Optimization of Fibre Length and Fibre Weight Fraction in Natural Fibre Reinforced Composites

[1]Arun Joy Kurian, [2]Vikas Mathew, [3]P.Sivasubramanian

[1]Dept of Mechanical Engineering, St Joseph's College of Engineering & Technology, Palai, Kerala, India.
[2]Asst. Professor, Dept of Mechanical Engineering, St Joseph's College of Engineering & Technology, Palai, Kerala, India,
[3]Asst. Professor, Dept of Mechanical Engineering, Saint Gits College of Engineering, Kottayam, Kerala, India
Email: [1]arunjoykurian@gmail.com, [2]vikasmathew@rediffmail.com, [3]sivasubramanian.p@saintgits.org

Abstract— Progresses in the field of materials science and technology have given birth to fascinating and wonderful materials known as 'composites'. A composite material can be defined as a macroscopic combination of two or more distinct materials, having a recognizable interface between them.

This thesis work comprises of fabrication of biodegradable polymer composite material samples, followed by the analysis of its mechanical properties. Also to compare the properties of composite samples on the basis of different length of the fibres and weight fractions. The influence of fibre length and fibre weight fraction on mechanical properties like tensile strength, tear strength, hardness and abrasion loss are validated using analysis of variance. Regression equations are also generated to predict the mechanical properties at intermediate fibre lengths and weight fractions. The major attraction of this work is that both the matrix and the fibre are naturally available. Hence products based on this work will be both cheaper and sustainable.

Index Terms— Natural Fibre, Natural Rubber, Regression Analysis, Fibre Weight Fraction.

I. INTRODUCTION

Composites are made up of continuous and discontinuous medium. The discontinuous medium that is stiffer and stronger than the continuous phase is called the reinforcement and the so called continuous phase is referred to as the matrix. The properties of a composite are dependent on the properties of the constituent materials, and their distribution and interaction. At present composite materials play a key role in aerospace industry, automobile industry and in other engineering applications as they exhibit outstanding strength to weight and modulus to weight ratio.

Based on the matrix material which forms the continuous phase, the composites are broadly classified into metal matrix (MMC), ceramic matrix (CMC) and polymer matrix (PMC) composites. Of these, polymer matrix composites are much easier to fabricate than MMC and CMC.[1] This is due to relatively low processing temperature required for fabricating polymer matrix composite. The fibrous reinforcing constituent of composites may consist of thin continuous fibres or relatively short fibre segments. When using short fibre segments, fibres with high aspect ratio (length to diameter ratio) are used.

The present work aims at investigating the prospect of using Phormium Tenax (New Zealand Flax) fibre as reinforcement in natural rubber matrix. Research work is going on with other natural fibres like coir, banana, flax etc. In order to achieve this major objective several fundamental investigations on the fibre and its composites have been undertaken. Currently the fibre is being utilized for the preparation of ropes, cordages, gunny bags etc. These fibres if put to better use, as reinforcement in polymers will definitely contribute to the development of the economy of the country and will open up new avenues for our natural resources.

The factors which affect the properties of natural fibres are the cellulose content and microfibrillar angle. Phormium Tenax fibre has relatively high cellulose content and a low micro fibrillar angle.[9] These two are the desirable properties in a natural fibre to be used as reinforcement in polymer composites. For the successful design of a composite material from Phormium Tenax fibre and natural rubber, several parameters like fibre aspect ratio, fibre matrix adhesion etc. that influences the performance of a short fibre composite have to be considered and to be optimized. Careful analysis of the literature indicates that no systematic studies have been reported about the use of Phormium Tenax (New Zealand Flax) fibre as reinforcement in polymers. The major attraction of this work is that both the matrix and the fibre are naturally available. Hence products based on this work will be both cheaper and sustainable.

Nowadays natural fibre reinforced polymer composites come prior to synthetic fibre reinforced composites in properties such as biodegradability, combustibility, light weight, non toxicity, decreased environmental pollution, low cost, ease of recyclability etc. These advantages place the natural fibre composites among the high performance composites having economical and environmental advantages. The versatile high performance applications of natural fibre composites, which can replace glass and carbon fibres. Natural fibres like sisal, coir, oil palm, bamboo etc. have been proved to be a better reinforcement in rubber matrix. Incorporation of natural fibres resulted in better long term mechanical performance of elastomers.

The range of products in the automobile industry based on natural fibres is based on polymers like plastics and elastomers and fibres like flax, hemp, sisal etc.[4] The use of natural fibres in automobile industry has grown rapidly over the last five years. Natural fibres enjoy the right potential for utilization in composites due to their adequate tensile strength and good specific modulus, thus ensuring a value added application avenue.

To eliminate problems resulting from the incorporation of synthetic fibres such as high abrasiveness, health hazards, disposal problems etc. incorporation of natural fibres is proposed. They are abundant, renewable, and cheap and are having low density. Material scientists all over the world focus their attention on natural composites reinforced with fibres like jute, sisal, coir, pineapple, banana etc. primarily to cut down the cost of raw materials.

II.EXPERIMENTAL PROCEDURE

A.Materials Required

1. Phormium Tenax Fibre.

Phormium Tenax fibers were collected from Coimbatore. Actual extraction includes stripping the leaves and the hanks of fiber were washed and then ‘paddocked (left in an enclosed area to dry) and scotched[7].

2. Natural Rubber

Natural rubber used for the study was ISNR 5(light colour) grade obtained from Rubber Research Institute of India, Kottayam, Kerala. The molecular weight, molecular weight distribution and non rubber constituents of natural rubber are affected by clonal variation, season and methods of preparation. Hence rubber obtained from same lot has been used in this study.

3. Compounding Ingredients

a) Cross linking agent: sulphur (ρ =2.05)

b)Accelarators:CBS(Ncyclohexyl.benzothiazyl sulphanamide ρ =1.30)

c) Activators: ZnO (ρ =5.5)

d) Antioxidant: TDQ (1, 2 dihydro 2, 2, 4, trimethyl quinoline polymerized (ρ = 1.1)

B. Preparation of composites and test specimens

The fibre was mixed with rubber on a laboratory two roll mixing mill with size 150 X 300 mm as per ASTM D 3184-80 at a friction ratio of 1:1.25. The mill opening was set at 0.2mm. The rubber was first masticated by careful control of temperature, nip gap, time and uniform cutting operation. The nip gap, mill roll speed ratio and number of passes were kept the same in all mixes.

The fibres were incorporated at the end of the mixing process, to avoid breakage of fibres taking care to maintain the direction of compound flow, so that majority of fibres are aligned in the grain direction. The samples were milled for sufficient time to disperse the fibres in the matrix at a mill opening of 1.25 mm. the stock was sheeted out after complete mixing. The homogenization was done by passing the rolled sheet six times endwise through the tight nip gap of 0.8mm and finally sheeted out at a nip gap of 3mm.

C. Cure characteristics of the Composite Sample

Cure time is defined as the length of time needed for an elastomer to cure fully. If an elastomer is not given enough time to cure, the bond will fail.In this work cure characteristics at 150°C were determined by using Goettfert elastograph model 67.99 . per minute.

Table I Different Mixes By Varying Fibre Length and Fibre Weight Fraction

Sample Name	W1	L2	W3	A	L3	B	C	L4	D
Narural Rubber	100	100	100	100	100	100	100	100	100
Zinc Oxide	5	5	5	5	5	5	5	5	5
StearicAcid	2	2	2	2	2	2	2	2	2
TDQ	1	1	1	1	1	1	1	1	1
CBS	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Untreated Fibre	Fibre Length (mm)	Sulphur
10	6	2.5
20	6	2.5
30	6	2.5
10	10	2.5
20	10	2.5
30	10	2.5
10	14	2.5
20	14	2.5
30	14	2.5

III. TESTING OF MECHANICAL PROPERTIES OF THE NATURAL COMPOSITES

1) Tensile strength

Tensile strength is the maximum tensile stress reached in stretching a test piece (either an O-ring or dumbbell). Tensile strength largely depends on an elastomer's ability to partially strain crystallize when stretched.[7] With greater crystallization comes increased strength and resistance to stress.Natural rubber is an example of an elastomer with a very regular chain structure that strain crystallizes. As a result, natural rubber has high tensile strength. Stress-strain measurements were carried out at a crosshead speed 500mm/min on a INSTRON 4411 Model universal testing machineTensile strength is measured according to ASTM D 412. Dum bell shaped specimens were punched out of the moulded sheet and tests were carried out.Tensile strength is reported in MPa.

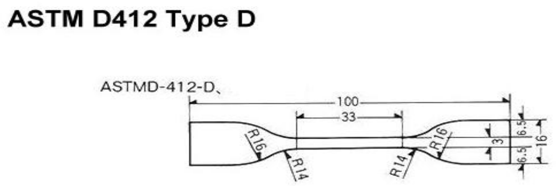

Fig 1: ASTM D 412 specifications for Tensile Testing

Fig 2: INSTRON 4411 Universal Testing Machine

2)Tear strength:

Tear resistance (or tear strength) is resistance to the growth of a cut or nick in a vulcanized (cured) rubber specimen when tension is applied. Tear resistance is an important consideration, both as the finished article is being removed from the mold and as it performs in actual service. Unit is kilo newtons per meter (kN/m).Natural rubber has excellent tear resistance. Once damaged, materials with poor tear resistance will quickly fail in service.

3)Hardness:

The hardness of rubber compounds is measured by the Shore A durometer; the higher the durometer reading, harder the compound is. Hardness is a measure of an elastomer's response to a small surface stress.[5] The hardness of the composite was measured using the Shore A type Durometer according to ASTM 224~81.The instrument used here is Mitutoyo Hardmatic GHU 217.. Readings were taken after 15 seconds of the indentation when firm contact has been established with the specimens.

Fig 3: Durometer for Hardness Testing

4) Abrasion Resistance:

Measured as a loss percentage based on original weight, abrasion resistance is the resistance of a rubber compound to wearing away by contact with a moving abrasive surface.

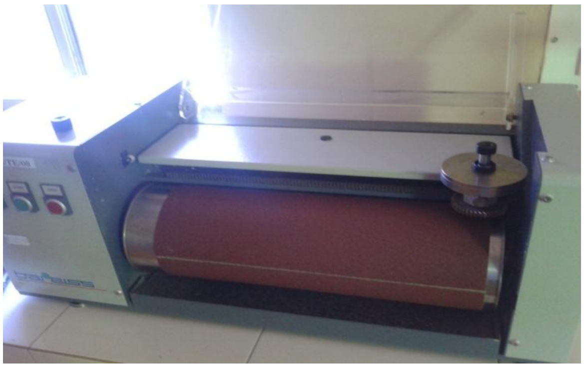

Fig 4: Abrasion Resistance Tester

The abrasion resistance of the samples was tested using a DIN 53516. [4] Cylindrical samples having diameter 16mm and length 20mm was kept on a rotating sample holder and 10N loads were applied. Initially a pre run was given and its weight was taken. The sample was then given a complete run and the final weight was noted. The difference in weight is noted as the weight loss. It is expressed as the volume of the test piece getting abraded by its travel through 40 m on a standard abradant surface.

The abrasion loss was calculated as follows.

$V = m / \rho$ where V is the abrasion loss, m is the mass loss and ρ is the density of the sample.

Table II Orthogonal Array with Two Parameters and Three Levels along with test results of mechanical

FL mm	FWF gm	TS MPa	Tear Strength k N/m	Hardness Shore A	AL cc/hr
6	10	5.06	29	46	0.36
6	20	6.31	31	55	0.35
6	30	1.77	32.08	62	0.26
10	10	4.91	28	45	0.43
10	20	2.27	29	52	0.42
10	30	1.70	30	56	0.39
14	10	3.70	24	48	0.46
14	20	3.49	25	49	0.45
14	30	1.6	26	52	0.4

properties

IV.OPTIMIZATION USING DESIGN OF EXPERIMENTS VIA TAGUCHI'S ORTHOGONAL ARRAY

A. Design of Experiments

The methodology of Taguchi for two factors at three levels is used for the implementation of the design of experiments. Taguchi's L9 orthogonal array is used to define the 9 trial conditions. Only the main effects are of interest and factor interactions are not studied. The process parameters and levels are listed in Table III

Table III Levels of process input process parameters

Process Parameter	Level 1	Level 2	Level 3
Fibre Length	6	10	14
Fibre Weight Fraction	10	20	30

Table VI Layout of L9 Orthogonal Array with cure times

Sample Name	Fibre Length mm	Fibre Weight Fraction gm	Cure Time min
W1	6	10	5.46
L2	6	20	5.66
W3	6	30	7.33
A	10	10	5.10
L3	10	20	4.60
B	10	30	5.05
C	14	10	5.70
L4	14	20	5.40
D	14	30	5.27

B. Taguchi Method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum result.

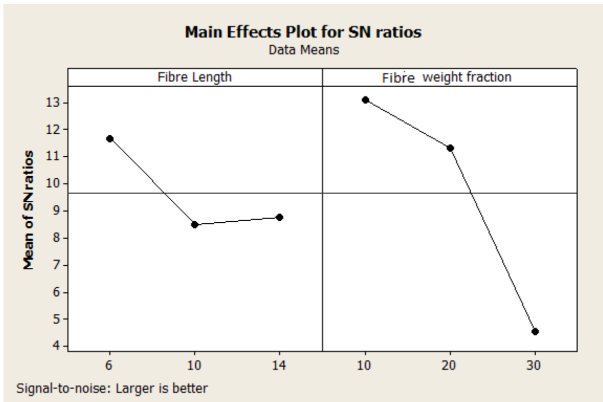

Fig 5 Main Effects Plot For SN Ratios For Tensile Strength

Table V Analysis Of Variance For SN Ratios

Analysis Of Variance for SN Ratios					
Source	DF	Seq SS	MS	F	P
Fibre Length	2	18.56	9.281	1.42	0.341
Fibre Weight Fraction	2	121.94	60.969	9.35	0.031
Residual Error	4	26.09	6.522		
Total	8	166.59			

In the Table V the factor level for fibre weight fraction is much higher than corresponding factor level for fibre length. Hence fibre weight fraction has got more influence on tensile strength than fibre length.

Fig 6 Main Effects plot for SN ratios for Tear Strength

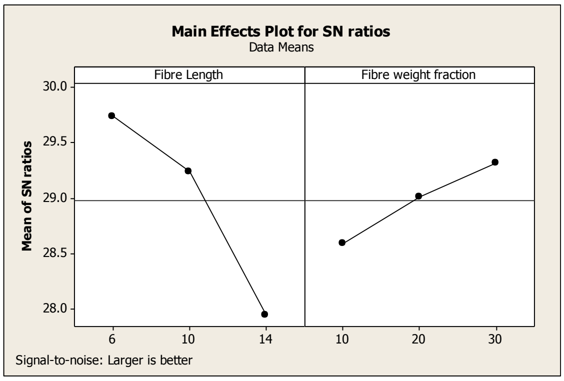

Table VI Analysis of Variance for SN Ratios

Analysis Of Variance for SN Ratios					
Source	DF	Seq SS	MS	F	P
Fibre Length	2	5.06	2.534	362.88	0
Fibre Weight Fraction	2	0.79	0.395	56.62	0.001
Residua l Error	4	0.02	0.0069 8		
Total	8	5.88			

In the Table VI the factor level for fibre length is much higher than corresponding factor level for fibre weight fraction. Hence fibre length has got more influence on tear strength than fibre weight fraction.

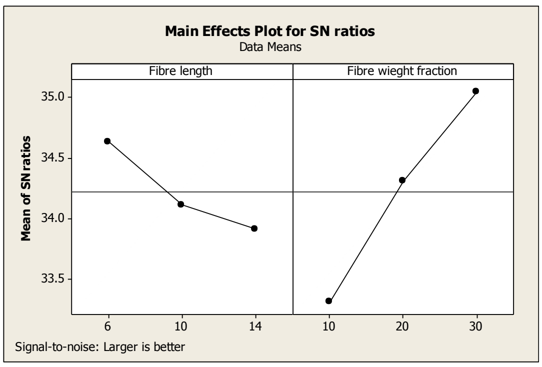

Fig 7 Main Effects Plot For SN Ratios For Hardness

Table VII Analysis of Variance For SN Ratios

Analysis Of Variance for SN Ratios					
Source	DF	Seq SS	MS	F	P
Fibre Length	2	0.8301	0.4151	1.64	0.302
Fibre Weight Fraction	2	4.5193	2.2596	8.93	0.033
Residua l Error	4	1.0125	0.2531		
Total	8	6.3619			

In the Table VII the factor level for fibre weight fraction is much higher than corresponding factor level for fibre length. Hence fibre weight fraction has got more influence on hardness than fibre length.

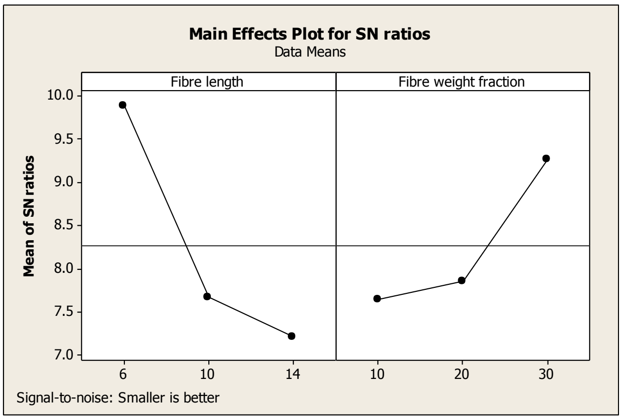

Fig8 Main Effects Plot for SN Ratios for Abrasion Loss

Table XIII Analysis of Variance for SN Ratios

Analysis Of Variance for SN Ratios					
Source	DF	Seq SS	MS	F	P
Fibre Length	2	12.338	6.169	17.1	0.011
Fibre Weight Fraction	2	4.707	2.3533	6.52	0.055
Residua l Error	4	1.443	0.3607		
Total	8	18.487			

In the Table XIII the factor level for fibre length is much higher than corresponding factor level for fibre weight fraction. Hence fibre length has got more influence on abrasion loss than fibre weight fraction.

V. Mathematical model of experimental values using Regression Analysis

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed..

Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. In restricted circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables.

Following mathematical model (Regression Equations) is generated

Tensile Strength=8.11-0.173FL - 0.1467 FW

Tear Strength=32.988-0.7117 FL-0.1180 FW

Hardness=47.17-0.583 FL + 0.517 FW

Abrasion Loss=0.3161 + 0.01417 FL – 0.00333 FW

VI. CONCLUSIONS

The present thesis work aimed at the fabrication of biodegradable polymer composite material samples, followed by the analysis of its mechanical properties. The biodegradable composite samples in this work were made up of natural rubber with natural fibre. The properties of the composite samples were compared on the basis of different length of the fibres and weight fractions.

From the fabricated composite samples, it has been inferred that at critical fibre length (6 mm), the composite exhibits better desirable properties. Also as the fibre loading increases the mechanical properties achieves better significant values at 30 phr fibre loading.

The influence of fibre length and fibre weight fraction on mechanical properties like tensile strength, tear strength, hardness and abrasion loss are validated using analysis of variance. Tensile strength and hardness are more influenced by fibre weight fraction. Tear strength and abrasion loss are more influenced by fibre length. Regression equations are also generated to predict the mechanical properties at intermediate fibre lengths and weight fractions.

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