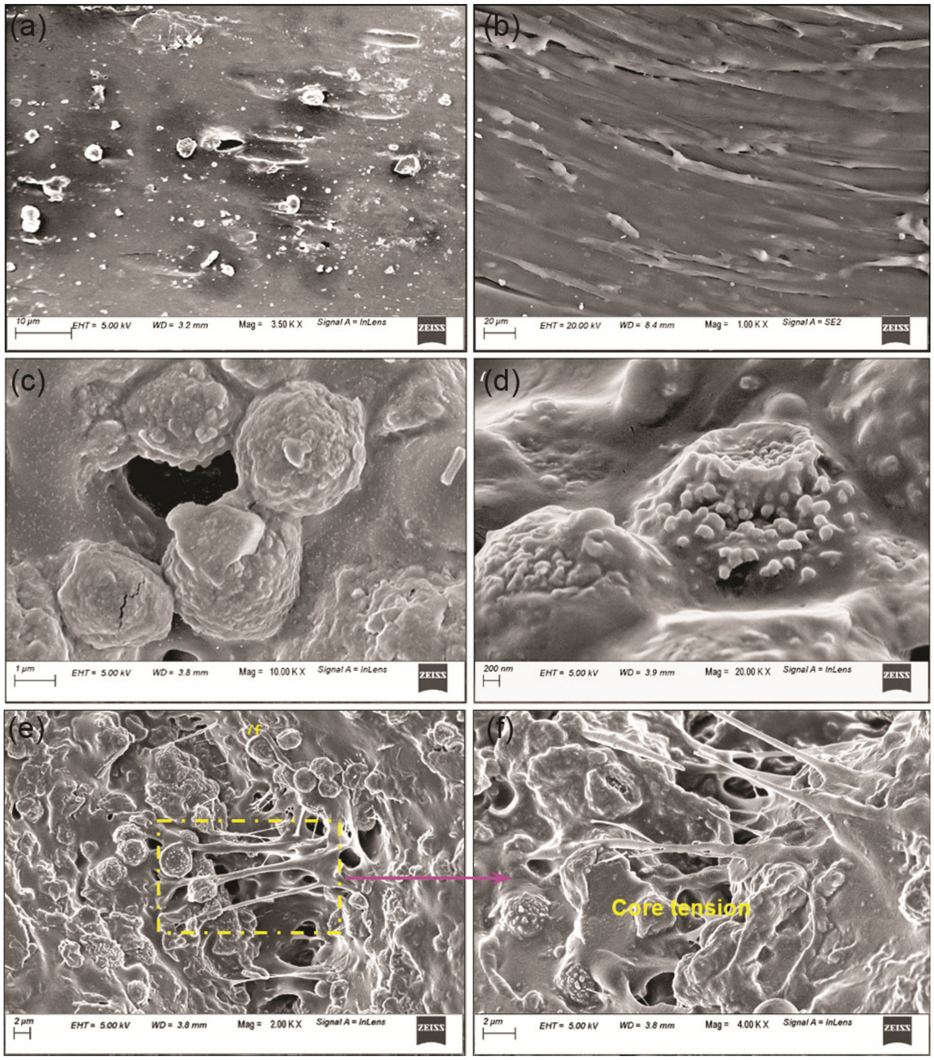

Fig. 11— SEM micrograph of indigenous NR for SwP core (a)-(d) before loading/unmodified, (e)-(f) after core delamination/flexural loading.

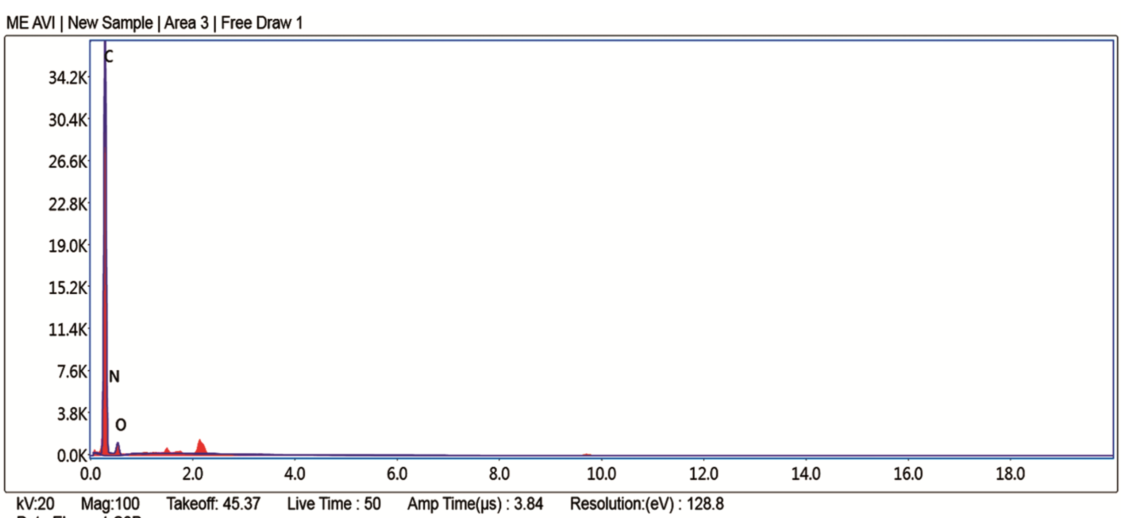

Fig. 12 — (a) Spectrum of natural rubber and

Table 6 — Weight percentage and atomic percentage.

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	A	F
C K	90.37	92.57	2.13	4382.90	0.8180	1.0041	0.9014	1.0000
N K	0.28	0.25	99.99	1.19	0.0002	0.9798	0.0681	1.0000
O K	9.35	7.19	16.74	105.85	0.0114	0.9588	0.1276	1.0000

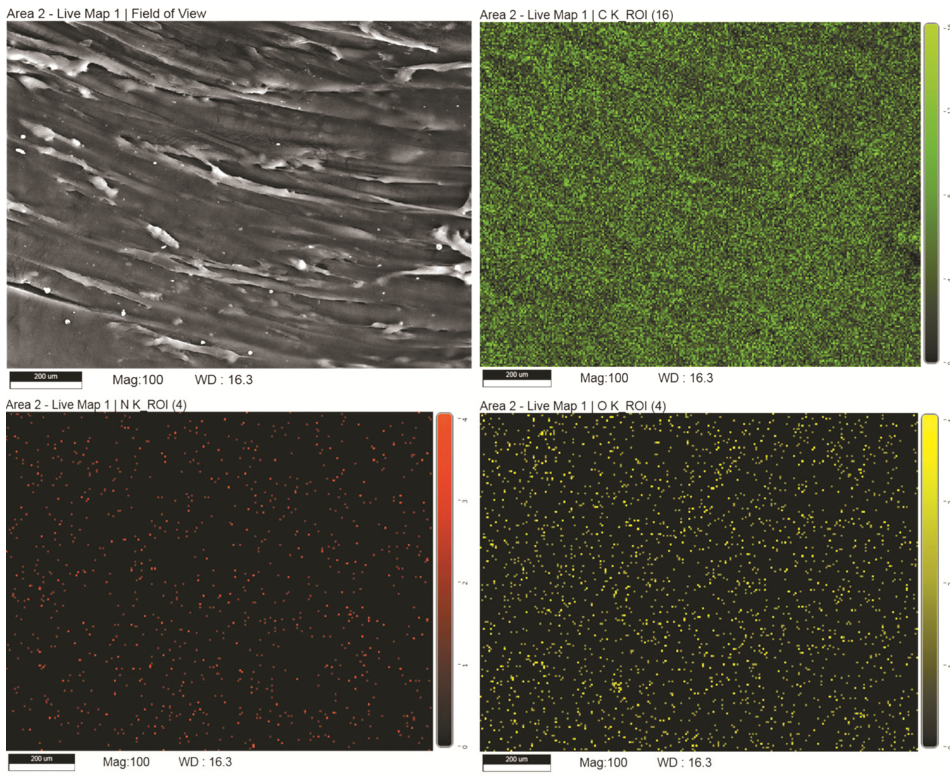

Fig. 12 — (b) Elemental mapping distribution of NR.

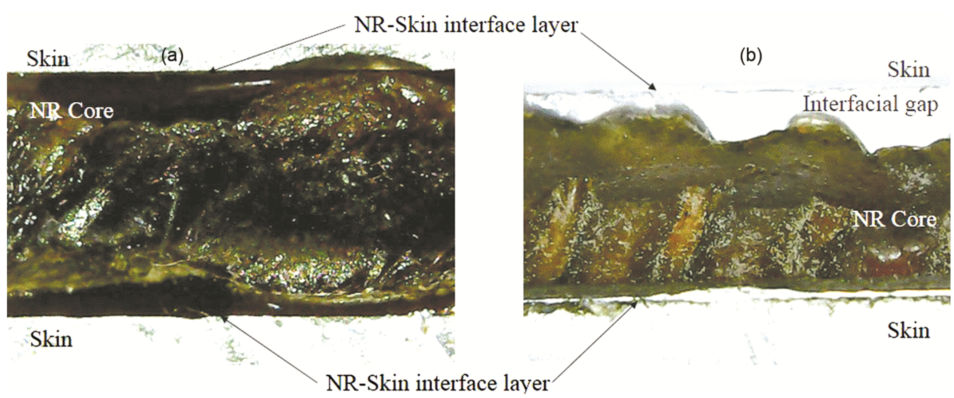

Fig. 13 — NRCSB (a) before loading and (b) after loading.

layers. This might be an added advantage for the novel sandwich structure when compared to the other cored sandwich structures under high load co-relating to flexural loading.

3.5 Flexural test of NRCSB

A three-point bending test technique, also known as transverse bending technique, is followed for the purpose that provides values of elasticity modulus in bending (E_f), the stress of flexure (f), a strain of flexure (ε_f) and the stress-strain characteristic of the beam material. For carrying out a flexural test of sandwich structures, ASTM C393/C393M standard is customarily followed to find the core shear properties. Either a three-point or a four-point bending setup,

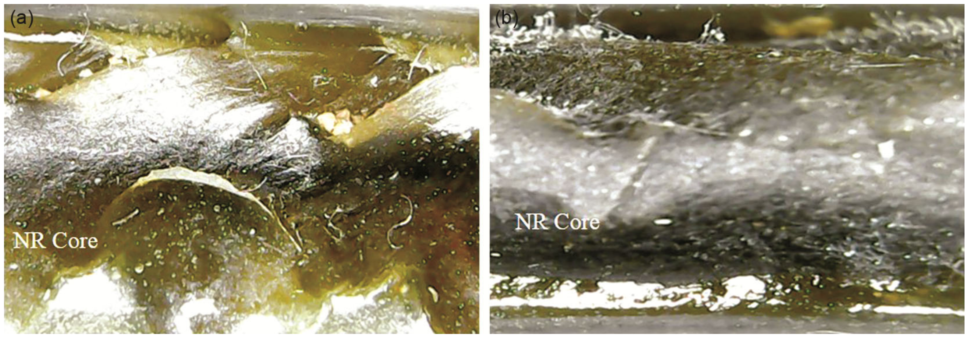

Fig. 14 — Macrograph of NR core in a NRC sandwich panel (a) before loading and (b) after loading.

where the sandwich beam is subjected to bending moment normal to the plane of sandwich [22], recording the force versus deflection measurements is advisable. To analyse the material properties, the flexural strength study of SB has been done under 3-point loading condition.

The 3-point bend test method was endorsed according to ASTM C393/C393M as the arrangement depicted in Fig. 15 with the load at the mid-span of beam with a roller force indenter.The setup of experiment is a closed-loop servo hydraulics dynamic testing machine (INSTRON) of 100 kN capacity with maximum elongation of 150 mm ± 5mm that was used for the flexural test of the novel sandwich panels, at a test facility elsewhere, is shown in Fig. 16.

The test samples, as per the standards, were distinctly labelled so that those could be easily traced and would neither influence nor affect the test. Secondly, as the specimens were prepared in an environment (at room temperatures) that was different from the conditioned environment of the test conducted, therefore, the specimens were stored in the conditioned environment till the test was conducted. For the test, according to standards, the speed for the crosshead displacement was taken as 6 mm/min. The deflected samples of the novel sandwich beams after the test has influence on the overall mechanical property of the sandwich structure. The subsequent results obtained from the 3 point bend tests performed on various samples considered as the above cases for NRCSBs reveals the improvement of the overall structure when compared to conventional beams. Referring to experimental figures (Fig. 17) and the graphical representations of the results, it may be implied that the no significant failure occurred at the maximum loads in each case, which indicates an excellent bonding strength between the adherends and core materials has been achieved.

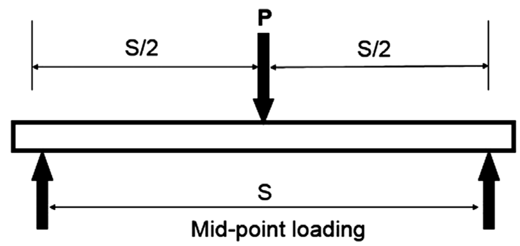

Fig. 15 —The standard configuration for three-point loading for a flexural test.

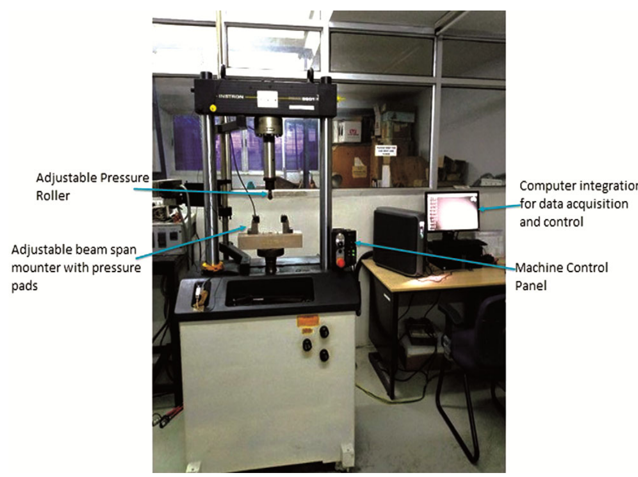

Fig. 16 — Flexural test experimental setup.

Figures 18 and 19 show the flexural stress vs strain and maximum flexural load vs deflection respectively for all 3 cases described in previous sections.

Thus, the results have obtained from the flexural test have been summarized in Table 7. Also, a comparison of maximum deflection for the NRCSB and a simple rectangular cross-sectioned AA 5083-H112 beam has been determined using per Eq5. The depth and maximum loads for rectangular beams were considered equal to that of the depth of NRCSBs in the three cases considered with skin thicknesses 1mm, 3mm and 5mm, respectively.

$$\delta_{max} = \frac{P_{max} \times L^3}{48 \times E \times I} \quad \ldots (5)$$

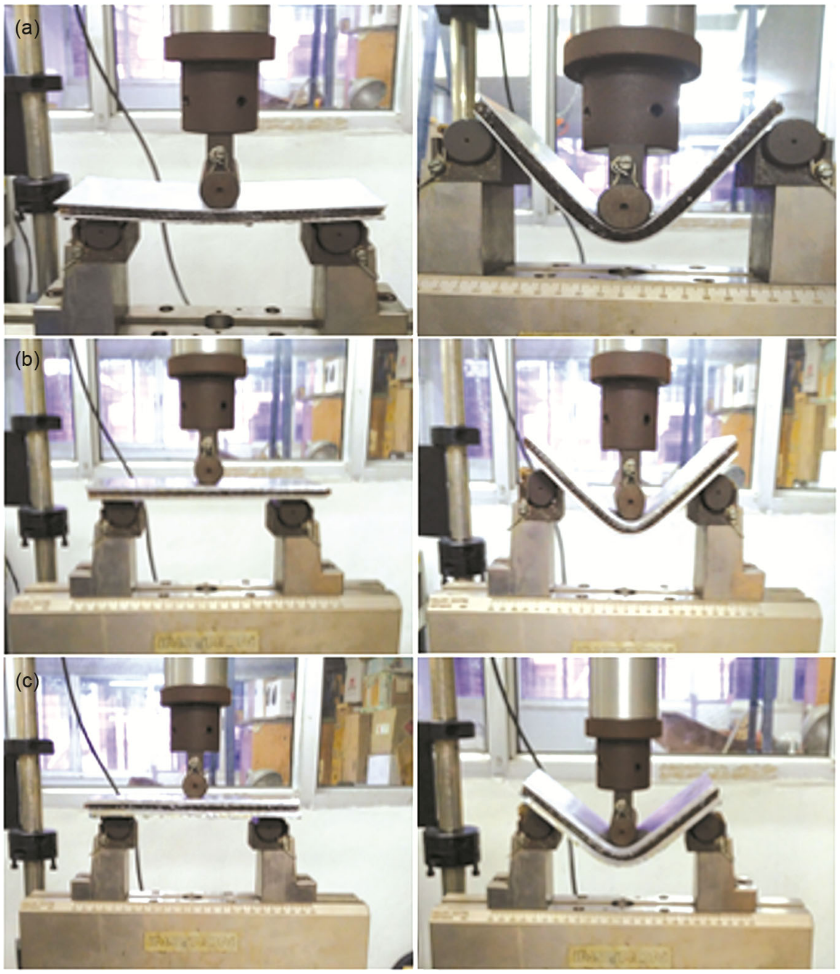

Fig. 17 — (a) Flexural test for CASE- I, (b) Flexural test for CASE- II and (c) Flexural test for CASE- III.

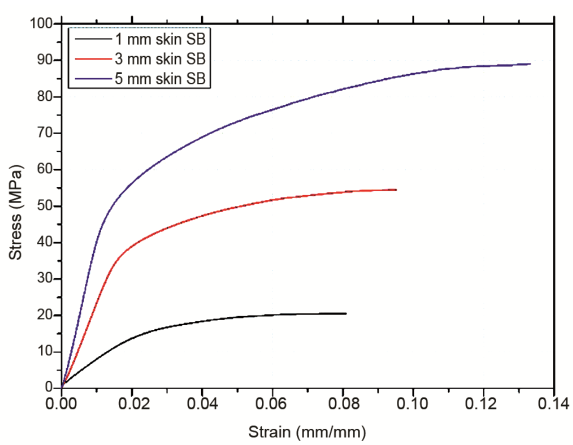

Fig.18 — Flexural Stress versus Strain diagram.

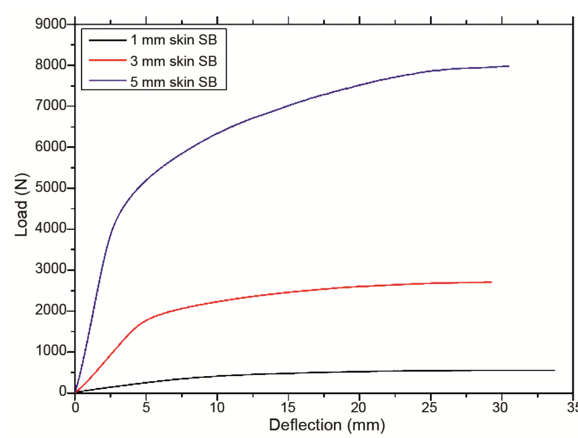

Fig. 19 — Max. Load versus Deflection.

For validation of the experimental data of beam stress, the following Eq 6 has been used:

$$\sigma_b = \frac{M \times y}{I} \quad \dots (6)$$

Table 8 shows that experimental beam stress is instituted to be in acceptable agreement with the theoretically calculated results. From the theoretical and experimental calculations for the maximum deflection for beams, it is revealed that the

Table 7 — Flexural test results.

Skin-Sample thickness (mm)	Max. Flexural Stress (MPa)	Max. Flexural Strain (mm/mm)	Max. Load (MPa)	Max. Deflection of NRCSB (mm)	Deflection for AA5083-H112 (mm)
1	20.566	0.0808	555.271	33.679	0.119
3	51.476	0.095	2702.743	29.237	0.193
5	89.033	0.133	7982.086	30.479	0.255

Table 8 — Validated beam stress results.

Skin-Sample thickness (mm)	Experimental beam stress (MPa)	Theoretical beam stress (MPa)	Deviation (%)
1	20.566	20.34	1.09
3	51.476	47.61	7.51
5	87.033	82.37	5.35

deformation for NRCSBs has shown an excellent elastic property when compared to the maximum permissible deflection of the simple rectangular cross-sectioned beams. This may imply that the impersonating properties of core material have prolonged the elasticity range for the overall sandwich structure that may be an added advantage for applications. Also, it has been observed that due to the added elasticity, the viscoelastic property of core, widens even the possibility for the sandwich structure might recapitulate from its deformed shape without any considerable fracture. Similar research was carried out by some researchers[23], wherein aluminium honeycomb was considered as core for the sandwich structure. Flexural study on those sandwich structures revealed the maximum load and corresponding deflection of specimen under the 3-point bend test. The main reason of considering the 3-point bend result is that the present study has been carried out under similar bend condition. The present study shows better results revealing the characteristics/properties of the core material being used.

4 Conclusion

At the outset, it was revealed that adhesive bonded structures still finds an extensive prospect due to their adaptability in multidimensional engineering arenas. Thus, an attempt has been made to manufacture and study their performances with a modification in core and adhesive that comprised of NRCSB. From this study, the conclusions may be drawn as below:

This study revealed from the surface morphology of the aluminium 5083 alloys (used as face sheet/skin for NRCSB), for all substrate thicknesses 1 mm, 3 mm and 5 mm, with average suitable roughness values instituted to be 0.231, 0.192, 0.259 µm respectively. It may be noted for complacent bonding behaviour at the core interface for future applications. During the characterization of the mechanical properties of NR core material, some noticeable and reportable values *viz.* 0.74 MPa as tensile strength, Shore A hardness of 26.4HBA, elongation percentage at 685.52, and Mooney viscosity of 46.25 were observed and may be kept for future reference. IR spectroscopy and thermo-gravimetry tests, revealing the existence of about 90% of volatile content in the NR considered, which proved the content as well as the genuinity of the indigenous NR. For macrographs, a lesser delamination of core from the adherend surfaces it was observed, which proves the withstanding of the localised stress and adaptability of loading variations in the core. The thickness of the core material at NR has sufficiently influenced the mechanical behaviour of developed SBs. Test performance of NRCSB, prepared at room temperatures found in well agreement with theoretical results, all under 7% average deviation. Also, maximum deflection results of NRCSBs were found to be higher compared to results considering AA5083-H112 beams with similar thicknesses. No significant failure of NSCSB occurred at maximum loads in each of the cases during the test, which confirmed the achievement of excellent bonding strength between the adherends and core materials. It may also be concluded by studying the mechanical behaviours of NRCSB that the core material of the beam influenced well on overall mechanical property of the sandwich structure. The use of natural rubber as core material may also offer advantages in ways of cost and environmental sustainability compared to other materials that are commonly used in sandwich structures. This may imply that the NRCSB when compared to other bonded structures are economical too. The use of indigenous natural rubber as a core material in sandwich beams is a novel area of research that has received relatively little attention in the literature. Unlike synthetic rubbers, which are commonly used in composite materials, indigenous natural rubber is sourced from trees that are native to a particular region, and may have unique properties that are specific to that location.

In view of the above conclusions drawn, it may be instituted that the developed novel NRCSBs, in the present study, showed better results when compared to conventional beam considered, and may be applied in several fields of engineering for the attainment of better structural performances. This also provides opportunities for new and innovative research, as well as the potential for significant advances in the field of composite materials.

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