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ANALYSIS OF MECHANICAL BEHAVIOUR OF HYBRID FIBER (JUTE-GONGURA) REINFORCED HYBRID POLYMER MATRIX COMPOSITES

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In this work, an attempt is made to study the mechanical behaviour of polymer based composite made of hybrid natural fiber reinforcement and hybrid polymeric matrix. The natural fibres used for the reinforcement are Jute fibres and Gongura fibres. Both the fibres are used in the long continuous form and are taken in a standard size of 2mm diameter. The hybrid matrix is prepared with a combination of 75% and 25% by volume of general purpose resin (GP) resin and cashew nut shell liquid (CNSL) oil respectively to increase the green content of the matrix material. Fibres are subjected to alkaline treatment by using different concentrations of alkaline sodium hydroxide (NaOH) for different time periods to improve the adhesiveness and strength of the fibres. Hybrid composites are prepared by using hand layup technique. The composition of composite material was decided based on Taguchi L9 orthogonal array with three parameters and three levels for each parameter were employed in the design of experiments procedure. As per the results of L9 array, nine specimens were prepared for each test. The influence of different parameters on flexural strength of the composite is studied using analysis of variance (ANOVA) technique. Flexural test is conducted to find the maximum flexural stress and maximum deflection. Fatigue test is for finding the maximum fatigue life of the composite. Fracture test is performed to find the fracture behaviour of the material. Vibration test is performed to find out the natural frequency of the hybrid composites prepared.

Keywords: Hybrid composites, Green composites, CNSL, GP resin, Jute fiber, Gongura fiber.

1. Introduction

The use of polymer composites in industrial applications are increasing due to its superior properties like lightweight, design flexibility, low cost, etc. Polymer composites contain two phases namely reinforcement phase and the

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matrix phase. The reinforcements can be fibers, particulates or whiskers, and the matrix materials can be metals, plastics or ceramics. Due to the increasing demand from the industries for the development of green composites, the research are being under taken in the filed of green polymer composites by researchers.

Chandramohan D. and J. Bharanichandar [1] investigated the advantages of using natural for the development of composite materials based on polymer and particles of natural fibers for Conservation of natural resources. In this research, natural fibers like Sisal (*Agave Sisalana*), Banana (*Musa Sepientum*) and Roselle (*Hibiscus Sabdariffa*), Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and Sisal (hybrid) are fabricated with bio epoxy resin using molding method and the mechanical properties were evaluated. G.Venkatachalam et al. [2] studied the tensile behaviour of Gongura natural fibres according to the industry requirement. Polyester resin is used as the matrix. The composite is prepared manually and its tensile behaviour is studied. The study on tensile behaviour of these composite shows good agreement with traditional composites. The variation of the tensile strength and Young's modulus with change in the fiber volume fraction is studied and analysed.

Cashew nut shell liquid (CNSL) oil, a phenolic based monomer is commercially available, a good example of a natural plant based resin precursor. The main constituents of cashew nut shell liquid are Cardanol, Anacardic acid, Cardol, 2-Methyl Cardol and small amount of polymeric material. The application of CNSL as a full replacement for synthetic resins is of immense interest in these days of diminishing petroleum reserves. L. Y. Mwaikambo and M. P. Ansell [3] reported the curing characteristics of the cashew nut shell liquid (CNSL). In this work the DSC technique has been applied to study the change in the Glass transition temperature of the oven-cured resin with and without HMTA in order to monitor the extent of cure. General purpose resin is unsaturated polyster resin which belongs to the Thermoset category of the synthetic resins. It possesses good mechanical and service properties and has excellent stability and weather resistance.

Alkaline treatment was performed on the fibers to increase the strength and adhesiveness. Dipa Ray et al. [4] studied the influence of alkaline treatment of Jute fibers over the mechanical properties of the composites. In this study Jute fibres were subjected to a 5% alkali (NaOH) solution treatment for 0, 2, 4, 6 and 8 h at 30°C. On plotting the different values of slopes obtained from the rates of improvement of the flexural strength and modulus, against the NaOH treatment time, two different failure modes were apparent before and after 4 h of treatment. In the first region between 0 and 4 h, fibre pull out was predominant whereas in the second region between 6 and 8 h, transverse fracture occurred with a minimum fibre pull out. This observation was well supported by the SEM investigations of the fracture surfaces. M. Boopalan et al. [5] investigated and compared the mechanical properties of raw Jute and Sisal fiber reinforced epoxy composites with sodium hydroxide treated Jute and Sisal fiber reinforced epoxy composites. The mechanical properties (tensile and flexural strength), water absorption and morphological changes were investigated for the composite samples. R. E. Mjoku et al. [6] analysed the effect of alkali treatment and fiber content variation on the tensile properties of Coir fiber reinforced cashew nut shell liquid (CNSL) composite. The results showed that tensile strength and modulus of the CNSL/Coir composite increased as the weight fraction of Coir fibers was increased up to a fiber content of 30%. The alkali- treated CNSL/Coir composite laminates showed improved tensile properties and this was attributed to an improvement of interfacial fiber-matrix adhesion in the composites.

Hybridisation of composites is commonly made for improving the properties and for lowering the cost of conventional composites. In this research work, "Hybrid green composites" are prepared, which is basically a “Hybrid Natural Fiber" reinforcement in hybrid resin matrix. Jute fibers and Gongura fibers are used make hybrid reinforcements. General purpose resin and CNSL resin mixture is used as hybrid resin. Hybrid composites are designed and developed with a view of utilizing the positive aspects of both the materials used for the development of the composites.

Girisha K. G. et al. [7] investigated the mechanical properties of epoxy and polyester matrix composites reinforced with Jute/Hemp fibres. The mechanical properties like impact strength, tensile strength and flexural strength were studied. The outcome of the research work suggests that the mechanical properties of the hybrid composites were found to be superior to that of the properties of the composites with fibers separately. Vasantha V. et al. [8] made an attempt to use coir fiber as the major reinforcement and rice husk as an additional fiber to improve the mechanical property of polymer composite with vinyl ester as the base material prepared by hand layup process. Test specimens are prepared with different weight fractions of Coir fiber at the optimization point of tensile test a small percentage of rice husks are added and tests were conducted and the improvement in mechanical properties of the hybrid composite material is observed.

Mohan Babu K. et al. [9] attempted to produce natural fibre made hybrid polymer composite. The matrix is made from cashew nut shell resin and general purpose resin with Jute as fiber. The hybrid polymer is made by mixing cashew nut shell liquid with general purpose resin in different proportions. The stress strain behaviour of composite during tensile loading is studied in this work. The test results show that by the addition of cashew nut shell resin, the strength of the composite decreases. Sharayu U. et al. [10**]** studied the vibration analysis of the composite materials. The present study involves extensive experimental works to investigate the free vibration of woven fiber Glass/epoxy composite plates in free-

free boundary conditions. Elastic parameters of the plate are also determined experimentally by tensile testing of specimens.

M. Ramesh et al. [11] evaluated the mechanical properties of hybrid Sisal-Jute-Glass fiber. In this study, Sisal–Jute–Glass fiber reinforced polyester composites is developed and their mechanical properties such as tensile strength, flexural strength and impact strength are evaluated. The results indicated that the incorporation of Sisal–Jute fiber with GFRP can improve the properties and used as a alternate material for Glass fiber reinforced polymer composites. Mohan Badu et al. [12] attempted to produce natural fibre reinforced hybrid polymer composite. The stress strain behaviour of composite during tensile loading is studied in this work. The test results showed that by the addition of cashew nut shell resin, the strength of the composite decreases. A. Athijayamani et al. [13] studied the mechanical properties of short Roselle and Sisal hybrid fiber reinforced polyester composite. Analysis was made based on the weight percentage for constant length of the fibers. The fractured surfaces of the composite specimens were investigated using Scanning Electron Microscopy. A positive hybrid effect was observed in tensile and flexural strength, while the fiber content increase. But a scatter and negative hybrid effect were observed in impact strength, while the fiber content increase.

Sharifah H. et al. [14] used long and random Hemp and Kenaf fibers combined with cashew nut shell liquid (CNSL) resin and hot-pressed to form natural fibre, natural matrix composite. The mechanical properties of the composites were investigated to observe the effect of fibre alignment and alkalization. Lifang Liu et al. [15] reported the fabrication of bio-composites with biodegradable polymer PBS and Jute fibre, and the effects of fibre surface modification on characteristics of Jute fibre and mechanical properties of the bio-composite were evaluated in this paper. The experimental results show that surface modification can remove surface impurities and reduce diameter of Jute fibres.

N. Venkateshwaran et al. [16] investigated the tensile strength and modulus of short, randomly oriented hybrid-natural fiber composite experimentally and also predicted using Rule of Hybrid Mixture (RoHM).The comparison between experimental and RoHM showed that they are in good agreement. F. Corrales et al. [17] studied the chemical modification of Jute fiber for producing green composites. Chemical modification of Jute fiber was done using a fatty acid derivative (Oleoyl Chloride) to provide hydrophobicity and resistance to biofibers. Kumar and Reddy [18] investigated the tensile properties of Jute/Sansevieria Cylindica fibers reinforced epoxy based hybrid composites. Significant improvement in tensile strengths of the Jute/Sc hybrid composites has been observed by the alkali treatments.

2. Experimental procedure

2.1 Design of experiments procedure

The number of samples to be prepared for various testing is designed using Taguchi method, in which 'L9 ARRAY' is used with three parameters and three different levels for each parameter respectively. The three parameters are percentage of NaOH concentration with levels 5%, 10% and 15% duration of fiber treatment with levels 6, 12 and 24 hours and third parameter is the nature of the fibre which is the combination of the fibres in three different types. Here the three levels are taken as A, B and C where each one of them represents different fibre combinations. The various combinations are as follows.
A: 3 Jute fibres +1 Gongura fibre;
B: 2 Jute fibres + 2 Gongura fibres;
C: 1 Jute fibre + 3 Gongura fibres.

Nine different test specimens are prepared with the combination of all the three parameters and with their respective levels. The table 1 below shows the nine different samples prepared for the experimentation.

Table 1

Test samples for experimentation

S. No	Duration of Fiber treatment (Hours)	% NaOH	Fibers combination
1	6	5	A
2	6	10	B
3	6	15	C
4	12	5	B
5	12	10	C
6	12	15	A
7	24	5	C
8	24	10	A
9	24	15	B

2.2 Preparation of the composites

The fiber treatment is carried out to improve the strength and adhesion characteristics, due to improved work of adhesion because it increases the surface tension and surface roughness. Fibers are treated with alkaline NaOH solution to enhance the strength and adhesiveness of the fiber and the matrix.

Composites specimens are prepared by using hand lay-up technique. Treated Jute and Gongura fibers are used as the reinforcement for the composites. Both the fibers are taken in the long forms and the diameter of the fibers is taken as 2mm. The fibers are placed in the moulds in straight manner before pouring the resin into the moulds. Moulds with different dimensions are used to prepare the composite specimens for different tests as per the required standards. Methyl Ethyl Ketone Peroxide (MEKP) is used as the catalyst and Cobalt 60 is used as the hardener for the matrix mixture of 75% GP resin and 25% CNSL oil. The Figs. 1-3 show the different stages of composite preparation. Fig. 1 shows the fibers placed in the moulds before pouring the matrix. Fig. 2 shows the prepared composites in the moulds after pouring the matrix.

Fig. 1 Fibers placed in the moulds before adding the matrix

Fig. 2 Composite specimens inside the moulds after curing

The specimens are allowed to cure in the normal atmospheric conditions for five days to get completely cured. Figure 3 shows the completely cured composites taken out from the moulds. Later the composites are trimmed to get the required size and dimensions as per ASTM standard for the different tests like flexural, vibration fracture and fatigue.

Fig. 3 Cured composites taken out of the moulds

2.3 Flexural test

Flexural test is performed to find out the maximum flexural stress in the composite material prepared. The test specimens are prepared according to the ASTM D-790-10 standards, for which specimens are prepared with the dimensions 200mm×20mm×8mm. The prepared samples are tested using INSTRON testing machine. Testing setup is shown in the Fig. 4.

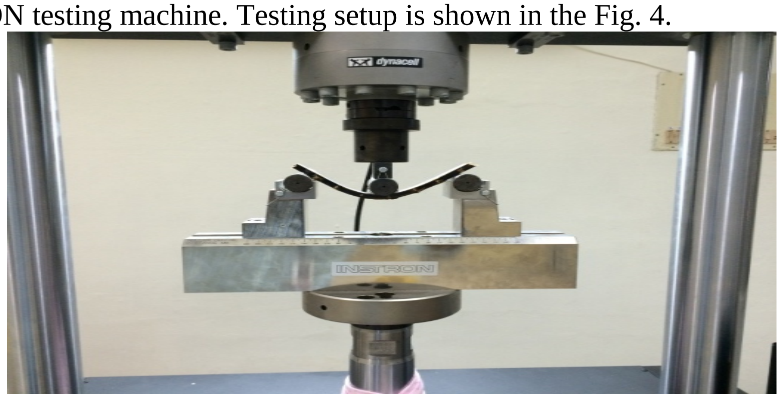

Fig. 4 Flexural testing setup

2.4 Vibration testing

Vibration testing is carried out to find the "Natural frequency" of the composites prepared. By finding the Natural frequencies of the specimens, one can determine the different mode shapes, thereby predicting the failure mode of the specimen. Pre determining the natural frequency of the specimen helps in avoiding the failure of the material under loading. Failure of the material can be avoided by operating or subjecting the material with the vibrations with the applied frequencies lesser than the natural frequencies of the material thereby avoiding the resonance phenomenon. Resonance is a phenomenon which takes place when the applied frequency is equal to the natural frequency of the system. During resonance, the System vibrates with the maximum possible amplitude leading to the failure of the material (system).

Vibration test samples are prepared as per the ASTM standards. As per the standards followed, the specimens are prepared with the dimensions 300mm×30mm×4mm. Since the specimens are prepared with matrix combination of 75% GP resin and 25% CNSL oil, the span length was taken as 200mm. Vibration testing setup are shown in the Fig. 5.

Fig. 5 Vibration testing setup

2.5 Fracture Test

Fracture test is carried out to determine the stress intensity factor (k) of the material. Fracture test specimens are prepared with the dimensions 96.8mm x 22mm x 5.5 mm. Gauge length from the testing was taken as 88mm. A notch is created and then made a pre crack with the help of a blade. Pre-crack length (a), chosen by a/W ratio, is equal to 0.5. Fig. 6 present the fracture test setup and specimens.

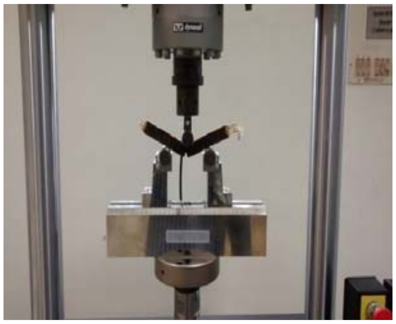

Fig. 6 Fracture test setup

2.6 Fatigue test

Fatigue test is performed to find out the fatigue life of the material. The test specimens are subjected to alternative tension and compression loading over a period of time as shown figure 7. Fatigue test samples are prepared as per the ASTM D3479 standards. Dimensions of the specimen is 200mm×30mm×4mm The number of cycles of alternate tension and compression loading required to cause the failure of the specimen is measured. The specimen which takes the maximum load and maximum number of cycles of loading has the maximum possesses the maximum fatigue life. Fatigue test was performed by using INSTRON testing machine.

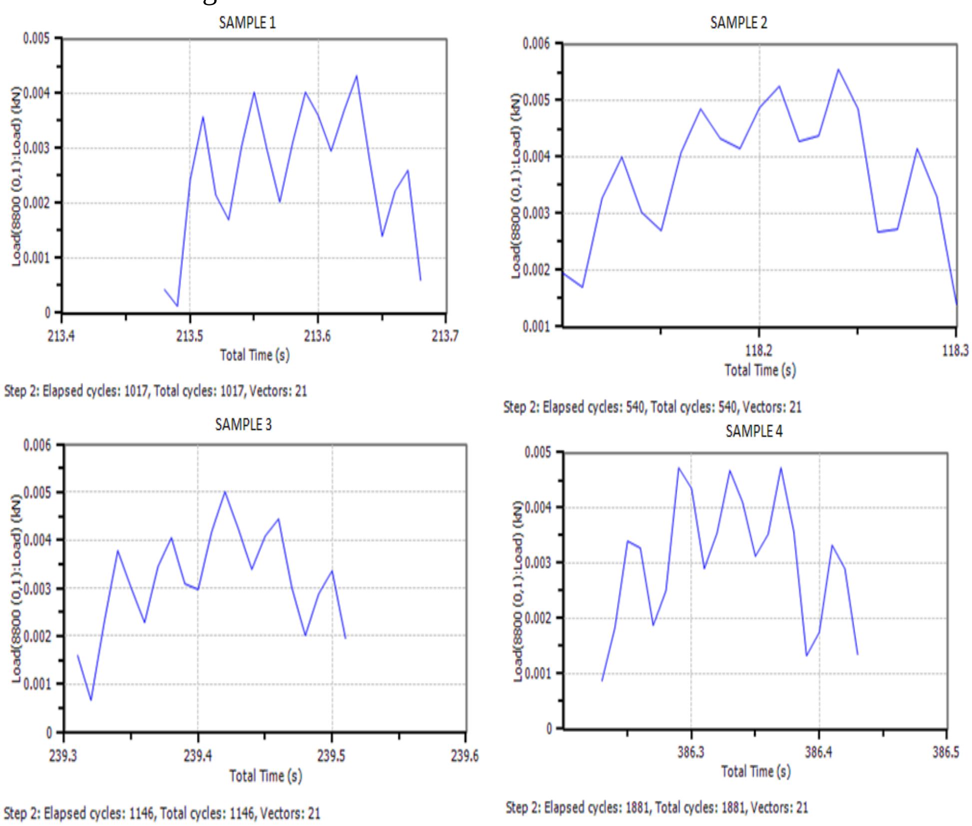

Fig. 7 Fatigue load cycle in INSTRON machine

3. RESULTS AND DISCUSSIONS

3.1 Flexural test results

Table 2.

Flexural test results

Sample No	Fiber treatment duration(Hours)	NaOH %	Fiber Combination	Maximum Flexural Stress (MPa)
1	6	5	A	3.34
2	6	10	B	3.33
3	6	15	C	2.472
4	12	5	B	3.001
5	12	10	C	2.543
6	12	15	A	4.206
7	24	5	C	2.396
8	24	10	A	4.692
9	24	15	B	2.659

From the table 2, it can be inferred that the Composite with fiber combination of 3 Jute and 1 Gongura fibers possesses maximum flexural strength for all the % NaOH concentration and fiber treatment duration. Among all the samples, Sample no 8 that is Composite with 3 Jute- 1 Gongura fiber combinations treated with 10% NaOH for 24 hours gives the maximum flexural stress.

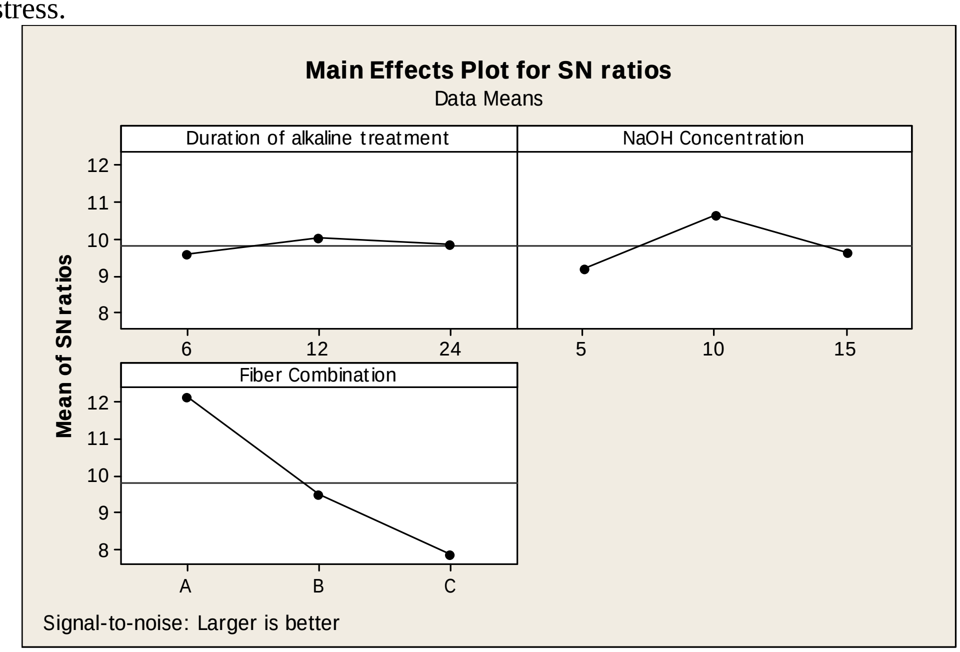

Fig. 8 Main Effects Plot for Flexural Stress

From figure 8, it is inferred that Fiber Combination has a higher influence on the Flexural Strength of the composite compared to other two parameters. There is a considerable increase in the flexural strength when the alkali concentration is increased from 5% to 10% followed by a significant decrease. The optimum fiber combination and NaOH concentration is A and 10 respectively. Duration of alkali treatment has the least influence on the flexural strength of the composite.

3.2 Fracture test results

Table 3

Fracture test results

Sample No	Fiber treatment duration(Hours)	NaOH %	Fiber Combination	Stress intensity factor (MPa-$m^{1/2}$)
1	6	5	A	20.27
2	6	10	B	22.32
3	6	15	C	23.72
4	12	5	B	22.33
5	12	10	C	30.22
6	12	15	A	26.99
7	24	5	C	18.66
8	24	10	A	19.33
9	24	15	B	23.79

Table 3 presents the Stress Intensity Factors of the respective specimens. The stress intensity factor for each of the specimens is calculated using the formula

$$\text{Stress intensity factor} = \sigma \times \sqrt{\pi a}$$

where, $\sigma =$ Maximum flexural stress, a = Notch length, here notch length has taken as 10mm.

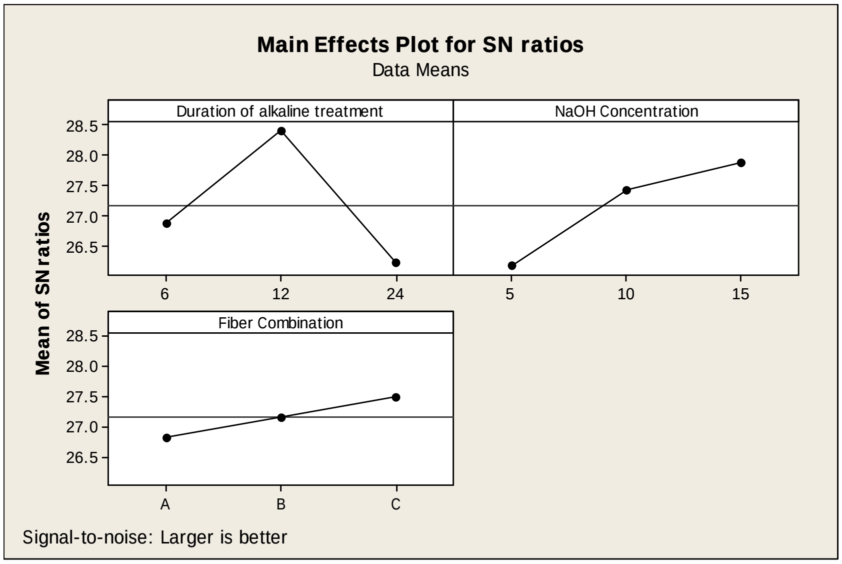

Fig. 9 Main Effects Plot for Stress Intensity Factor

From Fig. 9, it is inferred that the Stress Intensity Factor is directly proportional to the volume of Gongura fibers and alkali concentration. The optimum Fiber combination and NaOH Concentration is C and 15 respectively. There is an increase in the Stress Intensity Factor when the Duration of alkali treatment is increased from 6 to 12 hours followed by a decrease when the duration of alkali treatment is further increased to 24 hours.

3.3 Vibration test results

Vibration test is carried out for all the nine samples with 25% CNSL. The first natural frequency of the specimens is obtained and is presented in table 4.

Table 4

Vibration test results

S. NO	Duration(Hours)	NaOH %	Fiber Combination	Natural Frequency (Hertz)
1	6	5	A	62.50
2	6	10	B	50
3	6	15	C	56.25
4	12	5	B	56.25
5	12	10	C	62.50
6	12	15	A	62.50
7	24	5	C	62.50
8	24	10	A	56.25
9	24	15	B	56.25

It was found from the table 4 that the natural frequencies of all the samples are ranging from 56.25 to 62.50 Hertz.

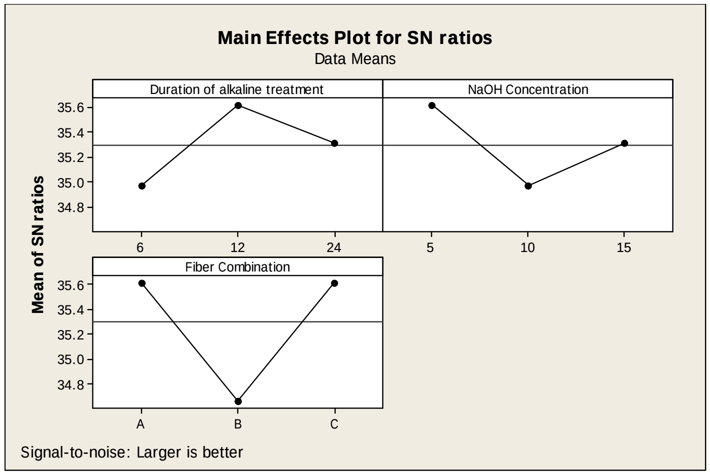

Fig. 10 Main Effects Plot for Natural Frequency

It is observed in Fig. 10 that the Natural Frequency increases when the duration of alkali treatment is increased from 6 hours to 12 hours followed by a significant decrease. The Natural Frequency decreases when the NaOH concentration increases from 5 to 10% followed by a considerable increase. The optimum duration of alkali treatment and NaOH Concentration is 12 hours and 5% respectively.

3.4 Fatigue test results

Table 5

Fatigue test results

Sample No	Maximum Load (N)	Number of cycles
1	106	1030
2	62	545
3	101	1150
4	104	1890
5	118	555
6	58	225
7	148	1100
8	203	6100
9	59	158

From the table 5, it can be inferred that the sample 8 that is sample with 3 Jute- 1 Gongura fibers treated with 15% of NaOH for 24 hours is having the maximum fatigue life.

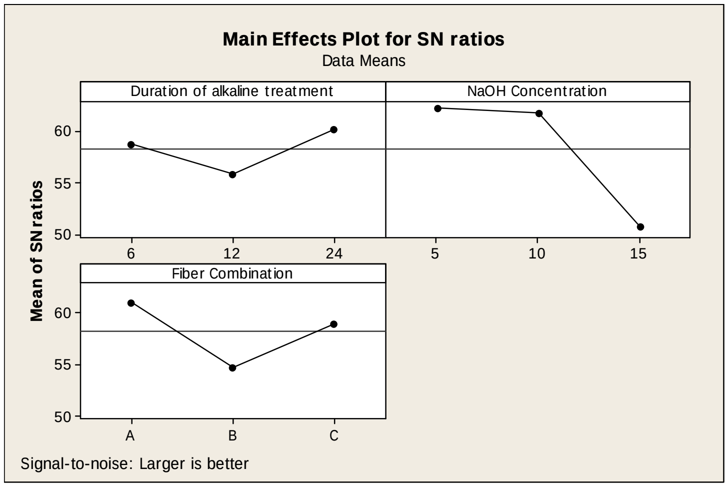

Fig. 11 Main Effects Plot for Fatigue Life

It is observed from Fig. 11 that there is a decrease in the fatigue life when the Duration of alkaline treatment is increased from 6 hours to 12 hours followed by a significant increase when the duration of alkaline treatment is further increased to 24 hours. A similar trend is observed in fiber combination. There is a negligible decrease when the NaOH Concentration is increased from 5 to 10 % followed by a decrease in the fatigue life. The optimum NaOH concentration and Duration of alkali treatment is 5% and 24 hours respectively

4. Conclusions

Hybrid green composites are prepared with Jute and Gongura as the reinforcement and with 75% GP resin and 25% CNSL oil by volume as matrix. The composites prepared are tested to evaluate the mechanical properties. From the results obtained, it can be inferred that Natural Fiber Reinforced Hybrid polymer Matrix composites (Green composites) can be made as a replacement for the synthetic fiber reinforced polymeric plastic materials. Green composites can be effectively used in manufacturing and replacing many polymeric plastic products used in automotive and general engineering applications like caps and protective covers used in dash boards of cabins, covers and supporting brackets used mining dozers and excavator panels.

Flexural, fracture, vibration and fatigue tests were conducted to evaluate the mechanical properties of the composites samples prepared. Following were the outcomes of the results

1. The sample with 3 Jute and 1 Gongura fiber gives the maximum flexural strength for all NaOH concentration and for all the fiber treatment duration considered. Among all the nine samples, the sample with 3 Jute-1Gongura

fiber combination treated with 10 % NaOH for 24 hours gives the maximum flexural stress.

2. Maximum stress intensity factor is obtained for sample with 1 Jute-3 Gongura fibers treated with 10% NaOH for 12 hours.
3. Natural frequencies for the prepared composite samples range between 56.25 and 62.50 Hertz.
4. Maximum fatigue life is obtained for the sample with 3 Jute- 1 Gongura fibers treated with 15% of NaOH for 24 hours.
5. Main Effects plots were obtained using MINITAB software and parametric analysis was performed on the Flexural stress, Stress Intensity Factor, Natural Frequency and Fatigue life of the composites.

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