Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Effect of Pressure on Biodegradable Boards

Preetesh Saxena

PhD Scholar, Mechanical Engineering
Department, Sri Satya Sai University of
Technology &Medical Sciences, Sehore (MP)
E-mail: saxena300@gmail.com

ABSTRACT

In this research chapter ten bio-boards have been produced under five experimental conditions and strength test was conducted to examine their mechanical properties. Following are the main points which were observed after the various tests were performed –

1) The results indicated that boards were successfully made by using raw materials of corn straws under the experimental conditions. Thus it is feasible to make board using this process.

2) The results of bending and tensile strength showed that as the deformations were increased in all the bio-boards , stress value was also increased . When the specimen failed, maximum value was attained by stress, then gradually it started decreasing & finally it becomes zero.

3) In the bending test, the range of rupture stress found were in the range of 21.25MPa ~ 30.78MPa. Likewise in the test of tensile strength, the range of rupture stress varied from 4.49MPa ~ 15.15MPa. Under 8MPa pressure condition of the bending strength of bio-boards were highest, near to value of 29.37MPa. Rupture stress was highest near to value of 10.89MPa of tensile strength under 10MPa pressure condition.

4) The result from the curves of stress-strain of the test of specimen, revealed that 1.4GPa~1.8GPa was the average range of Young's modulus of bio-boards .Also the static toughness values becomes large as pressure was increased.

The bio-board attained maximum static toughness of 85KPa under 10MPa pressure condition.
Also the fundamental properties of bio-board were examined and the results indicated, that bio-board can be made ,which can be used for different purposes like a material for packaging , as a mulch film in agriculture , for heat insulation in architectural purposes etc .

KEYWORDS -

Bioboards, corn straw, stress, strain, rupture stress, young's modulus, biomass, fiberboard, drying .compressing .tensile, strain energy.

1.1- Introduction

As per the earlier research done, regarding producing bio-board by using corn straw, the results demonstrated that bio-board can be successfully produced by using corn straw and all the techniques that have been implemented in conduction of the experiment are achievable
The present research has dealt with the manufacturing processes that have been proved feasible for producing bio-board by the usage of corn straw (leaves and stem). Principle behind producing board differs from that of fiberboard is hydrogen bonding .Outcome of pressure that has been applied in the process of forming, for determining the biomass strength has been investigated ,Further the various other mechanical properties Young's modulus ,rupture stress , strain energy have also been studied and discussed

1.2 Literature Review

Composite materials, such as particle board, fiberglass and carbon –fiber products are held together with a moldable glue or resin .Unfortunately, most glue are not safe for the environment, are not biodegradable, and are often toxic.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Many of the polymers used in composites are petroleum based which is nonrenewable high cost resource .Engineered wood products also contain formaldehyde, a known carcinogen that degasses slowly over time, creating indoor air quality problems. Huge amount of engineered wood products are thrown into landfills every year both from teardowns and new construction projects.

Scientists at Cornell University in Ithaca, New York, have invented an alternative to standard composite material biodegradable composites made entirely from plant materials.

This biodegradable composite technology is little bit stronger, cheaper and safe for the environment and can be processed into sheets.

Many of these fibers, such as bamboo and kenaf can be grown on unused islands .other advantages no petrochemical content and lower overall cost compared to traditional composite materials.

e2 Materials LLC, an Ithca company is developing biodegradable composites for different industries and applications.

Corn husk composites biodegradable film was prepared by Malaysia university by solution mixing .These results from , Atomic force Microscope (AFM), Thermal gravimetric analysis (TGA) and Differential Scanning Calorimeter (DSC) ,analysis exhibit the properties of the corn husk film fabricated .The biodegradability shows that 100 % composting achieved at 270 days .

American company BASF markets a product called Ecovio which is biobased blend of the company's certified compostable and biodegradable co-polyester ecoflex and PLA which are used for shopping bags, organic waste bags and for some other use.

2.1 -Materials and methods

''As per Martin A. Hubbe (2006) fibers are made up of two main components and hydroxyl groups cover them''. Due to oxygen atoms hydrogen bonds to the hydrogen atoms on the adjacent fibers or molecules of water, instead of fiber-to-water hydrogen bonds, fiber –to-fiber hydrogen bond are formed due to dryness present on bio-boards.

2.2 Board making process & Board making experiments

Basic principle-

In this work we have used Sweet corn . On 1st Apr 2020 it was sowed and on 10thof July it was harvested at Bio-resource farm , Leharpur Sitapur farm up, Figure 2-1 shows maize farm Grains were removed after harvesting was done for two months stem and leaves were air-dried in a ventilated storage

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Figure2.1- present situation of sweet corn cultivation in this research

Five processes that were applied in the previous experiment have been used in the present study as well these processes are – cutting , grinding , compressing and drying as shown in the block diagram below ,The process of compressing and drying were conducted together known as the "forming process"

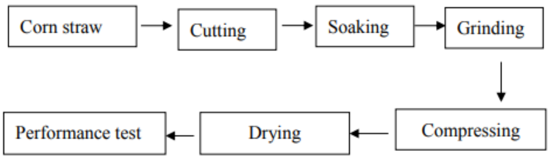

Figure2.2- Block diagram of Flow chart of Bio-board making process

At the time of pre-treatment firstly with an electric cutter dry corn straws were cut down into chips, then at the temperature of 22^{O} C, they were soaked for 168 hours for softening the fibers of straw. During the process of soaking, moisture was absorbed by fibers of corn straw. Softening bundles of fiber in wet condition was easy ,as in comparison to destroying the structure of lignin cellulose fibers in dry state. The process of soaking was carried out to fiberize the corn straws

With the help of atmospheric refiner, that has conical blades soaked straws were then fiberized (pulped) as shown in the figure below. Motor capacity was of 11 kW×4p-200, 60Hz, with a rotational speed of 1750 r.p.m (65 Hz). 0.05-0.1m^3 / min was the value of maximum flux control .Air pressure required was 0.6MPa. Conical cutters with blades have been assembled in the grinding part .Cutter dimension is2.5mm×3.0mm×8° (blade width×slot width×blade angle).

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Figure 2.3: An atmospheric refiner

Straw damp cut, were passed out along with the running water through the rotating blades of refiner to fiberize the corn straws at atmospheric pressure. At the time of grinding bundles of fiber would also be fiberized by milling Further the milled-corn straws were sieved so that they possess the size of the particle by using a screen with 2mm×2mm hole size into fine fraction the ground straws were fractionized with particle size0.5mm~2mm. Grinding was done using water thus corn straw pulp was prepared, before the process of compressing
.
The closed stainless steel die which comprises of accessories , such as metal block ,meshes was also designed in such a way to enable in obtaining, one square board with dimension (100mm l*100mm b*40 h) where l is length , b is breadth & h is height . After precise calculation the ground corn straw was filled in the die carefully, and then further pre-pressed by pressing out excessive water from the die At the bottom of the die holes were drilled, the size of metal block and plate was 2mm in diameter, grid size 7 mm×7 mm fit, for allowing water to pass through it during forming process.
The pressure required was applied at maximum temperature of 110 degree Celsius. The sample contained in the die took 8-10 minutes to reach the maximum temperature. At the table below the experimental conditions of forming has been displayed. ‘’As per Pan (2009) at the time of forming the hydrogen bonds held tightly side by side and tensile strength of micro fibrils is high and the water inside the bio-board can evaporate at high temperature and pressure “

Table 2.1 different drying temp versus pressure

bio-board No.	pressure (MPa)	dying temp. (℃)
A1,A2	2	100
B1,B2	4	100
C1,C2	6	100
D1,D2	8	100
E1,E2	9	100

3.1-Strength tests

The mechanical properties of bio-board have been analyzed by conducting tensile strength and bending test.
At the figure below, three Point Bending test has been shown, five bio-board named A1 to E1 were trimmed down to (50 millimeter *10 millimeter *1.2 millimeter). Standard JIS procedures and recommendations (JIS Z2248:1996) were followed & we prepared 25 rectangular beam specimens.
With a accuracy of + 0.02 mm all the dimensions were been measured.
On a motor capacity of 100N load cell was fixed and at a uniform rate of 0.57 mm/s vertically it was applied .Further a potentiometer was used for measuring the deformation signal .Into the amplifier and A/D converter both the signals of force and deformation were transmitted and then logged in a computer . The specimen’s bending moment and section modulus quotient were used for obtaining the bending stress of bio-boards. When the specimen got fractured quotients of maximum stress and section modulus defined the rupture stress. “As per William,(1957) the classic formula for determining bending stress is given “ :

$$\sigma_b = \frac{3PL_s}{2ba^2} \tag{3.1}$$

Where P = force at fracture of the test specimen; Ls = bearing distance between the supports; b = width of test specimen; a = thickness of test specimen.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Fig-3.1- UTM
To determine the internal bond strength, tensile strength tests were done by UTM under strict deformation control.
.
Speed of cross-head was 15mm/min. 20 specimens taken from five bio-boards named A2 ~ E2 & all were subjected to tensile strength tests following standard JIS procedures and
Recommendations (JIS z 2201) illustrated in figure 3-2.
Normal stress is defined by the quotients of axial load applied on specimen and original cross-sectional area of the specimen. Rupture stress was obtained when the axial load reaches to maximum value while the specimen was fractured. Rupture stress
is expressed below:

$$\sigma_t = \frac{P}{A}$$

Where P = the maximum axial load, A= original cross-sectional area of gauge section

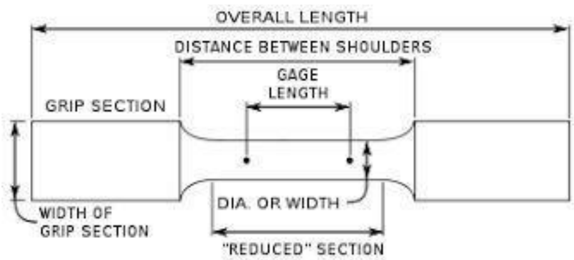

Fig-3.2
Shoulder length =50 mm, dia =12.4 mm. fillet radius= 14 mm

4.1 -Measurement of density and moisture content

The five conditions of experiment were demonstrated by making ten bio-boards. Two bio-board for each experimental conditions .Named A1, A2, ~, E1, E2.
The bio-board thickness has been measured by a method mentioned below.
On one bio- board firstly three horizontal lines and then three perpendicular lines were drawn then the bio-board area was divided into 16square blocks, area of each block 25mm*25mm .
For measuring the thickness eight points at the outer side of the four blocks in the center of board were selected .Therefore the bio-board densities were calculated, as given below:

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

Density = hot presser dry weight (g)/ sample volume (cm3)
After the strength tests. analysis of moisture content were done : specimens were numbered and then cut into chips and weighted , at 100 degree Celsius oven dried till constant weight , as per JSPP (2007) the percentage of moisture was calculated

5.1 -Young's modulus and strain energy

In the test of tensile strength, Young's modulus of bio-board was calculated from the curve of stress-strain . Material toughness is defined as the amount of energy per unit volume that a material can absorb before getting ruptured . It can also be defined as the resistance of a material against fracture when stress is given . And strain energy density is defined as strain energy per unit volume and it is the area beneath the curve of stress-strain up to the deformation point .As per the definitions static toughness of the five bio-boards has been calculated with the following formula

$$U = \int_0^{\varepsilon_f} \sigma d\varepsilon$$

Where, U= static toughness, σ= stress, ε= strain, εf = strain at fracture point.

6- Results and discussion

6.1- Board making - Bending test has been carried on bio board A1, B1, C1, D1, E1 while tensile strength was done on A2, B2, C2, D2, E2 .The dimension of all the bio-board was 100mm*100mm area wise and thickness wise 1.27 mm-1.56 mm .In the figure below the front and side of one bio-board has been shown .Thus this experiment has proved that we can successfully make bio-board under all the experimental conditions. Not just the bio-board also the processes involved in making bio-board proved to be successful**.**

Figure 6.1-: Bio-board

In the figure below density of bio-board demonstrated that respective density of bio-board is in the range of 0.87g/cm^3.-1.02g/cm^3. Density of the board slightly increased due to five pressure levels in the range of 2MPa to 10Mpa .Under 2Mpa the density of board is minimum .At 8Mpa the board density was maximum.
The moisture contents of bio-board made in this study showed a range of 3% ~ 6% in wet base. Properties of density and wet-basis moisture content of bio-boards are similar to MDF (medium density fiberboard) 5 Type ~ 30 Type based on JIS A 5905-2003

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

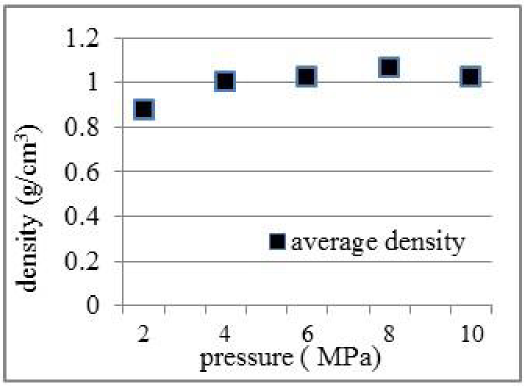

Fig-6.2 density versus pressure curve of bio-board

7.1-Section of bio-board

The bioboards seen through magnified electron microscopic represents the sectional image of the specimen. Inside the bio-board the corn straw fibers observed were compact and irregular .The image also shows a dentation fracture of the specimen. The fracture in the specimen is rough. In the fragment uniform fibrous fracture is clearly evident. Reason for this may be because of composite nature of bio-board. Performance of the bio-board depends on strength of its constituent units also their geometries and the unit to unit bonding.

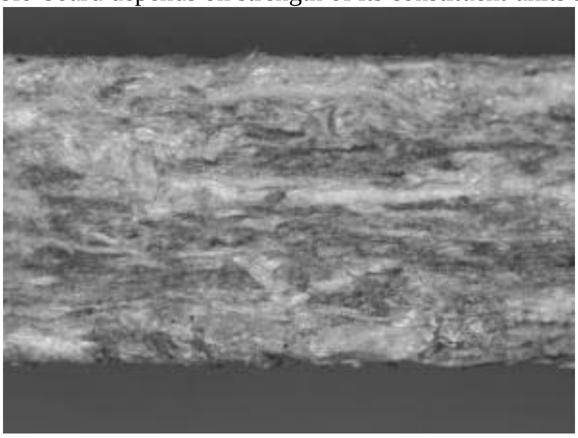

Fig 7.1- electron micrograph of bioboard

8.1- Bending strength test

For the bending test the twenty five specimens that were obtained from bio-board A1 to E1 were provided. In the figure below the curves of stress- deflection of the five boards has been shown in different figures shown below. Changes in the bending stress were applied to the five specimens then compared in the curves of stress-deflection. Generally the value of stress increases with increase in deflection until it reaches a maximum value .Additionally; stress-deflection curves almost approached a straight line before the fractures occurred. Approximately at 2 mm deflection fracture in the specimen occurred (value of rupture stress thus obtained) .
After the fractured occurred there was sharp decrease in the bending stress reaching an early zero , as the fibers were still connected , so bending stress, still appeared . In comparison to the other four specimens of one bio-board a distinct high peak in the value was observed in the boards of A1-P1, B1-P1 and C1-P4.
Unique characteristics are described by the curve of stress-deflection shows different modulus of elastic and rupture strength of each & every specimen, which was observed & noted. .

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

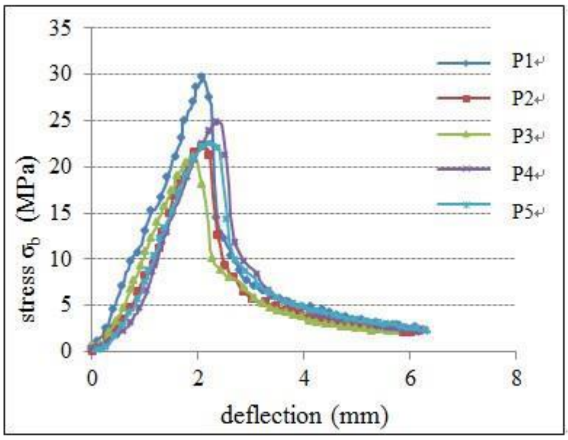

Fig8.1 - Stress of bio-board A1

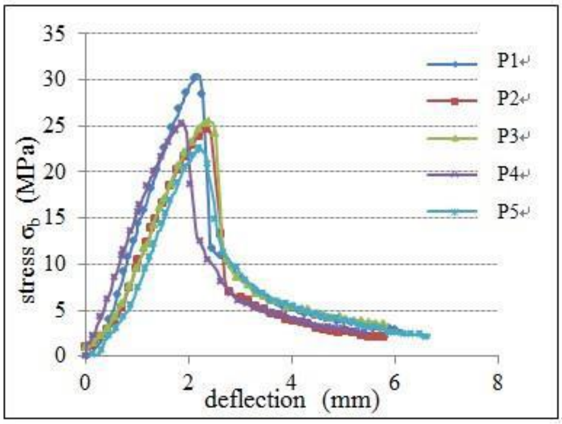

Fig 8.2 -Stress of bio-board B1

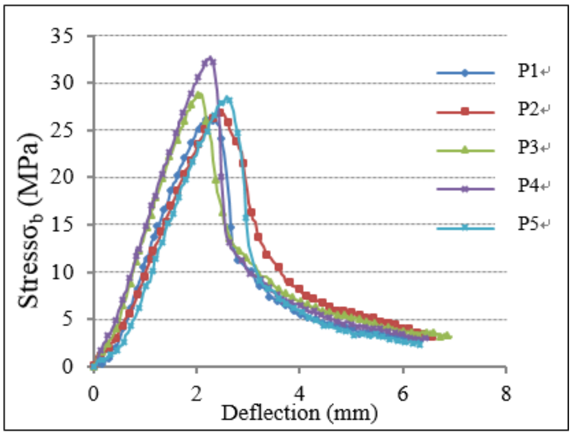

Fig 8.3 -Stress of bio-board C1

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

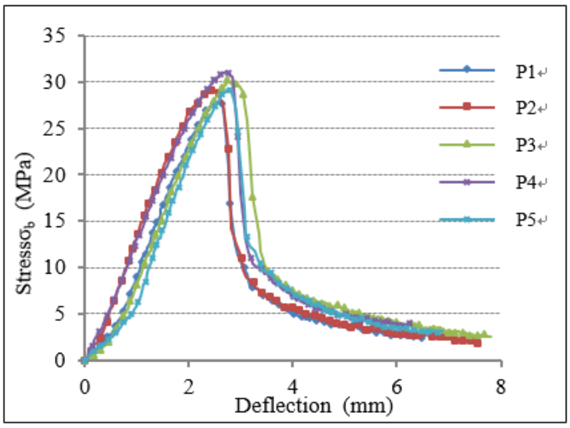

Fig 8.4 -Stress of bio-board D1

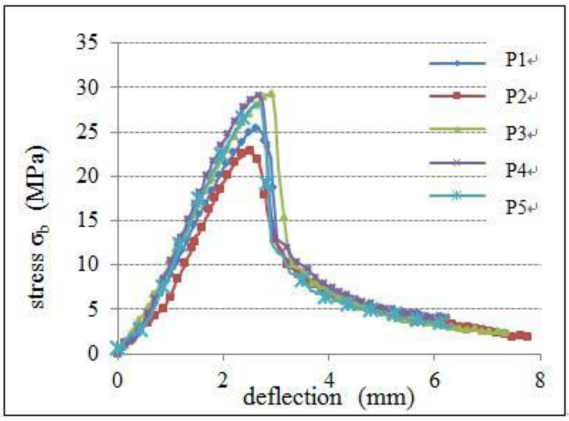

Fig 8.5 -Stress of bio-board E1

In the figure below different values of the rupture stress that is maximum value , minimum value , average value of the bio-boards were calculated from the curves of stress-deflection . The results indicated that high rupture stress was obtained when high pressure was applied; there was slight decrease in the rupture stress when 10MPa pressure was applied. Variations in the densities of bio-boards indicates that at 10Mpa density of EI bio-board is low in comparison to D1 bio-board Also , minimum variation was observed in the rupture stress of board D1.

In figure 3-15 the bending rupture stresses of board A1-E1 has been shown. As per the strength test results, it is clearly evident that rupture stress of all the five bio-board is different. At 8Mpa pressure maximum bending rupture stress of 29.37Mpa, occurred. Thus the results of the bending strength test proved that when 8Mpa pressure was applied during forming process it would be appropriate for producing bio-board.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

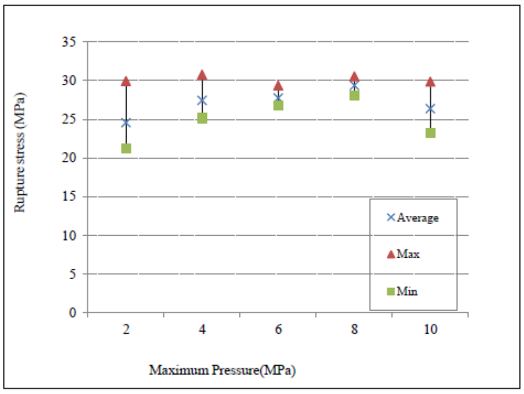

Fig 8.6 -Rupture stress of five provided Bio-board for bending test

9.1 - Tensile strength test

Tensile strength is one of the significant mechanical properties of bio-boards; test on different bioboards was conducted named as -. A2, B2, C2, D2, E2 respectively and were used in the test of tensile strength, then the curves of stress-strain are represented as shown in the figure below (fig 9.1 to fig 9.5). In the beginning all the curves indicated stress-strain curve, as the strain increased tensile stress increased, when the tensile strength reached maximum value specimen broke, then tensile strength decreased all of a sudden to zero. This maximum value is known as the tensile rupture stress.

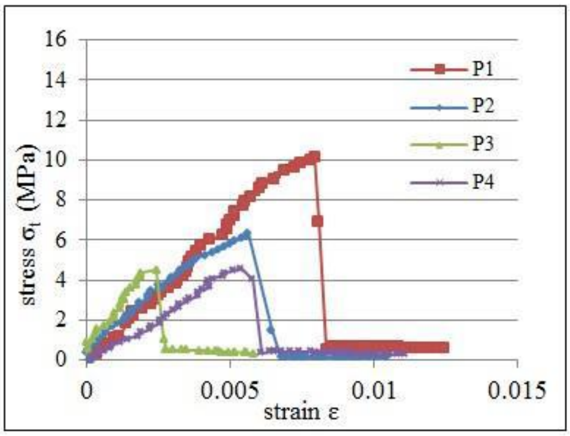

Fig 9.1-Stress-strain curve of bio-board A2

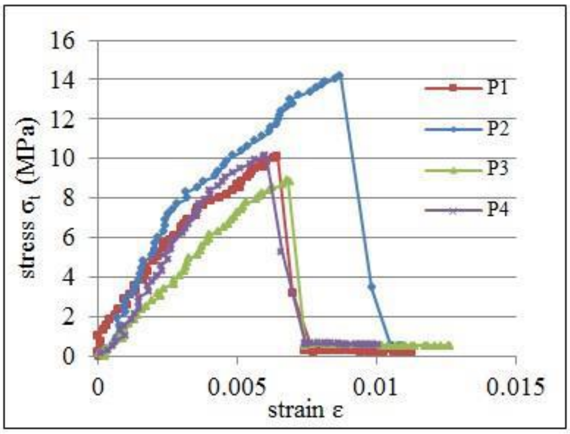

Fig 9.2-Stress-strain curve of bio-board B2

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

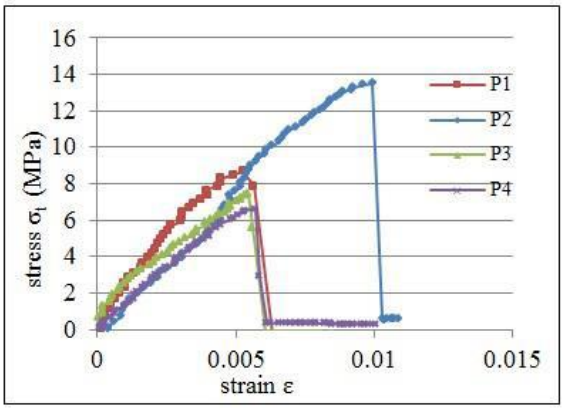

Fig 9.3- Stress-strain curve of bio-board C2

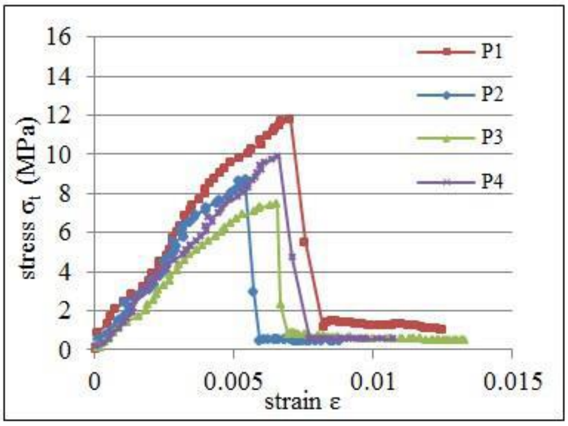

Fig 9.4- Stress-strain curve of bio-board D2

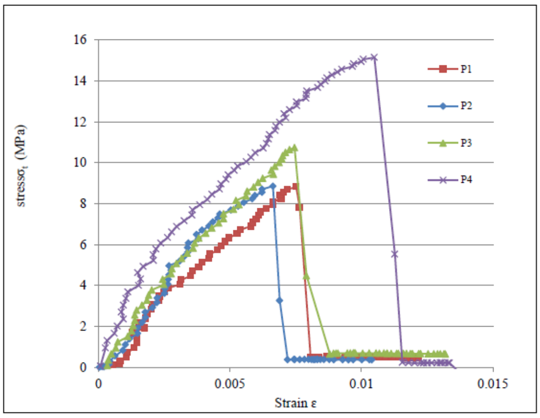

Fig 9.5- Stress-strain curve of bio-board E2

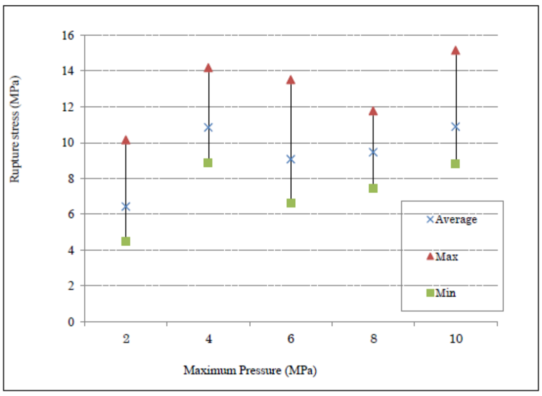

Fig-9.6 Tensile test report of bioboards rupture stress

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

In the figure above tensile rupture stress of five bio-boards has been shown with their minimum value, maximum value and average value.
Rupture stress has been obtained from the boards of A2 ~E2 shows a large variation & was observed between the minimum and maximum stress in one of the bio-board . In the table below rupture stress revealed that board E2 has attained, maximum rupture stress of 10.89MPa, when 10MPa pressure was applied, to make it.
If we compare different values showing bending rupture stress, we will notice that rupture stress σ_{tf} is lower, than bending rupture stress σ_{bf} . According to "An Introduction to the Building Standard Law NO.1452", the bending stress of coniferous wood is higher than tensile stress, because bio-board as well as wood is essentially composed of cellulose hemicelluloses, lignin, and extractives (Sjostrom 1993).

In the table below Bending rupture stress (σ_{bf} and tensile strength rupture stress (σ_{tf}) have been shown . We have stated two reasons why this distinct variation occurred. Firstly as stated by Kageyama (1998) in comparison to metal the distribution of stress in the material of fiber are more complex.
The stress distribution specimen in the test of bending performs in tension under neutral axis whereas above the neutral axis specimen suffered compression behavior .For the test of tensile strength , the specimen suffered tension force and tensile stress was distributed in the thrust surface area only .Secondly ,
Fibrous bio-board stress might relate to recombination of fiber due to mechanical properties of cellulosic fiber as proved by (The society of Polymer Science, Japan. 2009).

Table 9.1: Average rupture stress of bio-board

	2MPa	4MPa	6MPa	8MPa	10MPa
σ_{bf} (MPa)	24.58	27.50	27.78	29.40	26.45
σ_{tf} (MPa)	6.45	10.88	9.09	9.48	10.92

10.1 - Young's modulus and strain energy

In the test of tensile strength it was seen that the curve of stress-strain approached a line before the fracture in the specimen .Thus the association between stress and strain on the approximate portion of the curve of stress-strain was modeled linearly. In the table below Young's modulus of the bio-boards has been calculated and displayed .It was found that the Young's modulus of elasticity (E) , in each bio-board is different . Various deformation performances, was shown by four specimens of one of the board. 1.4GPa~1.8GPa is the average value or range of Young's modulus of bio-board prepared.

Table 10.1-Young's modulus of bio-boards

pressure(MPa)	range of *E* (GPa)	average *E*(GPa)
2	0.9 ~2.3	1.5
4	1.6~ 2.0	1.9
7	1.4~ 2.0	1.7
9	1.4~ 1.8	1.7
11	1.3~ 1.8	1.6

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 640-654
Received 25 April 2021; Accepted 08 May 2021.

CONCLUSION-

In the table below average static toughness of the five bio-boards has been shown. The findings showed that specimens were greatly affected with the values of pressure exerted, during forming. Maximum static toughness of 85KPa was shown by board E2 when it was made under 10MPa pressure condition on the contrary board A2 showed Minimum static toughness of value 48.3KPa ,when it was made under 2MPa pressure condition

Table 10.2 - Static toughness of bio-board

	A2	B2	C2	D2	E2
Range (KPa)	23~91	64~106	47~109	53~99	66~124
Average (KPa)	48.3	76.5	67.5	74.0	85.0

Limitations and Future Studies -

Due to the season dependent crop the tests performed are also done in the season just after crop cutting, so in future studies with modern biotech technologies we can try to produce the crop in all seasons & can perform all the above tests in all season & can study the changes in parameters of bioboards produced if any. With modern & much more advanced scientific electron micrograph the intermolecular constituent of produced bioboards & the effect of pressure on them may be studied in much better way & we may get some other advanced observations also, which may help in producing much better quality bioboards, also we may test on algae or on some other new biodegradable materials in producing bio-boards & compare their mechanical properties,

Acknowledgement-

This paper and the research behind it would not have been possible without the exceptional support of my supervisor, Dr Rajendra Kumar Srivastava. His enthusiasm, knowledge and exacting attention to detail have been an inspiration and kept my work on track from my first encounter with the corn straw in his farm house to the final draft of this paper.
I am most thankful for my University Doctoral library, that has provided me help in accessing different research papers & hence supported for the larger project, from which this paper grew, I would also like to support Mr Atul Yadav the farmer ,whose generous offer of free accommodation ,allowed me to continue my research . Finally, my deep and sincere gratitude to my family for their continuous and unparalleled love, help and support. I am grateful to my wife for always being there for me as a friend. I am forever indebted to my parents for giving me the opportunities and experiences that have made me who I am

References:

[1] - Alcaide, L. J., Baldovin, F. L., & Herranz, J. L. (1993). Evaluation of agricultural residues for paper manufacture. *Tappi Journal;(United States)*, *76*(3).

[2] Bowyer, J. (1995). Wood and other raw materials for the 21st century. *Forest Products Journal*, *45*(2), 17.

[3] Hubbe, M. A. (2006). Bonding between cellulosic fibers in the absence and presence of dry-strength agents–A review. *BioResources*, *1*(2), 281-318.

[4] Clancy-Hepturn, M. (1998). Agricultural residues: a promising alternative to virgin wood fiber. *Issue in Resources Conservation, Briefing Series*, *1*.

[5] Nichols, D. S., & Boelter, D. H. (1984). Fiber size distribution, bulk density, and ash content of peats in Minnesota, Wisconsin, and Michigan. *Soil Science Society of America Journal*, *48*(6), 1320-1328.

[6] Fletcher, D. (2010). Worst Inventions Plastic Grocery Bags. *Time Lists, The*, *50*.

[7] Rowell, R. M., Young, R. A., & Rowell, J. (1997). Paper and composites from agro-based resources CRC Press Inc. *Madison, WI*.

[8] Hurter, A. M. (1988). Utilization of annual plants and agricultural residues for the production of pulp and paper. In *Pulping Conference:[proceedings](USA)*.

[9] Ilvessalo-Pfäffli, M. S. (1995). *Fiber atlas: identification of papermaking fibers*. Springer Science & Business Media.

[10] Del Río, J. C., Rencoret, J., Prinsen, P., Martínez, A. T., Ralph, J., & Gutiérrez, A. (2012). Structural characterization of wheat straw lignin as revealed by analytical pyrolysis, 2D-NMR, and reductive cleavage methods. *Journal of agricultural and food chemistry*, *60*(23), 5922-5935.

[11] Tanka, V. D. (2018). *Effect of Temperature On, And the Efficacy of Eucalyptus Leaf Extracts Against Sitophilus Zeamais Motschulsky (Coleoptera: Curculionidae) in Stored Maize* (Doctoral dissertation, University of Ghana).

[12] Kellicutt, K. Q. (1951). Basic Design For The Use of Fiberboard in Shipping Containers. *NoD1911, United States Department of Agriculture, Forest Service, Forest Products Laboratory*, *12*.

[13] Tingting, W. U. (2015). Graduate School of Bioresources, Mie University

[14] Mobarak, F., Fahmy, Y., & Augustin, H. (1982). Binderless lignocellulose composite from bagasse and mechanism of self-bonding. *Holzforschung*, *36*(3), 131-135.

[15] Chandra IV, M. (1998). Use of nonwood plant fibers for pulp and paper industry in Asia: Potential in China.

[16] Balat, M., & Ayar, G. (2005). Biomass energy in the world, use of biomass and potential trends. *Energy sources*, *27*(10), 931-940.

[17] Nakagawa, Y., & Saito, K. (2006). Examination of Cushioning Property for Sleeve-structure Corrugated Fiberboard. *Japan Institute of Navigation*, *116*, 261-268.

[18] Saad, M. J., & Kamal, I. (2012). Mechanical and physical properties of low density kenaf core particleboards bonded with different resins. *Journal of Science and Technology*, *4(1)*

[19] Sabharwal, H. S., Akhtar, M., Blanchette, R. A., & Young, R. A. (1995). Refiner mechanical and biomechanical pulping of jute. *Holzforschung*, *49*(6), 537-544.

[20] Schellenberger, S. (1995, June). Overview of agrifibre utilization potential in Alberta. In *Proc. Alberta Agripulp Workshop on Pulp from Crop Residues*.

[21] Tingting, W. U. (2015). Graduate School of Bioresources, Mie University.

[22] Sun, H., Wang, X. L., & Kito, K. (2010). May. Production of Bio-board and Its Mechanical Properties.

Society of Environmental Conservation Engineering. *International Information Institute*, *13*(3), 1005-1011.

[23] Ye, X. P., Julson, J., Kuo, M., Womac, A., & Myers, D. (2007). Properties of medium density fiberboards made from renewable biomass. *Bioresource Technology*, *98*(5), 1077-1084.

[24] Koshiba, T., Yamamoto, N., Tobimatsu, Y., Yamamura, M., Suzuki, S., Hattori, T., ... & Umezawa, T. (2017). MYB-mediated upregulation of lignin biosynthesis in Oryza sativa towards biomass refinery. *Plant Biotechnology*, 16-1201.