This book describes the development of polymer composites with varying weight percentages of CSP/WSP (1:1) particulates and epoxy resin as the matrix material, fabricated using a hand lay-up technique resulting in six specimens. Physical properties such as density, moisture content, and dimensional stability were investigated, indicating the improved dimensional stability of CSP/WSP (1:1) reinforced epoxy composites with 2.5 wt.% particulates. The flammability behavior, flexural properties, and impact characteristics of the composites were also studied using statistical software and ANOVA to identify dominating parameters. Results showed that filler load and speed had an ascending effect on flexural properties. The composites were found to have promising physical and mechanical properties, indicating their potential for various engineering applications. The addition of CSP and WSP as reinforced particles to contribute the development of a new class of epoxy-based composites. This book highlights the importance of selecting suitable materials for matrix, reinforcement, and particulate and investigating physical and mechanical properties for the development of new composite.

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Green Hybrid Polymer Composite

Physical, Chemical and Mechanical Behavior along with ANOVA analysis

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PREFACE

In this book, authors developed a new set of polymer composites using different weight percentages of CSP/WSP (1:1) particulates (ranging from 2.5 to 15.0 wt%) in combination with epoxy resin (LY 556) as the matrix material and a mixture of epoxy resin (LY 556) and hardener (HY951) in a 10:1 ratio at room temperature. The composites were fabricated using a hand lay-up technique, resulting in six different specimens.

The physical properties of the newly developed composites, including density, moisture content, and dimensional stability, were investigated. The experimental results showed that the dimensional stability of CSP/WSP (1:1) reinforced epoxy composites was better at 2.5 wt% of particulates.

Furthermore, the flammability behavior, flexural properties, and impact characteristics of the composites were also studied. Flexural properties were investigated using an L18 ($6^1 * 3^1$) orthogonal design with MINITAB 14 statistical software. The signal-to-noise ratio (S/N) was evaluated to analyze the variance and identify the dominating parameters affecting flexural properties. ANOVA was conducted with a confidence level of significance of 95%. According to the Taguchi technique and the analysis of variance outcome, the experimental results showed that the sequence of parameter effect on flexural properties in ascending order was filler load and speed.

In conclusion, this book presents a new class of epoxy-based composites with the addition of coconut shell and walnut shell as particulates in various weight percentages. The experimental results showed that the composites had promising physical and mechanical properties, indicating their potential as a suitable material for various engineering applications.

CONTENTS

Chapter 1

INTRODUCTION

1.1Background and Motivation

Now-a-days, worldwide researchers are going on to motivates, study and develop a new classes of natural fiber reinforced polymer (NFRP) composite. Researchers are focusing not only environmental awareness but also economic value on to different type of polymer composites. Recently, researchers are also focusing geometrically rising crude oil cost get bigger global waste problem and more operation/processes price. So that researchers are going on the concepts of sustainability as well as reassessment of renewable resources [1]. Researchers tempted NFRP composites as a research point because of NFRP composites have a number of advantages over synthetic fiber reinforced composites such as option for low cost, low density, locally available, ease of manufacturing, non-toxicity, satisfactory mechanical properties, good insulation property, good renewable, biodegradable, completely or partially recyclable and environmental friendly [2, 3].

NFRP composites have a number of demerits such as sensitivity for dimensional stability which decreased effectiveness with hydrophobic polymers, shape as well as size composites are non-uniform due to filler, passivity to natural environment attacks, biological decay and non sustainable under more temperatures. However, NFRP composites can be post processed to minimize some of these drawbacks, namely, sensitivity for dimensional stability which is environment effects [3].

Combine properties of different material can be achieve by adding two or more material is known as composite material. Composites are implanted by number of continuous and discontinuous phase. Continuous phase is known as matrix where as discontinuous phase is called reinforcement. It was investigated by researchers from experiment that reinforcement based composites are not only harder but also stronger as compare to matrix based composites. The predominant functions of the matrix are not only transfer stresses between the reinforcing fibers and particulars but also protect them from environmental as well as mechanical damage [1, 4, 5].

The key functions of particulars introduced in matrix material such as to better the stiffness, upgrade performance at elevated temperatures, improve resistance again wear as well as abrasion, to reform the electrical as well as thermal conductivities, upgrade machinability, upgrade surface hardness, lower friction and minimize shrinkage [6] .

1.2 Classification of Composites

There are different types of composite materials categories depending on continuous phase. They are as follows:

1.2.1 Classification on The Basis of Type of Continuous Phase (Matrix) in The Material

- Polymer Matrix Composites (PMC)
- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)

1.2.1.1 Polymer Matrix Composites (PMC)

A polymer matrix, as the name implies called a plastic. It is a substance which has combination of a higher number of polymer molecules of un-similar equal length and similar chemical structure [7]. The process of fabrication of polymer matrix composite is simple than other matrix. Polymer matrix composites do not require application of high pressure and high temperature during fabrication process. There are two categories of polymer: Thermo set polymer and thermoplastic polymer [8].

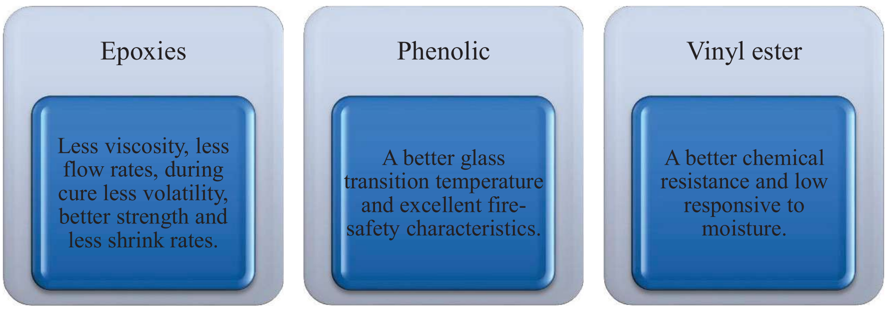

Figure 1.1 Classification of Thermo-set Polymers.

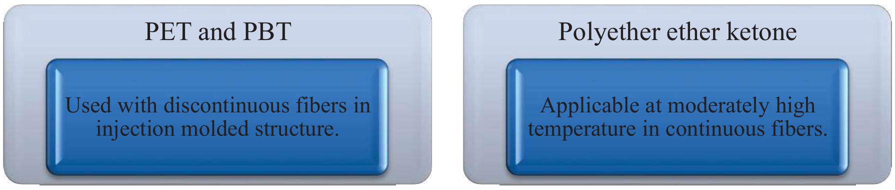

Figure 1.2 Classification of Thermoplastic.

1.2.1.2 Metal Matrix Composites (MMC)

Metal matrix composites are consisted of metallic alloy or metal as matrix material. In MMCs, light weight metal matrixes are formed generally by titanium, aluminum and their alloys, where as heavy metal matrixes are formed generally by copper as well as cobalt. Metal matrix has a number of advantages over polymeric matrix such as a long-term resistance to severe environments (at high temperature), high yield strength, high transverse strength and modulus as well as compressive strength, plastically deformed and strengthened by a variety of thermal and mechanical treatments. Metals are also known by its high melting points, high densities and a tendency toward corrosion at the fiber–matrix interface. The properties of titanium alloys are better strength retentions (at 4008C–5008C) as well as higher tensile strength–weight ratios over aluminum alloys. Aluminum alloys have good corrosion resistance (at pure aluminum state) as well as higher tensile strength–weight ratios (Al-201, Al-6061, and Al-1100) [7].

1.2.1.3 Ceramic Matrix Composites (CMC)

Ceramic matrix composites are consisted of non oxides and oxides ceramic material. CMCs are workable above 1200 OC temperature. Due to high processing temperature of CMCs, these materials are more costly. The properties of ceramics are high temperature stability, high corrosion resistance, high modulus, high thermal shock resistance, high hardness and low density. Ceramics are also known as possessing low resistance to crack propagation and brittle materials. In part of oxides category, mullit (Al_2O_3–SiO_2) and Alumina (Al_2O_3) are most commonly used due to their chemical and stability. In part of non oxide ceramics category, silicon carbide (SiC) is used for high modulus, aluminum nitride (AlN) is used for high thermal conductivity, boron carbide (B_4C), and silicon nitride (Si_3N_4) is used for high strength [7].

1.3 Classification of Natural Fiber

The sources of natural fibre can be categorized into two major parts: such as plant cellulose fibers and animal fibers. According to utilization, Plants which is producing natural fibers can be again divided into primary and secondary plant fibers. Kenaf, jute, sisal and hemp are example of primary plant fibers which are grown for their fibers. Oil palm, Pineapple, coir and Bagasse are example of secondary plant fibers, which are pluck out from the waste product. There fibers are again divided in number of category which is as show in below flowchart [9].

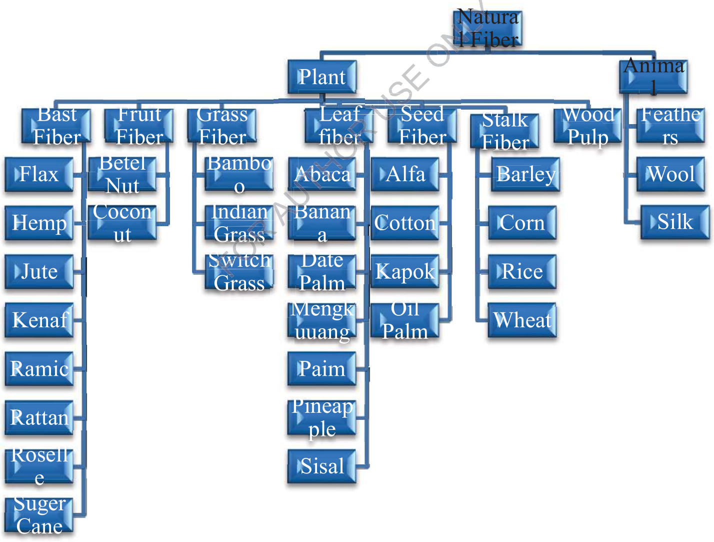

Figure 1.3 Classifications of Natural Fibers [9]

Table 1.1 Chemical Properties of Natural Fibers [10, 11]

S.No	Type of Plant Fiber	Cellulose (wt%)	Hemi cellulose (wt%)	Lignin (wt%)	Pectin (wt%)
Bast Fiber					
1	Flax	71	18.6-21.6	2.2	2.3
2	Hemp	57 - 77	14 - 22.4	3.7 - 13	0.9
3	Jute	59-71.5	13.6 - 20.4	11.8 - 26	0.2
4	Kenaf	45-57	21.5 - 23	15 - 21.5	0.6
5	Ramic	68.6 - 91	5 - 16.7	0.6 - 0.7	1.9
Fruit Fiber					
1	Betel Nut	53.2	32.98	7.2	-
2	Coconut coir	37	20	42	-
Grass Fiber					
1	Bamboo	26 - 65	30	5 to 31	11
Leaf Fiber					
1	Abaca	56 - 63	15 - 25	7 to 13	-
2	Banana	62 - 64	10-0 - 19.0	5	-
3	Curaua	70.7 - 73.6	9.9	7.5 - 11.1	-
4	Henequen	60 - 77.6	4 to 28	8 - 13.1	-
5	Palm	60 - 65	11 to 29	6	-
7	Sisal	47 - 78	10 - 25.7	7 - 12.1	10
Seed Fiber					
1	Alfa	45.4	38.5	14.90	-
2	cotton	82.7 - 90	5.7	< 2	8

Table 1.2 Physical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites [1, 9, 11, 12]

S.No	Plant Fiber	Density (Kg/cm2)	Tensile strength (MPa)	Young's modulus (GPa)	Flexural Strength (MPa)	Elongation %	Equipment's used
Bast Fiber							
1	Flax	1.5	800 - 1500	30- 80	165	1.2-3.2	-
2	Hemp	1.47	550 - 900	25 - 70	-	1.6	-
3	Jute	1.3	320 - 800	8.0 - 26.0	45	1.3-4.6	UTM
4	Kenaf	1.45	930	53	74	1.6	UTM
5	Ramic	1.5	220-938	44 - 128		2-3.8	-
Fruit Fiber							
1	Betel Nut	-	53.2	32.98	7.2	-	-
2	Coconut	-	500	2.5	58	-	UTM
Grass Fiber							
1	Bamboo	0.60-1.10	140 - 800	30 - 50	32.00	2.00	UTM
Leaf Fiber							
1	Abaca	1.5	400 - 980	6.2 - 20		3.0-10	-
2	Banana	1.35	600	17.85	76.53	5.9	UTM
3	Curaua	1.4	87 - 1150	11.8 - 96	-	3.7-4.3	UTM
4	Henequen	1.2	430 - 570	10.1 - 16.3	95	4.8 ± 1.1	UTM
5	Data Palm	1-1.20	97-196	2.5-5.4	-	2-4.5	-
6	Oil Palm	0.7-1.55	248	3.20	-	24.5	UTM
7	Piassava	1.4	134 - 143	1.07 - 4.59	-	7.8-21.9	-
8	Pinappile	0.80-1.60	413 - 1627	34.5 - 84.5	-	14.5	UTM
9	Sisal	1.5	600 -700	8.0-38	288.6	2.0 - 14.0	UTM
10	Vakka	-	549	15.85	-	--	UTM
Seed Fiber							
1	Alfa	0.89	35	22	-	5.80	-
2	Cotton	1.50-1.60	287-597	5.5-12.6	43.3	3.0 - 10.0	UTM
Wood							
1	Wood	-	120 - 174	2.3 - 3.4	-	-	-

Table 1.3 Application of Natural Fiber [9].

Building and construction industry	Panels for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc.
Storage devices	Post-boxes, grain storage silos, bio-gas containers, etc.
Furniture	Chair, table, shower, bath units, etc.
Electric devices	Electrical appliances, pipes, etc.
Everyday applications	Lampshades, suitcases, helmets, etc.
Transportation	Automobile and railway coach interior, boat, etc.

1.4 Coconut Shell and Walnut Shell as Particular Filler Composites

Cocos nucifera (coconut) is one of place in list of the palm family. Which is not only used for decoration but also uses for culinary and non-culinary, it's means each components of the coconut palm has some human use. One of the parts of coconut palm is CS, which is not only non-food but also lignocellulosic agro-waste. It is the hardest part of the nut. Other part of coconut is coconut husk, which is composed of fibers [9, 13].

CS lignocellulosic agro waste particular has a number of admirable properties over mineral filler (such as kaolin, mica, talc and Calcium carbonate.) such as high specific strength-to-weight ratio, low cost, minimal health hazard, low density, certainly biodegradability, less abrasion to machine, renewable, and environmental friendly [9].

CS polymer composites fabricates by using number of methods such as esterification, alkaline treatment, silane treatment, using treatment as well as compatibilizers with other chemical compound, which useful for improve interfacial adhesion between the lignocelluloses filler and polymer matrix. So that CS achieved improve mechanical characteristics not only in tensile mode but also in flexural mode [9].

Walnut shell is one of place in list of lignocellulosic agro-waste materials. WS has neither economic value nor industrial uses in India. Generally, it is used as a firewood replacement material. WS lignocellulosic agro waste particular has a number of admirable properties as a reinforcing particular over thermoplastic composites such as need higher dimension stability in outdoor application. The main advantage of WS, it does contain less amount of cellulose as well as hemicelluloses, which is known as hygroscopic materials. Other hand it does contain much amount of lignin, which is known as hydrophobic material [14, 15, 16] .

1.5 The Objectives of This Work

- Fabrication of a series of reinforced CSP/WSP epoxy based composites.
- Investigation of physical properties such as density, moisture content and dimensional stability of these composites.
- Investigation of mechanical properties such as strength and modulus of flexural and impact strength of these composites.
- Implement of Taguchi's technique for optimization of flexural characteristic.

1.6 Outline of the Dissertation

This research work was written down in six chapters, which were present in following section. First two chapters provide theory background and literature information, where as other four chapters provide materials and methodology, detailed information of experimental research work and last chapter provide summary and conclusions report of present research.

Chapter 1 Introduction includes theoretical background of composites. It includes also an overview of coconut shell and walnut shell particular. Finally this chapter gives objective of this research work.

Chapter 2 Literature Review, presents a report on coconut shell as well as walnut shell particulate reinforces polymer composites by various investigators. More than twenty five research papers are used for a review over physical properties of coconut shell as well as walnut shell particulate reinforced /natural fiber reinforced, mechanical properties of coconut shell as well as walnut shell particulate / natural fiber reinforced and explanation of DOE (Taguchi's technique) on fiber as well as particulate reinforce polymer composites.

Chapter 3 Materials and methodology, explains the completed procedure of material selection and fabrication. It presents detailed information regarding designation and compositions of the composites, specification for specimen (according to ASTM) and machine parameters used during experiment work. Finally it includes also an explanation of the Taguchi experimental design.

Chapter 4 CSP /WSP filled epoxy based composites: Physical properties, Flammability resistance and Impact test, the aim of this chapter is completed study on physical characteristics of CSP/WSP reinforced epoxy based composites. The elucidation of the results and the comparison among various composite samples are also accounted.

Chapter 5 CSP /WSP filled epoxy based composites: Optimization of flexural characteristics, the aim of this chapter is detailed description on the effect of CSP/WSP reinforced epoxy based composites in flexural mode. The essential analysis of the design of experiment by using Taguchi technique is also accounted.

Chapter 6 Results and conclusions, presents the result and conclusion of research worked into two parts. The first part has provided the description of physical characteristics of the composites, while the second part has reported the effect of reinforcement of CSP/WSP in impact and flexural mode of epoxy based composites.

Chapter 2

LITERATURE REVIEW

Introduction

This chapter gives justification of literature review which is enclosed information behind the scenes on the topic to be reflecting in this research work and to spotlight the admissible of the present study. These studies hold various feature of polymer based composites. The subject takes into account brief review:

- On physical and mechanical characteristics of Coconut Shell reinforced polymer based composites.
- On physical and mechanical characteristics of walnut Shell reinforced polymer based composites.
- On physical characteristics of fiber reinforced polymer based composites.
- On physical characteristics of fiber reinforced polymer based hybrid composites.
- On implementation of DOE and optimization techniques (Taguchi's technique and ANOVA).

2.1 Review on Physical and Mechanical Characteristics of Coconut Shell Reinforced Polymer Based Composites.

Md. T. Islam and S. Chandra evaluated mechanical characteristics namely tensile strength (TS), elongation at break, tensile modulus (TM), impact strength (IS), bending modulus (BM) and bending strength (BS) of coconut shell powder (CSP) reinforced Coir mat/polyester resin based composites. The researchers were fabricated seven composites by hand layup technique using CSP as a reinforced materials, polyester as a PMC material and polyester and Methyl Ethyl Ketone Peroxide (MEKP) mixed at room temperature. Authors were fabricated seven samples in the variation of CSP content from 0 to 60 by percentage of weight with 10 wt% in each step.

Composites with 0% wt CSP filler content denotes only coir chopped based polyester composites and filler is not presented here. On the other hand, 100% wt CSP filler content composite denotes CSP reinforced polyester composites and coir chopped mat is not presented in this case. It was examined by author from experiment that the maximum improvements of mechanical characteristics were found for 30 wt % of CSP filler composite among other filler specimens [17].

K. Vignesh and K. Sivakumar investigated mechanical characteristics namely flexural strength, impact strength and hardness of coconut shell powder (CSP) reinforced alkaline treated (NaOH and KHO at 24 hr soaking time) epoxy resin based composites. The researchers were fabricated specimens of composites by hand layup technique using 30 wt % CSA as a reinforced material and 70 wt % epoxy resin as a PMC material and epoxy resin and hardener mixed in 10:1 at room temperature. Specimens are treated with different level of concentration (2%, 5% and 8%) KOH and NaOH as well as soaking time (24 hr). It was noticed by author from experiment that the mechanical characteristics of CSP reinforced composites such as impact strength, hardness and flexural strength are examined and 5% level of concentration KOH treated CSP reinforced composite gives better results [18].

S. Muthukumar and K. Lingadura studied mechanical behavior such as tensile and flexural strength as well as impact strength of groundnut shell powder (GSP) and coconut shell powder (CSP) reinforced epoxy based hybrid composite. Authors were fabricated five specimens by open mould casting technique with different weight percentage of GSP/CSP (1:1) (30, 40, 50, 60 and 70 wt%) and remaining according to calculation epoxy resin (GradeVBR8912) and hardener VBR-1209 mixed in 10:1 at room temperature. It was observed by author from experiment that GSP/CSP 40 wt% composite has maximum ultimate tensile strength (865.75 MPa) among filler specimens. The higher value of impact strength (0.25 J/m^2) as well as higher value of flexural strength (63.21 MPa) was observed at 50 wt% GSP/CSP compared with other filler sample [19].

S. I. Durowaye *et al*. worked mechanical characteristics namely Bending strength at peak, bending modulus, impact strength, brinell hardness, tensile strain and Ultimate tensile strength of coconut shell powder (CSP) reinforced polyester based composites as well as palm fruit particulate

(PFP) reinforced polyester based composites. The researchers were fabricated six –six specimens with different composition as follow (resin 95 wt%+ CSP or PFP 5 wt%), (resin 90 wt%+ CSP or PFP 10 wt%), (resin 85 wt%+ CSP or PFP 15 wt%), (resin 80 wt%+ CSP or PFP 20 wt%), (resin 75 wt%+ CSP or PFP 25 wt%) and (resin 70 wt%+ CSP or PFP 30 wt%) of composites by open mould casting technique using CSP or PFP as a reinforced materials, epoxy resin as a PMC material and epoxy resin and hardener mixed in 10:1 at room temperature. 1g of catalyst and 0.5g of accelerator were also added to each specimen composite . It was observed by the author from experiment that CSP reinforced epoxy based hybrid composite has better mechanical characteristics [20].

N. Özsoy *et al*. evaluated mechanical characteristics namely density, Hardness (HRB), with the help of three point bend test find strength and tensile strength of chopped bamboo (CB) and chopped coconut shell (CCS) reinforced epoxy based composites. It was examined by author from experiment that the maximum improvements of mechanical characteristics of CB were found at 10 wt % of CB for tensile strength, 8 wt % of CB for flexural stress, 10 wt % of CB for hardness (Shore D) and 6 wt % of CB for density. It was also observed by author from experiment that the maximum improvements of mechanical characteristics of CCS were found at 6 wt % of CCS for tensile strength, 10 wt % of CCS for flexural stress, 10 wt % of CCS for hardness (Shore D) and 6 wt % of CCS for density [21].

A. Singh *et al*. investigated physical characteristics namely density and water absorption behavior and mechanical behavior in tensile and flexural mode of coconut shell particle (600 - 212μm) reinforced epoxy based composite. The researchers were fabricated three specimens by open mould casting technique with different weight percentage of CSP (20 wt%, 30 wt% and 40 wt%) and remaining according to calculation epoxy resin and hardener mixed in 5:4 at room temperature. It was observed by author that the value of density and percentage of water take up were increased with increment of coconut (maximum at 40 wt %) content in composite. Similarly it was also examined by author from experiment that the value of strength in tensile and flexural mode of CSP reinforced composites were decreased with increasing of percentage of weight of CSP (strength in tensile mode maximum at 20 wt % and strength in flexural mode maximum at 30 wt %) in composites [2].

J. Bhaskar and V.K. Singh studied physical characteristics namely density and mechanical characteristics namely ultimate strength, modulus of elasticity and percentage of elongation of coconut shell particle (size between 200-800µm) reinforced epoxy based composite. The researchers were fabricated four specimens by open mould casting technique with different weight percentage of Coconut shell (20, 25, 30 and 35 wt%) and remaining according to calculation epoxy resin SY-12(319) and hardener SY-31(B) mixed in 10:1 at room temperature. It was observed by author that the value of density is decreased with increment of coconut (maximum at 20 wt %) content in composite. Similarly it was also observed by author that the value of ultimate strength, modulus of elasticity and percentage of elongation are decreased with increment of coconut (maximum at 20 wt %) content in composite. The composite has maximum value of density (1.288 gm/cm^3), ultimate strength (30.60 MPa), modulus of elasticity (856.00 MPa) and percentage of elongation (25.44) at 20 wt % of coconut shell [5].

R. chanap worked physical and mechanical characteristics namely density, tensile strength, flexural strength and hardness of coconut shell ash (CSA) (heat treated at 600 degree) reinforced epoxy based composites as well as CSA (heat treated at 800 degree) reinforced epoxy based composites. The researchers were fabricated four (heat treated at 600 degree) plus four (heat treated at 800 degree) specimens by hand layup technique using 10 V_f% CSA increment up to CSA 30 V_f% as a reinforced materials, epoxy resin (araldite LY 556) as a PMC material and epoxy resin (araldite LY 556) and hardener (HY951) mixed in 10:1 at room temperature. It was examined by author from experiment that CSA heat treated at 800 degree reinforced epoxy based composite has greater physical (density 1.095g/cc) and mechanical characteristics (tensile strength (36.95 MPa), flexural strength (65.98 MPa) and hardness (29.1 Hv)) than CSA heat treated at 600 degree reinforced epoxy based composite at 20 V_f % of CSA filler composite among other filler specimens [8].

2.2 Review on Physical and Mechanical Characteristics of Walnut Shell Reinforced Polymer Based Composites.

Q. Zhang *et al*. evaluated mechanical behavior such as bending strength, impact strength and tensile strength of peanut husk (PH), rice husk (RH) and walnut shell Powder (WSP) reinforced high density polyethylene (HDPE) composites. The researchers were fabricated three kinds of composites such as peanut husk/HDPE, rice husk/HDPE and walnut shell /HDPE with addition of maleic anhydride grafted polyethylene (8 wt%) and TPW 613 lubricant (3 wt%) by using extrusion method. It was examined by author from experiment that PH/HDPE, RH/HDPE and WSP/HDPE composites have maximum value of maximum tensile strength and Bending strength at 40 wt% of filler (PH or RH or WSP) and Impact strength at 30 wt% of filler (PH or RH or WSP) among other filler specimens. It was also observed by author that mechanical strength of RH/HDPE composite was the best among other filler composites [22].

S. A. Rayabag *et al*. investigated mechanical characteristics namely hardness and with the help of three point bend test find strength and modulus of flexural WSP reinforced with GF polyester based composites. The researchers were fabricated four specimens with fixed glass fiber and different weight percentage of WSP (0, 5, 10, 20, 30 and 40 wt %) of composites by hand layup technique using WSP as a reinforced materials, polyester resin as a PMC material and MEKP (Methyl Ethyl Ketone Peroxide) as a hardener mixed at room temperature. It was observed from experiment by author that the value of hardness, bending strength as well as modulus of bending was examined as 78 (by shore D durometer), 1557.66 N/m^2 and 165.64×103 N/m^2 respectively at 30 wt % of WSP [23].

N. A. Sarsari *et al*. studied physical characteristics namely dimension stability and mechanical behavior in tensile and flexural mode of walnut shell flour/thermoplastic starch (WSF/TPS) with and without nanoclay composites**.** The researchers were fabricated thirteen samples in the variation of nanoclay content 0, 3 and 5 by percentage of weight with increment of WSF from 0 wt% to 50 wt% in each step. It was observed by author that water take up and TS are increased with increment of WSF/nanoclay (50/5) in composite. It was observed from experiment by author that, tensile strength and modulus, flexural strength and modulus of composite were increased with increment of WSF/nanoclay reinforcement (maximum at WSF/nanoclay - 50/5). Similarly the maximum result for impact strength was evaluated by experiment at WSF/nanoclay - 40/5 reinforced specimens. It was observed by author that the maximum amount of weight loss after soil burial degradation occurred in 100 wt% of TPS composites [14].

D. K. Rao *et al*. worked mechanical behavior such as bending strength, modulus of elasticity, modulus of bending yield strength and tensile strength of walnut shell powder (WSP) as well as coconut fibres (CF) reinforced epoxy based hybrid bio-composites. The researchers were fabricated two kinds of composites such as first 100 wt% pure epoxy resin and second 20 wt% of WSP of size 1.618-2.685 and 10 wt% of CF of length 2-3 mm were added with 70 wt % of epoxy resin by hand layup technique using WSP/CF as a reinforced materials, epoxy resin (CY 230) as a PMC material and epoxy resin (CY 230) and hardener (HY 951) mixed in 10:1 at room temperature. It was observed from experiment by author that tensile strength, yield strength and modulus of elasticity of 20 wt% of WSP with10 wt% of CF epoxy based composite were increased about 54.3%, 88.3% and 86.4% of pure epoxy resin respectively. Similarly it was also examined by author from experiment that bending modulus (1706.15 MPa) and bending strength (34.04 MPa) of 20 wt% of WSP with10 wt% of CF epoxy based composite were increased about 86.3% and 35.7% of pure epoxy resin respectively [15].

C. B. Talikoti *et al*. evaluated mechanical characteristics namely compressive strength, with the help of three points bends test find strength and tensile strength of walnut shell powder (WSP) reinforced epoxy based composites. The researchers were fabricated specimens of composites by hand layup technique using 5 wt % WSP as a reinforced material and 95 wt % epoxy resin (Bisphenol-A of grade 220) as a PMC material and epoxy resin (Bisphenol-A of grade 220) and hardener (Promoter Andonox KP9, accelerator Polyflex 999-30 and catalyst Polyflex KP9) added in 10:1 at room temperature. It was noticed by author from experiment that the mechanical characteristics of WSP reinforced composites such as tensile strength, compressive strength and flexural strength are examined as 88.22 MPa, 82.60 MPa and 109.18 MPa respectively at 5 wt % of WSP [4].

V. K. Singh investigated physical and mechanical characteristics namely density, water take-up, ultimate tensile of strength, flexural modulus, hardness, ultimate compressive of strength, flexural strength and flexural strain of walnut shell flour (WSF) reinforced epoxy based composites. The researchers were fabricated four specimens with the help of hand layup technique (with mechanical stirring) with different weight percentage of WSF (10, 15, 20 and 25 wt %) and remaining according to calculation epoxy resin (CY-230) added. It was observed from experiment by author that the value of modulus of elasticity, bending modulus of elasticity and hardness of the bio composite increased with addition of WSP. Similarly it was also examined by author from experiment that the value of ultimate strength both in tension as well as compression and bending strength and strain of bio composite deceased with increasing of percentage of weight of WSP. It was also examined by author from experiment that the value of density and resistance again water take up of WSP reinforced composites were decreased with increasing of percentage of weight of WSP in composites [24].

N. Ayrilmis *et al*. studied physical and mechanical characteristics namely density, water take-up, dimensional stability, tensile strength, tensile modulus, elongation at break, flexural strength and flexural modulus of walnut shell flour (WSF) reinforced polypropylene composites. The researchers were fabricated seven specimens with the help of injection molded technique with different weight percentage of WSF (0, 40, 50 and 60 wt %), 3 wt% MAPP and remaining according to calculation polypropylene resin added. It was also studied that water take up and TS with 3 wt% MAPP of composites are lower than other composites. It was observed by author from experiment that density of composites is increased with increment of WSF wt% in composite. The maximum result for flexural strength (41.0 MPa) and tensile strength (21.4 MPa) were evaluated by experiment at MAPP 3 wt%+ WSF 40 wt% compared with other filler specimens. Similarly The maximum result for flexural modulus (3830 MPa) and tensile modulus (3911 MPa) were evaluated by experiment at MAPP 3 wt%+ WSF 60 wt% compared with other filler specimens. Last the maximum elongation at break was found out with 100 wt% resin composite [16].

H. pirayesh *et al*. worked physical and mechanical characteristics namely water take up, dimension stability, internal bond strength, modulus of elasticity (MOE) and modulus of rupture

(MOR) of walnut/almond shell powder (WSP/ASP) reinforced urea – formaldehyde resin based particleboard composites. The researchers were fabricated six different particleboard specimens with version of 0 wt %, 10 wt%, 20 wt%, 30 wt% and 100 wt% of WSP/ASP using urea – formaldehyde resin. . It was observed from experiment by author that the value of internal bond strength, MOE and MOR of WSP/ASP reinforced urea – formaldehyde resin based particleboard composites were deceased with increasing of percentage of weight of WSP/ASP in particleboard composites. Similarly it was also examined by author from experiment that resistance again water take up (for 24 hours) and dimensional stability (for 24 hours) of WSP/ASP reinforced urea – formaldehyde resin based particleboard composites were increased with increasing of percentage of weight of WSP/ASP in particleboard composites [25].

S. Nitin and V.K. Singh investigated physical and mechanical characteristics namely density and tensile properties of walnut particles reinforced epoxy based composites. The researchers were fabricated four specimens by hand layup technique (with mechanical stirring) with different weight percentage of WSP (10 wt%, 20 wt%, 30 wt% and 40 wt%) and remaining according to calculation epoxy resin S-Y 12(319) and hardener SY31(B) mixed in 10:1 at room temperature. It was observed from experiment by author that the values of physical and mechanical characteristics of the bio composite decreased with increasing of percentage of weight of WSP [6].

2.3 Review on Physical Characteristics of Fiber Reinforced Polymer Based Composites.

A. Atiqah *et al*. studied physical characteristics namely density and dimension stability of sugar plam fiber (SPF) reinforced thermoplastic polyurethane (TPU) based composites. Authors fabricated six samples in the variation of fiber content from 0 to 50 by percentage of weight with 10 wt% in each step. It was observed by author that dimensional stability is increased with increment of SPF (maximum at 50 wt%) content in composite and dimensional stability is gradually increased from 72 hours to 168 hours. It was also examined by researcher that higher fiber content got more density (maximum at 50 wt%) of composite [26].

M. L. Sanchez et *al*. evaluated physical and mechanical behavior such as absorption capacity, density, thickness swelling, flexural strength, compression and tensile strength of bamboo fiber reinforced polyurethane (vegetal) based composite (call as a agglomerated panels). It was examined by author that moisture content, density and percentage of swelling of bamboo fiber is lesser than pich, flax and jute. It was also examined by author that moisture content (19.55±4.32%) and percentage of swelling (10.99±1.18%) of Guadua fiber (GAK) are lesser than Sugarcane bagasse (Sb), Bambusa Vulgaris (BV), coconut (C) and Dendrocalamus Giganteus (DG) fiber. Whereas density (1.06±0.09 g/cm^3) of GAK is greater than Sugarcane bagasse (Sb), Bambusa Vulgaris (BV), coconut (C) and Dendrocalamus Giganteus (DG) fiber. It was examined by researcher that GAK got more improve mechanical properties [27].

J. shari *et al*. investigated physical and mechanical characteristics namely water take-up, moisture content, flexural strength, impact strength and tensile strength of sugar palm fiber (SPF) reinforced plasticized sugar palm starch (SPS) bio-composites. It was observed by author that water absorption as well as moisture content is decreased with increment of amount of SPF in composite. It was examined by researcher that higher SPF fiber content got better mechanical properties (maximum at SPF 30 wt%) of composite [28].

M. Bootklad *et al*. worked physical characteristics namely water absorption and soil burial degradation of eggshell powder reinforced thermoplastic starch based (TPS/EP) composites as well as commercial calcium carbonate reinforced thermoplastic starch based (TPS/CC) composites. Authors were fabricated six samples in the variation of eggshell powder content from 0 to 50 by percentage of weight with 10 wt% in each step. Similarly Authors were fabricated six samples in the variation of commercial calcium carbonate content from 0 to 50 by percentage of weight with 10 wt% in each step. It was observed by author that weight loss after soil burial degradation was in descending order: TPS, TPS/EP and TPS/CC composites. Similarly it was also examined by researcher that water absorption resistance was in descending order: TPS/EP, TPS/CC, TPS composites [29].

V. Mishra *et al*. studied physical and mechanical characteristics namely void fraction, density, Hardness (HRB), with the help of three point bend test find strength and modulus of flexural, strength and modulus of tensile, and impact strength of jute fiber reinforced epoxy based composites. It was observed by author that the value of void fraction is maximum and minimum at 0 wt% of jute fiber and 12 wt% of jute fiber. It was also observed by author that the value of void fraction is decreased with increment of jute fiber (from 24 wt% to 48 wt %) in composite. It was evaluated by author that property of hardness, properties of tensile as well as impact strength is increased with increment of amount of jute fiber (maximum at - resin 52 wt%+ jute fiber 48 wt %) in composite. It was examined by researcher that inter-laminar shear strength, modulus and strength of flexural are decreased from 0 wt% to 12 wt% of jute fiber [30].

M. G. L. Ramirez *et al*. studied physical characteristics namely dimensional stability and moisture absorption of coconut fiber (CCF) reinforced cassava starch based bio composites. The researchers were fabricated seven samples by thermal molding technique with different weight percentage of CCF (0, 5, 10, 15, 20, 25 and 30 wt %) and remaining according to calculation cassava starch and glyceraol mixed in ratio of 70:30. It was observed by author by experiments that the value of dimensional stability and moisture absorption are decreased with increment of amount of coconut fiber amount in composite. It was examined by researcher that higher CCF content got better mechanical properties (maximum at CCF 30 wt %) of composite [31].

K. B. AdhiKary *et al*. investigated physical characteristics namely moisture absorption and TS of pinus radiate sawdust (PRS) reinforced recycled thermoplastics (RTP) based composites. The researchers were fabricated specimens of hybrid composites by hot press moulded technique (twin screw extrude) using PRW as a reinforced materials, HDPE/MAPP and PP/MAPP as a PMC material. It was also studied that moisture absorption and TS with 5 wt% MAPP of composites are lower than 0wt% as well as 3 wt% of MAPP of composites. It was examined by researcher that PP (45 wt %) + PRW (50 wt %) + MAPP (5 wt %) composite got more dimensional stability as compare to other composite [32].

2.4 Review on physical Characteristics of Fiber Reinforced Polymer Based Hybrid Composites.

A. Afzaluddin *et al*. investigated physical and mechanical characteristics namely water take-up, density, thickness swelling (TS) flexural strength, impact strength and tensile strength of sugar plam fiber (SP) and glass fiber (G) reinforced polyurethane based hybrid composites. It was observed by author that water take up and TS are increased with increment of SP/G (30/10) in hybrid composite. It was observed from experiment by author that density, impact strength, flexural strength and modulus of SP/G hybrid composite is increased with increment of glass fiber reinforcement (maximum at SP/G- 0/40). It was examined by researcher that higher natural fiber content SP/G (30/10) got more elongation at break, tensile strength and modulus of hybrid composite [33].

Ashik K P *et al*. studied physical and mechanical characteristics namely moisture absorption (in the means like sea water, bore water, normal water and distilled water), flexural strength and impact strength of coconut coir fiber and glass fiber reinforced epoxy based hybrid composites. It was observed by author that moisture absorption is increased with increment of coconut coir fiber in hybrid composite. It was examined by researcher that higher fiber content got more flexural strength and impact strength of hybrid composite [34].

M. Jawaid *et al*. studied physical characteristics namely void fraction, dimensional stability, density and chemical resistant again acids (like as HCl, HNO_3, CH_3COOH), solvents (NaOH Na_2CO_3, NH_4OH), alkalis (benzene, toluene, CCl_4) and water for one day of oil plam EFB fiber and jute fiber reinforced epoxy based hybrid composites. It was observed by author that density of hybrid composites is increased with increment of jute fiber in hybrid composite whereas void content is decreased with increment of jute fiber in hybrid composite. It was also studied that TS and water take up of hybrid composites is decreased with increment of jute fiber in hybrid composite. It was examined by researcher that higher jute fiber content hybrid composites got more chemical resistance again acids (like as HCl, HNO_3, CH_3COOH), solvents (NaOH Na_2CO_3, NH_4OH), alkalis (benzene, toluene, CCl_4) and water [35]

A. Ashori and S. Sheshmani investigated physical characteristics namely moisture absorption and TS of recycled news paper fiber (RNF)/poplar wood flour (PWF) reinforced recycled polypropylene (RPP) based hybrid composites. The researchers were fabricated three specimens in each five category of hybrid composites by injection molded technique (twin screw extruder) using RNW/PWF (fixed 40 wt% like as 30/0 (category-A), 22.5/7.5 (category -B), 15/15 (category-C), 7.5/22.5 (category-D) and 0/30 (category-E)) as a reinforced materials, RPP/MAPP (fixed 60 wt% like as 70/0 (sample-1), 68/2 (sample-2) and 6/4 (sample-3)) as a PMC material. Authors were fabricated three specimens in each five category in the variation of MAPP content from 0 to 4 by percentage of weight with 2 wt% in each step. It was observed by author that the values of TS and moisture absorption are higher for category-A and category-B whereas the values of TS and moisture absorption are lower for category-C and category-B. It was also studied that moisture absorption and TS with 6 wt% MAPP of hybrid composites are lower than 2 wt% as well as 0 wt% of MAPP of hybrid composites. It was examined by researcher that 100 wt% RPP composite got more dimensional stability as compare to other hybrid composite [36].

2.5 Review on Implementation of DOE and Optimization Techniques (Taguchi's Technique and ANOVA).

H. Bankoti *et al*. investigated the tensile strength and flexural strength properties of epoxy based composites with reinforced walnut. They prepared the six specimens with the help of compression molding technique with different weight percentage of walnut (5, 10, 15, 20, 25 and 30 wt %) and remaining according to calculation epoxy added. Tensile strength and flexural strength were optimized using Taguchi method. After L_{18} run they were evaluated that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (10 wt%), speed (2 mm/min) for both flexural tensile strength. They also found significant parameter in descending order filler content, and speed for both flexural strength and tensile strength [37].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and speed (0.5 mm/min, 1 mm/min and 2 mm/min) for both flexural strength and tensile strength at 95% confidence level. The value of S/N ratio were 0.8681 dB (2.386%) and 0.6193 dB (2.053%) for flexural strength and tensile strength respectively [37].

N. R. Kumara *et al*. evaluated impact strength, tensile strength and flexural strength properties of polypropylene based composites with reinforced vakka fiber. In first level, they fabricated the six specimens with the help of injection moulding machine with different weight percentage of vakka fiber (0, 5, 10, 15, 20 and 25 wt %) and remaining according to calculation polypropylene pellets added. Impact strength, tensile strength and flexural strength were optimized using Taguchi method. After L_{12} run they evaluated that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (15 wt%) and treatment of with MAPP (level–2) for impact strength, flexural strength and tensile strength. They also found significant parameter in descending order filler content and treatment of with/without MAPP (level-1/level–2) for flexural strength and tensile strength as well as impact strength [38].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and treatment of with MAPP (level–1) and without MAPP (level–2) for impact strength, flexural strength and tensile strength at 95% confidence level. With the help of ANOVA, it evaluated that both filler content and treatment are significant parameter for tensile strength and impact strength whereas for flexural strength treatment with MAPP is most significant parameter [38].

B. A. M. Pasha and K. Mohamed fabricated the four different specimens with mass fraction variation of silicon carbide and aluminum oxide particles (size 10−20 µm) range of 0−9% at a step of 3% each in Al7034-T6 metal matrix by mechanical stirrer technique. They studied erosion response with the functions of impact velocity (20, 80, 100 and 120 m/s), standoff distance (30, 40, 50 and 60 mm), erodent temperature (30 ^{0}C, 60 ^{0}C, 100 ^{0}C and 120 ^{0}C) impingement angle (30^0, 45^0, 60^0 and 90^0) and Alumina content (0, 3, 6 and 9% by mass fraction) on reinforced with silicon carbide and aluminum oxide particles (size 10−20 µm) metal matrix composite (Al7034-T6). After L_{16} run they were evaluated that impact velocity and filler content are the most significant factors for the erosion rate on Al7034-T6 metal matrix composites filled with silicon carbide and aluminum oxide particles (size 10−20 µm). After study of L_{16} run they observed that the factor combination of impact velocity (20m/s), standoff distance (60 mm), erodent temperature (60 ^{0}C) impingement angle (90^0) and Alumina content (9% by mass fraction) leads to reduce the erosive wear rate. They also found less significant parameter in ascending order standoff distance, impingement angle and erodent temperature [39].

A. M. Hebbalea and M. S. Srinath studied slurry erosive wear on cobalt based microwave cladding on stainless steel AISI-420. They studied slurry erosion response with the functions of speed (1000, 1250 and 1500 rpm), particles (212, 425 and 600 μm) and angle (15^0, 30^0 and 45^0) on metal matrix composite (AISI-420). After L_9 run they evaluated that speed (S) and particles (P) are the most significant factors for the slurry erosion rate on metal matrix composite (AISI-420). After study of L_9 run they observed that the factor combination of particle size (425 μm), impingement angle (30 deg) and Speed (1000 rpm) gives the minimum erosion wear rate. They also found less significant parameter the impingement angle [40].

A. Prakash *et al*. worked the tensile strength and flexural strength properties of epoxy based composites with particulate kaolinite ($Al_2SiO_5(OH)_4$). They prepared six specimens with the help of compression molding technique with different weight percentage of kaolinite (0, 1.5, 3, 4.5, 6 and 7.5 wt %) and remaining according to calculation epoxy added. Tensile strength and flexural strength optimized using Taguchi method. After L_{18} run they observed that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (4.5 wt%), speed (7 mm/min) for both flexural strength and tensile strength [41].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and speed (3 mm/min, 5 mm/min and 7 mm/min) for both flexural strength and tensile strength at 95% confidence level. The value of S/N ratio were 0.8681 dB (2.386%) and 0.6193 dB (2.053%) for flexural strength and tensile strength respectively [41].

K. Karuppusamy *et al*. evaluated flexural strength property of epoxy base composites with reinforced bagasse fiber. They prepared three specimens with the help of compression moulding technique with different volume percentage of bagasse fiber (40 v_f%, 50 v_f% and 60 v_f %) and remaining according to calculation epoxy added. Epoxy based composites were used bagasse fiber as a reinforcement and Araldite AW554 epoxy for resin and relative hardener Araldite HY951. Flexural strength optimized using Taguchi method with the design constraints like as: for tensile strength is fiber content, alkali concentration (4%, 5% and 6% with NaOH solution at room temperature) and treatment time (3 hr, 4 hr and 5 hr). After L_{27} run they evaluated that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (40 v%), alkali concentration (5% with NaOH solution at room temperature) and treatment time (3 hr) for flexural strength. They also found significant parameter in descending order filler content, alkali concentration and treatment time for flexural strength [42].

The statistical tool, ANOVA is also used for evaluation of three factors such as fiber content, alkali concentration and treatment time for flexural strength at 95% confidence level. The value of R^2 was 99.45% and the value of adjusted R^2 was 99.28% for flexural strength [42].

A. Dixit and K. Kumar evaluated the tensile modulus and flexural modulus properties of aluminum MMC composites with reinforced silica gel. They prepared the six specimens with the help of metal matrix by mechanical stirrer technique with different weight percentage of silica gel (0, 2, 4, 6, 8 and 10) and remaining according to calculation aluminum added in MMC. MMC based composites were used silica gel particles as a reinforcement and aluminum as a MMC. Tensile modulus and flexural modulus were optimized using Taguchi method. After L_{18} run they observed that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (8 wt%), speed (3 mm/min) for tensile modulus and filler content (6 wt%), speed (3 mm/min) for flexural modulus. They also found significant parameter in descending order filler content, and speed for both flexural strength and tensile strength [43].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and speed for both flexural strength and tensile strength at 95% confidence level. The value of S/N ratio was 0.626 dB and 0.5731 dB (2.053%) for tensile modulus and flexural modulus respectively [43].

N. R. Kumar *et al*. investigated impact strength, tensile strength and flexural strength properties of polypropylene based composites with reinforced corn fiber. In first level, they fabricated the six specimens with the help of injection moulding machine with different weight percentage of corn fiber (0, 5, 10, 15, 20 and 25) and remaining according to calculation polypropylene pellets added. PMC composites were used corn fiber as a reinforcement and polypropylene for resin. In secondary level, again they fabricated the six specimens with the help of injection moulding machine with different weight percentage of corn fiber (0, 5, 10, 15, 20 and 25) and remaining according to calculation polypropylene pellets added and also MAPP is added for enhancement of adhesion property of PMC composites. All the specimens of different percent of weight of corn fiber were tested at speeds of 1 mm/min. The shape and size of specimens for Izod impact test according to ASTM standard has designation (D256-97). The various design constraints for tensile strength, impact strength and flexural strength are same like as filler content and treatment of without MAPP (level–1) and with MAPP (level–2). Impact strength, tensile strength and flexural strength were optimized using Taguchi method. After L_{12} run they evaluated that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (5 wt%) and treatment of with MAPP (level–2) for both flexural strength and tensile strength. Whereas the optimal combination of design parameters for impact strength can be obtained as filler content (10 wt%) and treatment of with MAPP (level–2). They also found significant parameter in descending order filler content and treatment of with/without MAPP (level-1/level–2) for flexural strength and tensile strength as well as impact strength [44].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and treatment of without MAPP (level–1) and with MAPP (level–2) for impact strength, flexural strength and tensile strength at 95% confidence level. With the help of ANOVA, it evaluated that both filler content and treatment are significant parameter for tensile strength, for flexural strength weight percentage of fiber is most significant parameter where as impact strength treatment with MAPP is most significant parameter [44].

M. Bagci studied erosion response with the functions of impingement angle (30^0, 60^0, and 90^0), fiber loading (0 wt%, 30% [15% (Al_2O_3) + 15% (SiO_2)]) and impact velocity (23, 34, 53 m/s), angular alumina erodent's having sizes (200 μm) and the fiber directions (0/90/0, 45/-45/45 and 90/0/90) on epoxy based composite without and with filler. After L_{18} run (2^1 3^3) mix level orthogonal array, he evaluated that minimum erosion was taken place at fiber direction (45/-45/45), filler material (0 wt% [(Al_2O_3) + (SiO_2)]) impingement angle (30^0) and impact velocity (23 m/sec). He also found sequence of parameter effect in ascending order as impingement angle, the impact velocity, fiber direction and filler material [45].

R. Kumar *et al*. worked the tensile strength and flexural strength properties of epoxy base E glass fiber composites with filler wood dust. They prepared the six samples with the help of hand layup technique with different weight percentage of sundy wood dust (0, 2.5, 5, 7.5, 10 and 12.5) and remaining according to calculation epoxy added. Epoxy based composites were used sundy wood dust particle as a reinforcement and LY 556 epoxy for resin. After L_{18} run they evaluated that larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as filler content (10%), speed (2 mm/min) for load and filler content (10%), speed (1 mm/min) for both flexural and tensile stress [46].

The statistical tool, ANOVA is also used for evaluation of two factors such as filler content and speed for both flexural strength and tensile strength at 95% confidence level. The value of S/N ratio were 1.2502 dB (1.80%), 2.3895 db (9.13%) and 2.0802 dB (6.805%) for load, tensile strength and flexural strength respectively [46].

Siddartha and K. Gupta investigated DOE response on abrasive wear test with the functions of normal load (2.5kgf, 5kgf, 7.5kgf, 10kgf and 12.5kgf,), fiber loading (15wt%, 20wt%, 25wt%, 30wt% and 35wt%), sliding velocity (0.48m/sec,0.72m/sec,0.96m/sec,1.20m/sec and 1.44m/sec), abrasive size (125µm, 210µm, 355µm, 420µm and 600µm) and sliding distance (50m, 60m, 70m, 80m and 90 m) on epoxy based composite bidirectional and chopped E- glass fiber. After L_{25}run they evaluated that minimum abrasive wear was taken place at abrasive size (125µm), fiber content (25wt%), sliding velocity (1.44 m/sec), sliding distance (90 m) and normal load (2.5kgf) for bidirectional fiber epoxy based composites. The result for chopped fiber epoxy based composites was abrasive size (125µm), fiber content (25%), sliding velocity (7.2 m/sec), sliding distance(70m) and normal load (2.5kgf) [47].

2.6 Research Gap

After review of SCI index research papers, it is found that in most of researcher was worked on different type of natural fiber as well as natural particular reinforced polymer based composites. Researchers investigated physical properties, mechanical properties, surface morphologies and strength (tensile as well as flexural) behaviours of natural fiber as well as natural particular reinforced polymer matrix composites using various filler. There were less worked on combination coconut shell particle and walnut shell particle (1:1) of reinforced epoxy based composites.

The review SCI index research papers donated above reveals directing knowledge gap and which is also helpful for direction of aim of this present experimental research work.

- Most of investigators investigated density and dimension stability of fiber bio- composites only, in fact no study has been found more than one particular filled with epoxy based composites.
- Most of researchers investigated flammability test of fiber bio- composites only. There is a possibility that two particular embedded into thermo set polymer matrix could provide the lowest burning rate in length per unit min.
- As far as impact and flexural mode test study of one filler particular epoxy based composites is evaluated. But there are very less examination on two particular such as CSP and WSP (1:1) embedded into thermo set polymer matrix.
- In most of the papers, researchers apply optimization technique to improve flexural performance by optimize velocity, particular load and others. The few investigators were worked with two particular for optimize velocity and particular load. So that there is definite scope on study of different properties of coconut shell particle and walnut shell particle (1:1) filler epoxy based composites under various manufacturing and testing conditions.
- Therefore, it feels in this research work that filler loading is use as response for optimization of performance of mechanical characteristics in flexural mode.

- For more accuracy of results, analysis of variance method is also applied in this research work.

2.7 Work Statement

Based on specific review of the literature, the following work statement has been formulated as "Development and Investigation of Physical and Mechanical Behavior of Epoxy Based Coconut Shell Particular And Walnut Shell Particular Reinforced Composite". The main purpose of the present work is to fabricate and obtain composite using lignocellulosic agro waste and evaluate the mechanical properties of designed composite.

Chapter 3

MATERIALS AND METHODOLOGY

Introduction

This chapter explains methodologies and designation and compositions of the composites used during this experimental work. This chapter explains the completed procedure of material selection, fabrication (Hand lay-up technique) and finally testing equipments (such Tinius Olsen Made in USA (UTM) for flexural test and Tinius Olsen Made in USA for impact test) used for the analysis of samples to find the properties of the material.

3.1 Material Selection

Epoxy resin (LY 556), hardener (HY951), mold sheet and a heavy duty silicone spray were supplied from Savita Scientific and Plastic Products at 445, mishra rajai's street 1st cross indira bazaar Jaipur-302001.

Figure 3.1 Mold Sheet.

3.1.1 Matrix-Material Selection

Epoxy resin (LY 556) (low/room temperature curing and density of 1026 gm/cc at 25^0C) and hardener (HY951) were supplied from Savita Scientific and Plastic Products at 445, mishra rajai's street 1st cross indira bazaar Jaipur-302001. Epoxy resin (LY 556) and hardener (HY951) manufactured by ASES Chemical Works at industrial chemical division B-48-50, industrial estate, Jodhpur- 342003.

Figure 3.2 Epoxy Resin (LY 556) with Hardener (HY951).

Figure 3.3 Heavy Duty Silicone Spray.

3.1.2 Coconut Shell Particulars as a Reinforced Material Selection.

The coconut shells were supplied from local dry fruit coconut distributor (Mansarovar, Jaipur 302020). Before their use, CS was dried under sunlight. After that CS was cleaned via pressurized water. This procedure removes fine particles, walnut shell residues and organic materials from the samples. CS was dried with hair drier then put into crushing mill for a micro size reduction.

Figure 3.4 (a) Coconut Shell.

Figure 3.4 (b) Coconut Shell Particular (Mesh 210).

Table 3.1 Chemical Composition of Coconut Shell [9].

S.No	Chemical composition %	Coconut shell
1	Cellulose	26.6
2	hemicelluloses	21
3	Lignin	29.4
4	Pentosans	27.7
5	Solvent Extractives	4.6
6	Uronic Anhydrides	3.5
7	Ash	0.6

Table 3.2 Physical and Mechanical Properties of Coconut Shell [9].

S.No	Properties	Coconut shell
1	Maximum size (mm)	12.5
2	Moisture content (%)	4.2
3	Water absorption (24 h) (%)	24
4	Specific gravity	1.05-1.20
5	SSDa apparent	1.40-1.50
6	Impact value (%)	8.15
7	Crushing value (%)	2.58
8	Abrasion value (%)	1.63
9	Bulk density (kg/m^3)	650
10	Compacted loose	550
11	Fineness modulus	6.26
12	Shell thickness (mm)	2 - 8

Cocos nucifera (coconut) is one of place in list of the palm family. Which is not only used for decoration but also uses for culinary and non-culinary, it's means each components of the coconut palm has some human use. One of the parts of coconut palm is CS, which is not only non-food but also lignocellulosic agro-waste. It is the hardest part of the nut. Other part of coconut is coconut husk, which is composed of fibers. Figure 3.4 shows the photograph of coconut shell.

3.1.3 Walnut Shell Particular as a Reinforced Material Selection.

The walnut shells were supplied from local dry fruit walnut distributor (Mansarovar, Jaipur 302020). Before their use, WS was dried under sunlight. After that WS was cleaned via pressurized water. This procedure removes fine particles, walnut shell residues and organic materials from the samples. WS was dried with hair drier then put into crushing mill for a micro size reduction.

Figure 3.5 (a) Walnut Shell Particular.

Figure 3.5 (b) Walnut Shell Particular (Mesh 210).

Walnut shell is one of place in list of lignocellulosic agro-waste materials. WS has neither economic value nor industrial uses in India. Generally, it is used as a firewood replacement material. WS lignocellulosic agro waste particular has a number of admirable properties as a reinforcing particular over thermoplastic composites such as need higher dimension stability in outdoor application. The main advantage of WS, it does contain less amount of cellulose as well as hemicelluloses, which is known as hygroscopic materials. Other hand it does contain much amount of lignin, which is known as hydrophobic material.

Table 3.3 Chemical Composition of Walnut Shell [14, 16].

S.No	Chemical composition of Walnut shell	Percentage of Weight
1	Cellulose	23.9
2	Hemicelluloses	22.4
3	Lignin	50.3
4	Hot water solubility	9.44
5	NaOH (1%) solubility	22.5
6	Ash	3.4
7	Toluene Solubility	0.5 - 1.0
8	Cutin	0.8-1.60
9	Chlorine	0.11
10	Nitrogen	0.11

3.2 Fabrication of Composite (Hand Lay-up Technique)

The Hand Lay-up technique is the method used for the processing of the composite materials. This technique is simplest kind of processing method with minimal infrastructural requirement. Following steps are there in hand lay-up technique (as shown in table 3.4).

Table 3.4 Composite Preparation [48].

Part – I	Preparation of Raw Materials
Step -1	Approximately two weeks, coconut shell and walnut shell were dried under sunlight.
Step -2	The coconut shell and walnut shell samples were cleaned via pressurized water. This procedure removes fine particles, coconut shell and walnut shell residues and organic materials from the samples.
Step -3	The coconut shell and walnut shell were dried with hair drier.
Step -4	The coconut shell and walnut shell were crushing for a micro size reduction.
Part - II	Epoxy Resin and Hardener
Step -5	According to calculation mixer are prepared. Also curing agent (HY951) is mixed with epoxy composite in 1: 10.
Step - 6	According to calculation, taken coconut shell particular and walnut shell particular (1:1) and epoxy in six different composition with epoxy (95, 90, 85, 80, 75 and 30 wt %) and CSP/WSP (1:1) (2.5, 5, 7.5, 10, 12.5 and 15 wt%).
Part - III	Preparation of Composite Laminates
Step - 7	The dough (epoxy filled with CSP/WSP (1:1)) is mechanically stirred and placed in a vacuum chamber to remove air bubbles that got introduced. This procedure was performed for 10 minutes initially.
Step - 8	The mixture was re-stirred and the vacuum procedure was performed again for 10 minutes for further removal of bubbles.
Step - 9	The dough (epoxy filled with CSP/WSP (1:1)) is then gradually poured into the vacuum glass chamber of required dimension of 200 mm x 150 mm x 5 mm, coated beforehand with glass paper and a mold release spray was applied at the inner surface of the mold for quick and easy removal of composite sheets.
Step - 10	After curing at room temperature in 24 hours, mold is opened and the composite part is taken out.
Step - 11	From step 6 to step 10 were repeated for different weight percentage of filler specimen (such as 2.5, 5, 7.5, 10, 12.5 and 15 wt %).
Step - 12	After that the filler reinforced specimen is used to study the various mechanical behaviours.

Table 3.5 Designation and Compositions of the Composites.

Specimen		
Compositions	**A** - Epoxy (95 wt%) + 2.5 wt% CSP + 2.5 wt% WSP	**B** - Epoxy (90 wt%) + 5 wt% CSP + 5 wt% WSP
Specimen		
Compositions	**C** - Epoxy (85 wt%) + 7.5 wt% CSP + 7.5 wt% WSP	**D** - Epoxy (80 wt%) + 10 wt% CSP + 10 wt% WSP
Specimen		
Compositions	**E** - Epoxy (75 wt%) + 12.5 wt% CSP + 12.5 wt% WSP	**F** - Epoxy (70 wt%) + 15 wt% CSP + 15 wt% WSP

3.3 Physical Characterizations of CSP/WSP (1:1) Particulates Reinforced Epoxy Based Composites.

3.3.1 Density Measurement Test

Density is an important physical property of the composites. Low density composites are favorable due to less production coats. The density of composites depends on quantities of fiber filler and epoxy resin. Archimedes principle method is widely used to determine the density of the composites. Archimedes principle states that "when a body is partially or fully submersed in a liquid then a buoyant force act on the body in upward direction whose magnitude equal to the weight of the liquid displaced by body". The specimens for density test are cut from the composite product in 40 mm in length and 20 mm in width.

Figure 3.6 Specimens for Density Test.

Figure 3.7 (a) Weighing of Specimen in Air [RCERT, Jaipur].

Figure 3.7 (b) Weighing of Specimens in Distilled Water [RCERT, Jaipur].

Density can be calculated by this formula [26]:

$$\text{Density} = W_a \times \sigma_w / (W_a - W_w)$$

Where W_w = mass of specimen weighed in distilled water.

W_a = mass of specimen weighed in air.

σ_w = density of distilled water at NTP.

= 0.998 gm/cm^3.

3.3.2 Moisture Content Test

Moisture content test gives the water content of composites by drying the specimens in oven to constant mass at specified temperature. It is necessary to find out the moisture uptake for the composites because fiber is more sensible with water and humidity and it is also a special parameter for application for the composites. This test is based on the mass fraction method. For this experiment first weight the samples hereafter keep in oven for dry until a constant weight is reached. The drying time to reach constant mass depends upon types of material, quantity of the material and condition of the material. In most cases 16 hrs to 24 hrs drying period is enough to gain constant mass. When constant mass reaches again weight the samples. The size of the specimen for moisture content test according to ASTM D570 is 20 mm x 20 mm with 5 mm average thickness.

Figure 3.8 Specimens for Moisture Content Test.

Figure 3.9 (a) Weighing of Specimen in Air [RCERT, Jaipur].

Figure 3.9 (b) Baking of Specimen in Oven [RCERT, Jaipur].

The moisture content can be calculated by using following equation [27]:

$$\text{Moisture Content} = [(W_{t0} - W_{t1}) / W_{t1}] \times 100$$

Where: W_{t0} = The weight of the specimen before dry in oven.

W_{t1} = The weight of specimen after dry in oven.

3.3.3 Water Absorption Test

Water absorption can be finding out by weight percent process. The size of the specimen for moisture content test according to ASTM D570 is 20 mm x 20 mm with 5 mm average thickness. All specimens kept in an electric oven at 80 ^{0}C for 24 hours to remove the moisture. Now determine the weight of each dried samples hereafter dip them in water for 72 hrs and then take out and weight again.

Figure 3.10 Specimens for Water Absorption Test.

Figure 3.11 Soaking up of Specimen in Tap Water for Water Take up Test [RCERT, Jaipur].

The water absorption can be calculated by using following equation [26]:

$$\text{Water absorption} = [(W_{t1} - W_{t0}) / W_{t0}] \times 100$$

Where: W_{t1} = The weight of the specimen after immersion in water.

W_{t0} = The weight of the specimen before immersion in water.

3.3.4 Linear Swelling Test

Linear swelling gives an idea of change in thickness/width/length. Linear swelling can be finding out by thickness/width/length percent method. The size of the specimen for linear swelling test according to ASTM D570 is 20 mm x 20 mm with 5 mm average thickness. All specimens kept in an electric oven at 80^0C for 24 hours to remove the moisture. Now determine the length/thickness/width of each dried samples hereafter dip them in water for 75 hrs and then take out and measure length/thickness/width again.

Figure 3.12 Specimens for Thickness Swelling Test.

Figure 3.13 Soaking up of Specimen in Tap Water for Linear Swelling Test [RCERT, Jaipur].

The linear swelling can be calculated by using following equation [26]:

$$\text{Linear Swelling} = [(L_1 - L_0) / L_0] \times 100$$

Where: L_1 = length/thickness/width of the sample after immersion in water.

L_0 = length/thickness/width of sample before immersion in water.

3.3.5 Flammability Test

The present test carried out on ASTM 635 standard with specimens dimension 125 mm x 13 mm with 5 mm average thickness. Each specimena are diveded into three parts by marking, one part has distance from free left hand 25 mm and similary other part has distance from free right hand 25 mm. Each specimena are held horizontal in a vectical stand with its transverse axis being inclined at 45^0. The flame front was kept at the free edge of specimen for 30 seconds. After the fire reached 25 mm mark, the stopwatch was started and the time was recorded till the fire reached 100 mm mark. The burning ate was calculated as mm/min which was obtained by dividing burned length with the time recorded. The left over mass was weighed after removing the ashes to get mass loss rate [49].

Figure 3.14 Specimens for Flammability Test.

Figure 3.15 (a) Arrangement of Specimens for Flammability Test.

Figure 3.15 (b) Specimens for Flammability Test During Burning.

3.4 Mechanical Characterizations of CSP/WSP (1:1) Particulates Reinforced Epoxy Based Composites.

All specimens of flexural and impact mode tested on the universal testing machine (UTM) and Model IT 504 Plastic Impact (Tinius Olsen Made in USA) respectively in Department of Chemical and Petrochemicals at CIPET: Centre for Skilling and Technical Support (CSTS), SP- 1298, Sitapura Industrial Area, Phase- III Tonk Road Jaipur 302022.

3.4.1Flexural Test

The flexural test is also called 3- point bend test. The shape and size of specimens for flexural test according to ASTM standard has designation (D2344-84) [50]. The size of the specimen for tensile test according to ASTM D2344-84 is 100 mm x 20 mm with 4±1 mm average thickness. The gauge length took as a 60 mm for tensile test. All the specimens of different percent of weight of

CSP/WSP (1: 1) (as 2.5 wt%, 5.0 wt%, 7.5 wt%, 10.0 wt%, 12.5 wt% and 15.0 wt %) were tested at three different speeds of 1 mm/min, 2 mm/min and 3 mm/min (shown in Figure 3.16 and 3.17). The flexural test is performed in the universal testing machine (UTM) and results are analyzed to calculate the flexural strength of composite samples is shown in Figure 3.17.

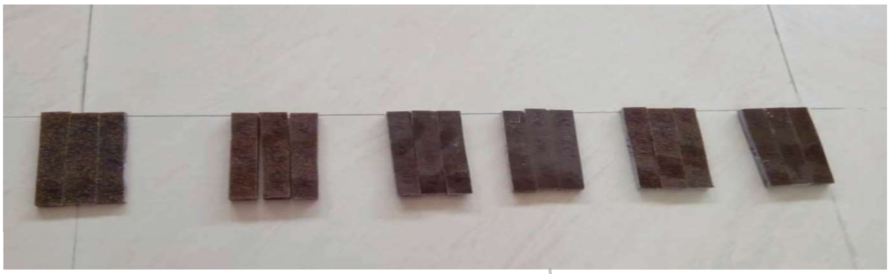

Figure 3.16 Specimens for Flexural Test.

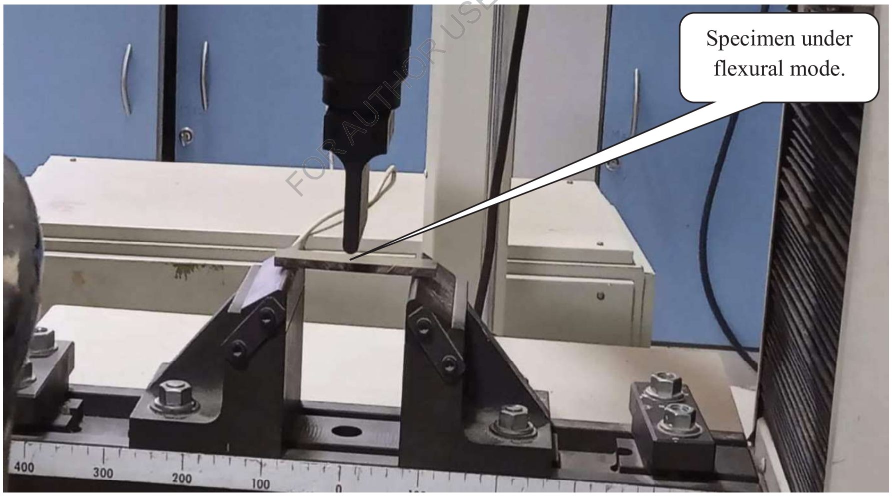

Figure 3.17 Specimen under Flexural Mode (Tinius Olsen Made in USA)
[Department of Chemical and Petrochemicals at CIPET, Jaipur].

3.4.2 Impact Test

Impact strength is the property of a material by virtue which the ability to resist fracture under the stress applied at high speed. The impact test of epoxy based composite was measured using Izod tester. The specimens were made to 300 x 300 x 5 mm dimension using mold having the dimension 125 x 2.7 x 5mm and notch was made according to ASTM-D6110-10 specifications. The impact test was performed at ambient conditions.

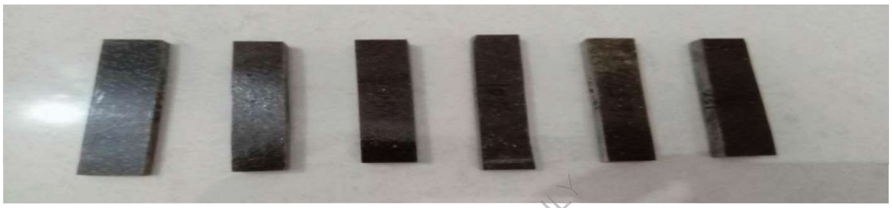

Figure 3.18 Specimens for Impact Test.

Figure 3.19 Specimen under V Notch Cutter (Tinius Olsen Made in USA) [Department of Chemical and Petrochemicals at CIPET, Jaipur].

Figure 3.20 Specimen under Impact Mode on Model IT 504 Plastic Impact (Tinius Olsen Made in USA) [Department of Chemical and Petrochemicals at CIPET, Jaipur].

3.5 Taguchi Experimental Design

Taguchi design of experiment is an important statistical method for analyzing and modeling the action of control parameter on response output. The control parameter selection is most essential level in the design of experiment. Therefore, initially a number of parameters are incorporated so that minor parameter can be recognized at preliminary opportunity.

From thorough out literature study on mechanical response of polymer based composites disclose that parameters such as speed and particulate filler widely affect the mechanical response of polymer based composites. In the present research work, the impact of two parameters at six levels are evaluated using L_{18} (6^1 3^1) orthogonal design. The experimental conditions under which mechanical response experiment are conduct are shown in table 3.6. The mechanical response experiments are performed at room temperature at six levels of each parameter as per experimental design represent in table 3.7.

Table 3.6 Parameter Settings for Flexural Test.

Control Parameter		Fixed Parameter	
Control Parameter	Symbols	Fixed Parameter	Dimensions
Filler content	Parameter A	Span Length (Flexural test)	60 mm
Speed	Parameter B	Test temperature	Room Temperature

The mechanical response study was conducted with two control parameters such as filler content (A) and speed each parameter at six levels as represented in table 3.7 in association with L_{18} orthogonal array. Taguchi's approach make cutbacks in L_{18} runs comparison to $6^3 = 216$ runs two parameter at six different levels in factorial test design. It provides excellent accuracy as well as less time in experimental work. In Table 3.8, each column describes a test parameter and a row describes a test state which is importance but combination of parameter levels.

Table 3.7 Levels of Variables (Control Factors) Used in Experiment.

	Levels						
Control factors	1	2	3	4	5	6	Units
Filler content	2.5	5.0	7.5	10.0	2.5	15.0	wt.%
Speed	1	1	1	1	1	1	mm/min
	2	2	2	2	2	2	
	3	3	3	3	3	3	

This method used a logarithmic function is known as signal- to- noise which is statistical measurement of parameters and also gives optimization condition of control parameters. The value of mean as well as variability of parameter is also measure by signal-to-noise ratio. Signal-to-noise is function of mean (signal) to deviation (noise). The optimal value of parameter of process/product is calculated with the help S/N ratios. Signal-to-noise ratio is calculated with the help of three methods which are lower the-better (LB), higher-the-better (HB) and nominal-the best (NB). The experimental inspection is converted into a signal-to-noise (S/N) ratio. Mechanical response can be maximum using under larger is better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below [37, 41, 42, 46].

Larger is the better characteristic $$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$$

Table 3.8 Orthogonal array for L_{18}

Test Run	Parameter A	Parameter B
P	1	1
Q	1	2
R	1	3
P	2	1
Q	2	2
R	2	3
P	3	1
Q	3	2
R	3	3
P	4	1
Q	4	2
R	4	3
P	5	1
Q	5	2
R	5	3
P	6	1
Q	6	2
R	6	3

Chapter 4

CSP/WSP REINFORCED EPOXY BASED COMPOSITES: PHYSICAL PROPERTIES, FLAMMABILITY RESISTANCE AND IMPACT TEST

Introduction

This chapter gives attention on the physical characteristics namely density, moisture content (MC) and dimensional stability (water absorption (WA) as well as thickness swelling (TS)) of different percentage of weight of CSP/WSP reinforced epoxy composites prepared for this research work. The elucidation of the results and the comparison among various composite samples are also accounted. This chapter account of three parts: first part relates to physical properties as well as second part deals to flammability resistance properties of CSP/WSP reinforced epoxy composites and last part has provided the description of impact test.

Part- I

4.1 Effect of Physical Properties on CSP/WSP (1:1) Particulates Reinforced Epoxy Based Composites.

4.1.1 Density Property.

Density is an important physical property of the composites. Low density composites are favorable due to less production cost. The density of composites depends on amount of resin (epoxy) as PMC material as well as CSP/WSP as reinforcement particulates.

Figure 4.1 represents the curve of density versus percentage of weight of CSP/WSP (1:1) particulate reinforced epoxy composites. The value of density of 2.5 wt% CSP/WSP (1:1) particulate reinforced epoxy based composite has 5.975 g/cm^3 due to better bonding between epoxy resin and maximum voids formation [35]. Void formation in composite is accused due to air bubbles entrapped within the PMC, vaporous arising during curing of epoxy and hardener and residual solvents. Voids are also accused due to resin difficult to wet completely after mixing of CSP/WSP (1:1) particles [26].

Table 4.1 Comparison of density of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	Run	Initial weight of sample in air (g) (Wt_a)	Weight of sample after immersion in water (g) (Wt_w)	Density (gm/cm^3)	Average density (gm/cm^3)
A	A-1	3.310	2.700	5.415	5.975
	A-2	3.470	2.940	6.534	
B	B-1	7.100	6.690	17.282	15.308
	B-2	4.810	4.450	13.334	
C	C-1	5.290	4.900	13.537	10.636
	C-2	4.030	3.510	7.734	
D	D-1	4.940	4.280	7.470	7.306
	D-2	5.010	4.310	7.143	
E	E-1	5.370	4.580	6.784	7.277
	E-2	5.450	4.750	7.770	
F	F-1	5.180	4.480	7.385	7.167
	F-2	3.830	3.280	6.950	

After that it was observed from figure 4.1 that the value of density of CSP/WSP (1:1) particulates reinforced epoxy based composite with 5 wt% suddenly increased due to the increase of density of CSP/WSP (1:1) particulates in composites. It was observed from figure 4.1 that the value of the density (15.308 g/cm^3 to 7.167 g/cm^3) is further decreases from 5 to 15 wt% of CSP/WSP (1:1) particulates reinforced epoxy based composites due to the increase of density of CSP/WSP (1:1) particulates in composites [21]. The decrease in value of density can be related to the fact that the coconut shell as well as walnut shell particles are light in weight but occupy a substantial amount of space [24].

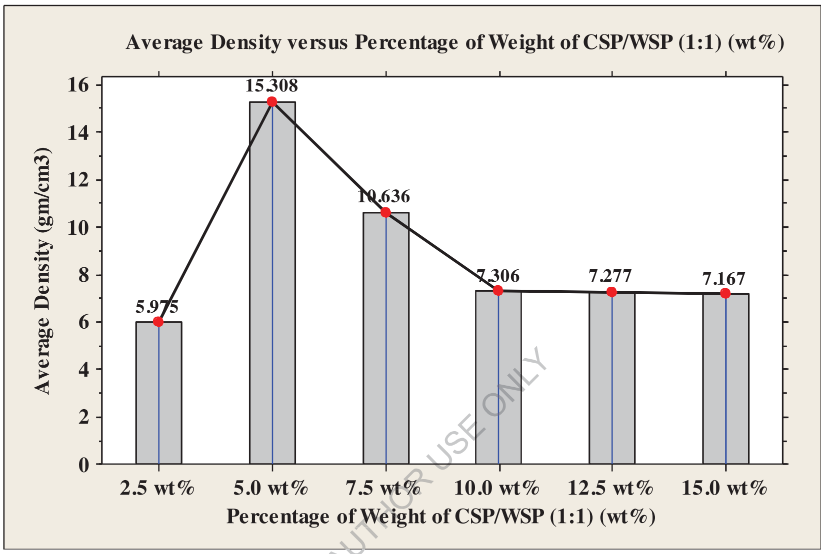

Figure 4.1 Comparison of density of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

4.1.2 Moisture Content (MC).

Storage conditions play an important role in moisture content (MC). MC of composites depends on amount of resin (epoxy) as PMC material and CSP/WSP as reinforcement particulates.

Figure 4.2 represents the curve of percentage of MC versus bake time of CSP/WSP (1:1) particulate reinforced epoxy composites. The maximum value of percentage of MC of 15 wt% CSP/WSP (1:1) particulate reinforced epoxy based composite has 0.925% due to free hydroxyl group inside of resin matrix as well as CSP/WSP particulate [28].

Table 4.2.1 Comparison of moisture content of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	A		B		C	
Run	A-1	A-2	B-1	B-2	C-1	C-2
Initial weight of sample in air (g) (W_{t0})	2.41	2.40	4.49	4.26	3.40	3.76
Weight of sample after dry in oven at 80 0C for 8 hr (g) (W_{t1})	2.41	2.39	4.47	4.25	3.39	3.74
Weight of sample after dry in oven at 80 0C for 16 hr (g) (W_{t2})	2.40	2.39	4.46	4.25	3.38	3.74
Weight of sample after dry in oven at 80 0C for 24 hr (g) (W_{t3})	2.40	2.39	4.46	4.25	3.37	3.73
Moisture content after 8 hr	0	0.418	0.447	0.235	0.265	0.481
Average moisture content after 8 hr (%)	0.209		0.341		0.373	
Moisture content after 16 hr	0.417	0.418	0.673	0.235	0.592	0.535
Average moisture content after 16 hr (%)	0.418		0.454		0.563	
Moisture content after 24 hr	0.417	0.418	0.673	0.235	0.890	0.804
Average moisture content after 24 hr (%)	0.418		0.454		0.847	

Table 4.2.2 Comparison of moisture content of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	D		E		F	
Run	D-1	D-2	E-1	E-2	F-1	F-2
Initial weight of sample in air (g) (W_{t0})	3.41	3.19	3.36	3.62	3.82	3.17
Weight of sample after dry in oven at 80 0C for 8 hr (g) (W_{t1})	3.40	3.18	3.35	3.60	3.80	3.16
Weight of sample after dry in oven at 80 0C for 16 hr (g) (W_{t2})	3.39	3.17	3.34	3.59	3.79	3.15
Weight of sample after dry in oven at 80 0C for 24 hr (g) (W_{t3})	3.38	3.16	3.33	3.59	3.78	3.14
Moisture content after 8 hr	0.442	0.314	0.299	0.556	0.553	0.316
Average moisture content after 8 hr (%)	0.378		0.427		0.435	
Moisture content after 16 hr	0.590	0.631	0.599	0.836	0.792	0.667
Average moisture content after 16 hr (%)	0.610		0.717		0.729	
Moisture content after 24 hr	0.888	0.949	0.901	0.948	1.058	0.955
Average moisture content after 24 hr (%)	0.918		0.925		1.007	

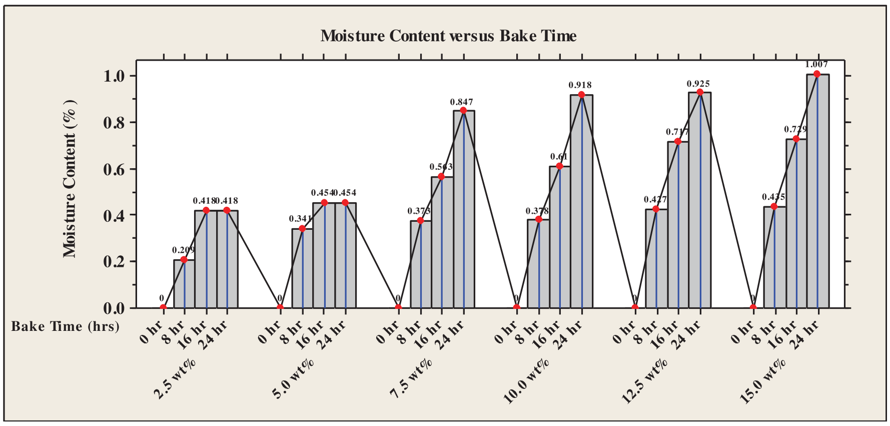

Figure 4.2 Comparison of moisture content of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

It was observed from figure 4.2 that the value of percentage of MC (0.418 % to 1.007 %) is increases from 2.5 to 15 wt% of CSP/WSP (1:1) content epoxy based composites due to the increment amount of cellulose as well as hemicelluloses (hygroscopic materials) inside composites with increment of percentage of weight of CSP/WSP (1:1) particulate.

4.1.3 Water Absorption (WA)

According to previous research, the lignocelluloses material has a poor barrier of absorption resistance due to the existence of polar groups, which attract the molecules of water through hydrogen bonding. This occurrence leads to a moisture take up in the fiber cell wall as well as interface of fiber - matrix. WA in composites is dependent on fiber loading, type of particulates, area of small the expose surface, filler/particulate loading, surface protection, void content, orientation of fibers, diffusivity, permeability of fiber and hydrophilicity of components [35]. For comparison of different percentage of weight of alumina and silicon carbide epoxy based composites, the value of WA at room temperture varied from 0h to 72h for water take up time is calculated in table 4.3.

Table 4.3.1 Comparison of water absorption of different percentage of weight of of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	A		B		C	
Run	A-1	A-2	B-1	B-2	C-1	C-2
Initial weight of sample in air after dry in oven for 24 hr (g) (W_{t0})	2.40	2.39	4.46	4.25	3.37	3.73
Weight of sample after immersion in water for 24 hr (g) (W_{t1})	2.44	2.44	4.56	4.32	3.44	3.82
Weight of sample after immersion in water for 48 hr (g) (W_{t2})	2.45	2.44	4.58	4.35	3.46	3.82
Weight of sample after immersion in water for 72 hr (g) (W_{t3})	2.45	2.44	4.58	4.35	3.47	3.82
Water absorption after 8 hr	1.667	2.092	2.242	1.647	2.077	2.413
Average water absorption after 24 hr (%)	1.879		1.945		2.245	
Water absorption after 16 hr	2.083	2.092	2.691	2.353	2.671	2.413
Average water absorption after 48 hr (%)	2.088		2.522		2.542	
Water absorption after 24 hr	2.083	2.092	2.691	2.353	2.967	2.413
Average water absorption after 72 hr (%)	2.088		2.522		2.690	

Table 4.3.2 Comparison of water absorption of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	D		E		F	
Run	D-1	D-2	E-1	E-2	F-1	F-2
Initial weight of sample in air after dry in oven for 24 hr (g) (W_{t0})	3.38	3.16	3.33	3.59	3.78	3.14
Weight of sample after immersion in water for 24 hr (g) (W_{t1})	3.46	3.24	3.42	3.68	3.87	3.24
Weight of sample after immersion in water for 48 hr (g) (W_{t2})	3.48	3.24	3.43	3.70	3.88	3.25
Weight of sample after immersion in water for 72 hr (g) (W_{t3})	3.49	3.25	3.44	3.71	3.90	3.26
Water absorption after 8 hr	2.367	2.532	2.703	2.621	2.381	3.185
Average water absorption after 24 hr (%)	2.449		2.662		2.783	
Water absorption after 16 hr	2.959	2.532	3.003	3.179	2.646	3.503
Average water absorption after 48 hr (%)	2.745		3.091		3.074	
Water absorption after 24 hr	3.254	2.848	3.303	3.458	3.175	3.822
Average water absorption after 72 hr (%)	3.051		3.381		3.498	

Figure 4.3 represents the curve of percentage of WA versus immersion time of CSP/WSP (1:1) particulate reinforced epoxy composites. The maximum value of percentage of WA of 15 wt% CSP/WSP (1:1) particulate reinforced epoxy based composite has 0.925% due to free hydroxyl group inside of resin matrix as well as CSP/WSP particulate [28].

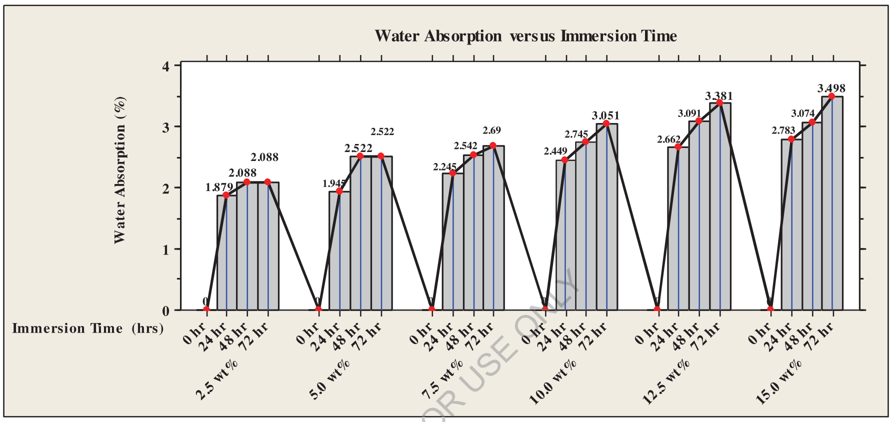

Figure 4.3 Comparison of water absorption of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

It was observed from figure 4.3 that the value of percentage of WA (0.710% to 0.840 %) is increases from 2.5 to 15 wt% of CSP/WSP (1:1) content epoxy based composites due to the increment amount of cellulose as well as hemicelluloses (hygroscopic materials) inside composites with increment of percentage of weight of CSP/WSP (1:1) particulate.

4.1.4 Linear Swelling

According to previous research, the lignocelluloses material has a poor barrier of absorption resistance due to the existence of polar groups, which attract the molecules of water through hydrogen bonding. This occurrence leads to a moisture take up in the fiber cell wall as well as interface of fiber - matrix.

Table 4.4.1 Comparison of thickness swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	A		B		C	
Run	A-1	A-2	B-1	B-2	C-1	C-2
Initial thickness of sample before immersion in water (mm) (T_{t0})	5.50	5.20	8.12	8.26	7.56	7.58
Thickness of the sample after immersion in water for 24 hr (mm) (T_{t1})	5.60	5.30	8.30	8.42	8.18	7.98
Thickness of the sample after immersion in water for 48 hr (mm) (T_{t2})	5.64	5.36	8.38	8.50	8.22	8.12
Thickness of the sample after immersion in water for 72 hr (mm) (T_{t3})	5.64	5.36	8.38	8.50	8.22	8.12
Thickness swelling after 24 hr	1.818	1.923	2.217	1.937	8.201	5.277
Average thickness swelling after 24 hr (%)	1.871		2.077		6.739	
Thickness swelling after 48 hr	2.545	3.077	3.202	2.906	8.730	7.124
Average thickness swelling after 48 hr (%)	2.811		3.054		7.927	
Thickness swelling after 72 hr	2.545	3.077	3.202	2.906	8.730	7.124
Average thickness swelling after 72 hr (%)	2.811		3.054		7.927	

Table 4.4.2 Comparison of thickness swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	D		E		F	
Run	D-1	D-2	E-1	E-2	F-1	F-2
Initial thickness of sample before immersion in water (mm) (T_{t0})	6.80	6.96	6.50	6.70	8.06	8.12
Thickness of the sample after immersion in water for 24 hr (mm) (T_{t1})	7.76	7.86	7.38	7.62	9.23	9.30
Thickness of the sample after immersion in water for 48 hr (mm) (T_{t2})	7.78	7.87	7.54	7.67	9.30	9.42
Thickness of the sample after immersion in water for 72 hr (mm) (T_{t3})	7.80	7.90	7.58	7.70	9.35	9.46
Thickness swelling after 24 hr	14.12	12.93	13.54	13.73	14.52	14.53
Average thickness swelling after 24 hr (%)	13.524		13.635		14.524	
Thickness swelling after 48 hr	14.41	13.07	16.00	14.48	15.38	16.01
Average thickness swelling after 48 hr (%)	13.743		15.239		15.697	
Thickness swelling after 72 hr	14.71	13.51	16.62	14.93	16.00	16.50
Average thickness swelling after 72 hr (%)	14.106		15.770		16.254	

The change in thickness/width/length was measured to determine the linear swelling. For comparison of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites, the value of TS at room temperture varied from 0h to 72h for water take up time is calculated in table 4.4.

Figure 4.4 represents the curve of percentage of thickness swelling (TS) versus immersion time of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy composites. The maximum value of percentage of TS of 15 wt% CSP/WSP (1:1) particulate reinforced epoxy based composite has 25.568% due to poor compatibility between epoxy resin and CSP/WSP (correlation between WA and TS) [35].

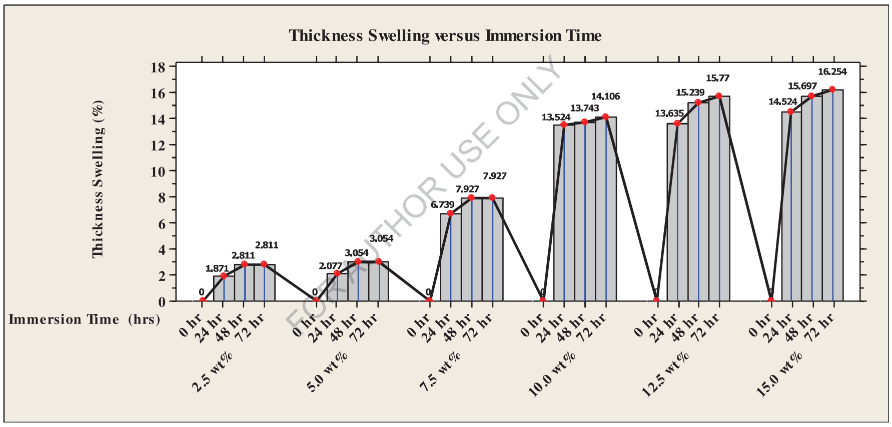

Figure 4.4 Comparison of thickness swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

It was observed from figure 4.4 that the value of percentage of TS (2.811 % to 16.254 %) is increases from 2.5 to 15 wt% of CSP/WSP (1:1) content epoxy based composites due to the increment amount of cellulose as well as hemicelluloses (hygroscopic materials) inside composites with increment of percentage of weight of CSP/WSP (1:1) particulate.

Table 4.5.1 Comparison of length swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	A		B		C	
Run	A-1	A-2	B-1	B-2	C-1	C-2
Initial length of sample before immersion in water (mm) (L_{t0})	20.24	20.44	21.04	20.64	21.80	21.74
Length of the sample after immersion in water for 24 hr (mm) (L_{t1})	20.30	20.52	21.12	20.72	21.90	21.84
Length of the sample after immersion in water for 48 hr (mm) (L_{t2})	20.36	20.58	21.20	20.78	21.96	21.90
Length of the sample after immersion in water for 72 hr (mm) (L_{t3})	20.36	20.58	21.20	20.78	21.96	21.92
Length swelling after 24 hr	0.296	0.391	0.380	0.388	0.459	0.460
Average length swelling after 24 hr (%)	0.344		0.384		0.459	
Length swelling after 48 hr	0.593	0.685	0.760	0.678	0.734	0.736
Average length swelling after 48 hr (%)	0.639		0.719		0.735	
Length swelling after 72 hr	0.593	0.685	0.760	0.678	0.734	0.828
Average length swelling after 72 hr (%)	0.639		0.719		0.781	

Table 4.5.2 Comparison of length swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	D		E		F	
Run	D-1	D-2	E-1	E-2	F-1	F-2
Initial length of sample before immersion in water (mm) (L_{t0})	20.24	20.30	21.52	20.32	19.12	20.92
Length of the sample after immersion in water for 24 hr (mm) (L_{t1})	20.30	20.44	21.64	20.44	19.26	21.06
Length of the sample after immersion in water for 48 hr (mm) (L_{t2})	20.34	20.50	21.70	20.50	19.32	21.12
Length of the sample after immersion in water for 72 hr (mm) (L_{t3})	20.38	20.52	21.72	20.52	19.34	21.14
Length swelling after 24 hr	0.296	0.690	0.558	0.591	0.732	0.669
Average length swelling after 24 hr (%)	0.493		0.574		0.701	
Length swelling after 48 hr	0.494	0.985	0.836	0.886	1.046	0.956
Average length swelling after 48 hr (%)	0.740		0.861		1.001	
Length swelling after 72 hr	0.692	1.084	0.929	0.984	1.151	1.052
Average length swelling after 72 hr (%)	0.888		0.957		1.101	

Table 4.6.1 Comparison of width swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	A		B		C	
Run	A-1	A-2	B-1	B-2	C-1	C-2
Initial width of sample before immersion in water (mm) (B_{t0})	19.70	19.02	20.04	20.70	19.80	20.74
Width of the sample after immersion in water for 24 hr (mm) (B_{t1})	19.80	19.08	20.12	20.80	19.90	20.82
Width of the sample after immersion in water for 48 hr (mm) (B_{t2})	19.84	19.16	20.14	20.90	19.94	20.92
Width of the sample after immersion in water for 72 hr (mm) (B_{t3})	19.84	19.16	20.14	20.90	19.96	20.94
Width swelling after24 hr	0.508	0.315	0.399	0.483	0.505	0.386
Average width swelling after 24 hr (%)	0.412		0.441		0.445	
Width swelling after 48 hr	0.711	0.736	0.499	0.966	0.707	0.868
Average width swelling after 48 hr (%)	0.723		0.733		0.787	
Width swelling after 72 hr	0.711	0.736	0.499	0.966	0.808	0.964
Average width swelling after 72 hr (%)	0.723		0.733		0.886	

Table 4.6.2 Comparison of width swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	D		E		F	
Run	D-1	D-2	E-1	E-2	F-1	F-2
Initial width of sample before immersion in water (mm) (B_{t0})	20.04	20.10	18.22	20.34	21.46	18.58
Width of the sample after immersion in water for 24 hr (mm) (B_{t1})	20.14	20.20	18.32	20.44	21.56	18.70
Width of the sample after immersion in water for 48 hr (mm) (B_{t2})	20.22	20.26	18.40	20.52	21.64	18.78
Width of the sample after immersion in water for 72 hr (mm) (B_{t3})	20.24	20.28	18.42	20.54	21.66	18.80
Width swelling after24 hr	0.499	0.498	0.549	0.492	0.466	0.646
Average width swelling after 24 hr (%)	0.498		0.520		0.556	
Width swelling after 48 hr	0.898	0.796	0.988	0.885	0.839	1.076
Average width swelling after 48 hr (%)	0.847		0.936		0.958	
Width swelling after 72 hr	0.998	0.896	1.098	0.983	0.932	1.184
Average width swelling after 72 hr (%)	0.947		1.040		1.058	

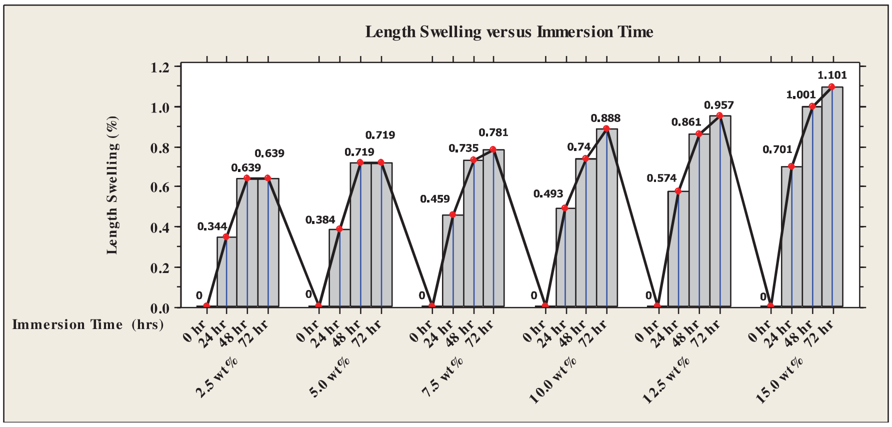

Figure 4.5 Comparison of length swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

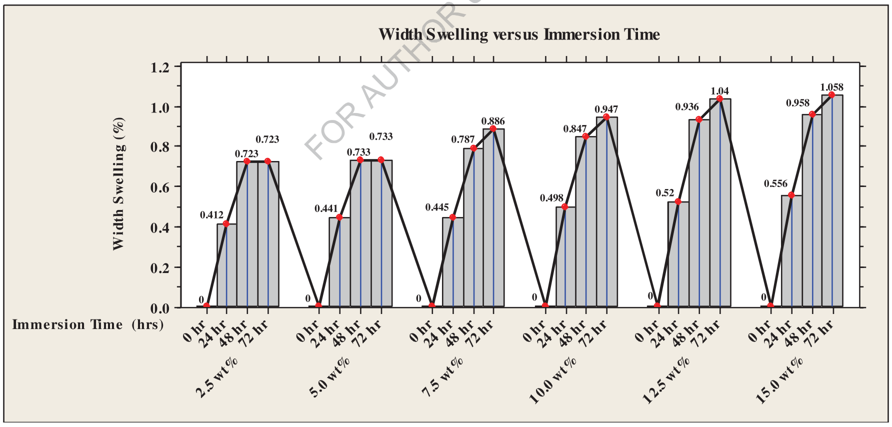

Figure 4.6 Comparison of width swelling of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Similarly it was observed from figure 4.5 and figure 4.6 that the value of percentage of length swelling (0.639 % to 1.101 %) and the value of percentage of width swelling (0.723 % to 1.058 %) are increases from 2.5 to 15 wt% of CSP/WSP (1:1) content epoxy based composites due to the increment amount of cellulose as well as hemicelluloses (hygroscopic materials) inside composites with increment of percentage of weight of CSP/WSP (1:1) particulate.

Part-II

4.2 Effect of Fire Resistance on CSP/WSP (1:1) Particulates Reinforced Epoxy Based Composites.

4.2.1 Flammability Test

The present test carried out on ASTM 635 standard with specimens dimension 125 mm x 13 mm with 5 mm average thickness.

Table 4.7 Effect of burning rate on different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Designation of Specimens	Run	Length of burn (mm) (L)	Time of burning (sec)	Average time of burning (sec)	Average time of burning (min)	Burning rate (mm/min)
A	A-1	100.0	197.0	201.50	3.36	29.78
	A-2	100.0	206.0			
B	B-1	100.0	272.0	266.00	4.43	22.56
	B-2	100.0	260.0			
C	C-1	100.0	274.0	278.00	4.63	21.58
	C-2	100.0	282.0			
D	D-1	100.0	278.0	285.00	4.75	21.05
	D-2	100.0	292.0			
E	E-1	100.0	327.0	333.50	5.56	17.99
	E-2	100.0	340.0			
F	F-1	100.0	404.0	393.00	6.55	15.27
	F-2	100.0	382.0			

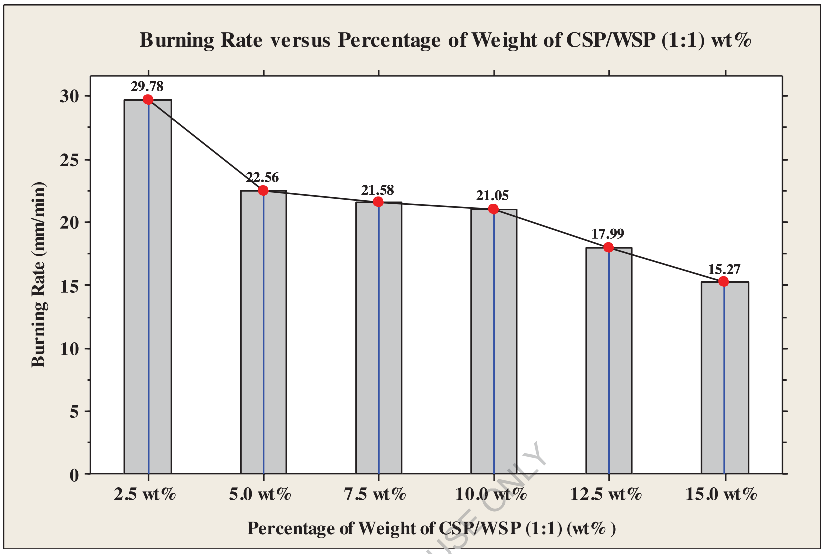

Figure 4.7 Comparison of burning rate of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

The burning of specimens length per unit min is decreased with increase of particulates in epoxy based composites. It is found from experiment that 'E' specimen has the lowest burning rate in length per unit min.

Part- III

4.3 Effect of Impact Properties on CSP/WSP (1:1) Particulates Reinforced Epoxy Based Composites.

4.3.1 Impact Strength Properties.

Mechanical impact properties of six specimens with variations of particulates of CSP/WSP into epoxy based composites are analyzed as per ASTM D-256 standard.

Table 4.8 Comparison of impact modulus of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

S.No.	Designation	Compositions	Impact Strength (J/m)
1	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	15.840
2	B	Resin + 5.0 wt% CSP+ 5.0 wt% WSP	18.760
3	C	Resin + 7.5 wt% CSP+ 7.5 wt% WSP	14.350
4	D	Resin + 10.0 wt% CSP+ 10.0 wt% WSP	15.960
5	E	Resin + 12.5 wt% CSP+ 12.5 wt% WSP	12.700
6	F	Resin + 15.0 wt% CSP+ 15.0 wt% WSP	13.462

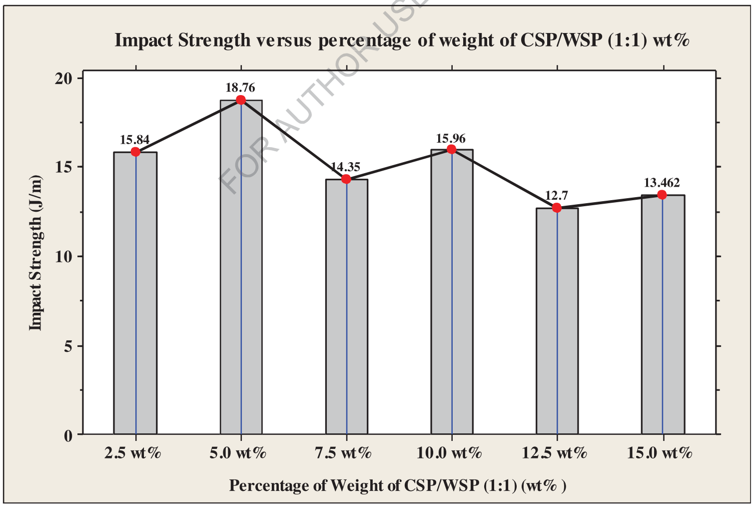

Figure 4.8 Comparison of impact strength of different percentage of weight of CSP/WSP (1:1) particulates reinforced epoxy based composites.

Izod Impact test of six different percentage of weight of CSP/WSP (1:1) content epoxy based composites are carried out at ambient conditions. It is observed from figure 4.8 that the value of the impact strength (18.760 J/m) at 5 wt % of CSP/WSP (1:1) is superior to other composites. The reason behind for this is the better bonding strength between epoxy resin and CSP/WSP particulates.

Chapter 5

CSP/WSP REINFORCED EPOXY BASED COMPOSITES: OPTIMIZATION OF FLEXURAL CHARACTERISTICS

Introduction

This chapter gives attention on the static mechanical characteristics of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites prepared for this research work. The essential analysis of the design of experiment by using Taguchi technique is accounted. These chapter accounts of flexural properties of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites.

Part- I

5.1 Effect of Flexural Properties on Coconut Shell Particle (CSP) and Walnut Shell Particle (WSP) (1:1) Reinforced Epoxy Composites.

5.1.1 Taguchi Analysis of Flexural Property.

Mechanical flexural properties six specimen with variations of filler particles of CSP/WSP (1:1) reinforced epoxy composites were analyzed as per ASTM D2344-84 standard.

Taguchi method was carried out with MINITAB 14 statistical software. Mechanical flexural properties study was conducted with two control parameters such as filler loading with parameter such as: 2.5 wt%, 5 wt%, 7.5 wt%, 10 wt%, 12.5 wt% and 15 wt% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and speed with parameter such as: 1 mm/min 2 mm/min and 3 mm/min as represented in table 5.1 and 5.3 in association with L_{18} orthogonal array flexural strength. It provides excellent accuracy as well as less time in experimental work. Tables 5.1 and 5.3 mechanical flexural properties of different composites for all 18 test runs and their corresponding S/N ratios are given.

Table 5.1 Experimental design using L_{18} orthogonal array for different percentage of weight of CPS/WSP carbide epoxy based composites for flexural strength along with S/N ratio.

Filler Content (wt%)	Speed (mm/min)	Flexural Strength (MPa)	SNRA
2.5	1	36.400	31.222
2.5	2	35.980	31.121
2.5	3	32.360	30.200
5	1	30.710	29.746
5	2	36.740	31.303
5	3	31.630	30.002
7.5	1	31.650	30.008
7.5	2	31.560	29.983
7.5	3	28.500	29.097
10	1	30.140	29.583
10	2	32.960	30.360
10	3	36.840	31.326
12.5	1	28.140	28.987
12.5	2	32.090	30.127
12.5	3	25.350	28.080
15	1	39.130	31.850
15	2	36.720	31.298
15	3	42.500	32.568

Figure 5.1 and 5.3 represent effect of filler loading with parameter such as: 2.5 wt%, 5 wt%, 7.5 wt%, 10 wt%, 12.5 wt% and 15 wt% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and speed with parameter such as: 1 mm/min 2 mm/min and 3 mm/min on mechanical

flexural properties. The most appropriate value of mechanical flexural properties is cause at highest S/N_L value in graph. The S/N_L graph is clearly representing optimal experimental condition for filler loading with parameter such as: 2.5 wt%, 5 wt%, 7.5 wt%, 10 wt%, 12.5 wt% and 15 wt% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and speed with parameter such as: 1 mm/min 2 mm/min and 3 mm/min on mechanical flexural properties. After interpretation of the flexural test result assist to the culmination that parameter combination of filler loading and speed change provides maximum mechanical flexural properties. Figure 5.1 also clearly represents how filler loading (15 wt%) and speed (2 mm/min) give maximum mechanical flexural strength .

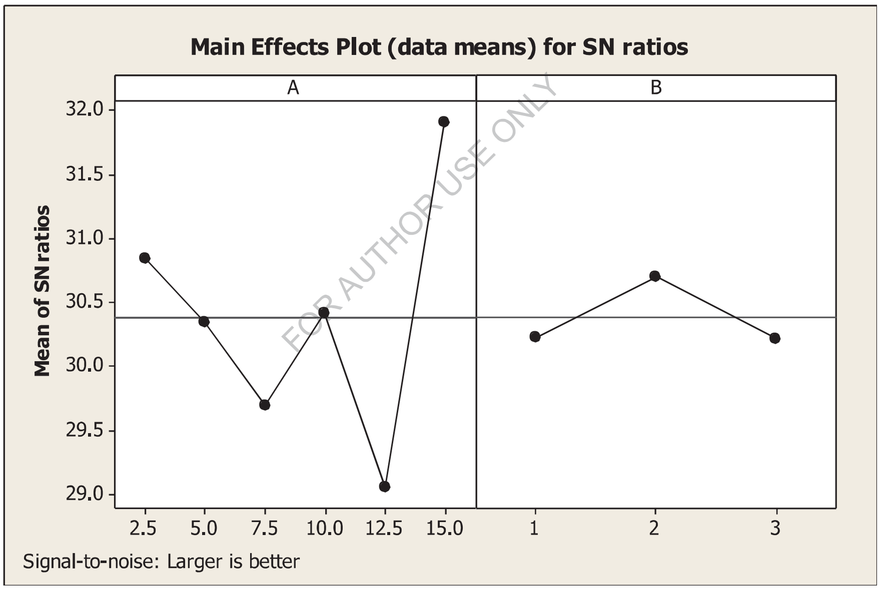

Figure 5.1 Main effects plot for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural strength.

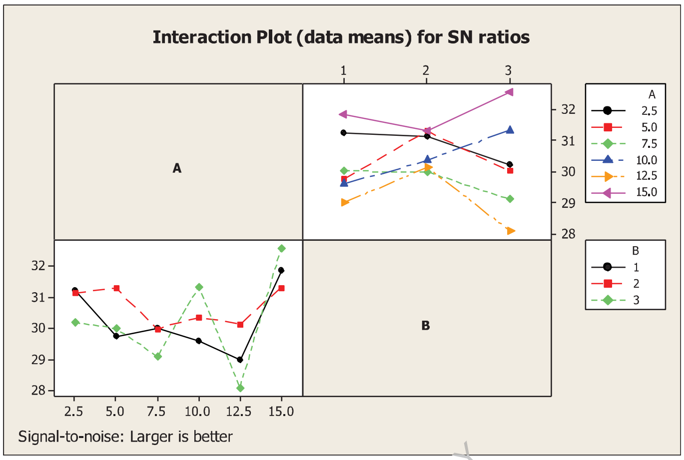

Figure 5.2 Interaction plot for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural strength.

Table 5.2 Response table of S/N ration for flexural strength.

Level	Filler Content (wt%)	Speed (mm/min)
1	30.85	30.23
2	30.35	30.70
3	29.70	30.21
4	30.42	-
5	29.06	-
6	31.91	-
Delta	2.84	0.49
Rank	1	2

Figure 5.2 also clearly represents interaction plot of filler loading and speed for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural sstrength. It was also observed that from table 5.2, speed was significant after filler loading.

Table 5.3 Experimental design using L_{18} orthogonal array for different percentage of weight of CPS/WSP carbide epoxy based composites for flexural Load along with S/N ratio.

Filler Content (wt%)	Speed (mm/min)	Maximum Flexural Laod (kN)	SNRA
2.5	1	0.207	-13.681
2.5	2	0.206	-13.723
2.5	3	0.141	-17.016
5	1	9.020	19.104
5	2	8.120	18.191
5	3	8.250	18.329
7.5	1	7.500	17.501
7.5	2	7.560	17.570
7.5	3	7.580	17.593
10	1	7.020	16.927
10	2	6.950	16.840
10	3	6.790	16.637
12.5	1	6.490	16.245
12.5	2	7.240	17.195
12.5	3	6.70	16.522
15	1	8.130	18.202
15	2	7.950	18.007
15	3	8.060	18.127

Figure 5.3 also clearly represents how filler loading (5 wt%) and speed (1 mm/min) give maximum mechanical flexural strength .

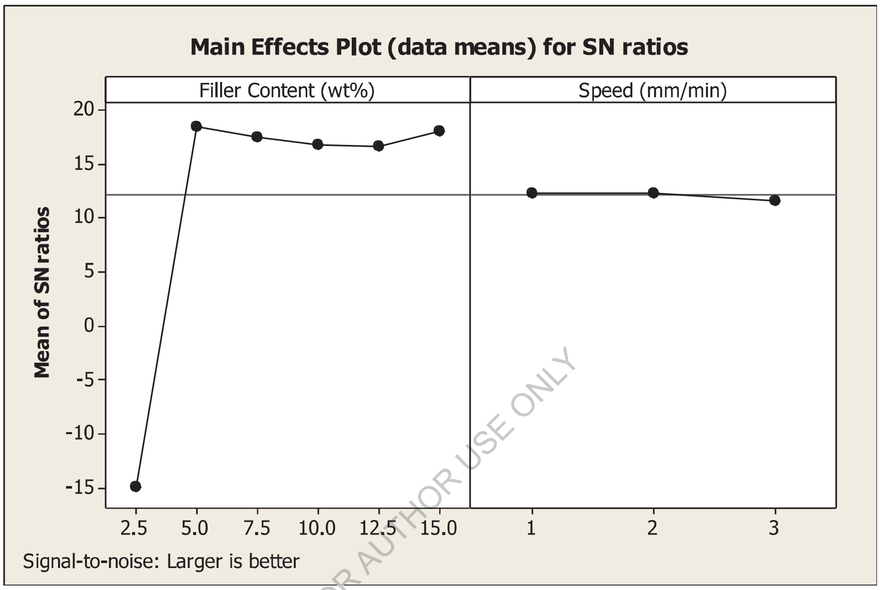

Figure 5.3 Main effects plot for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural load.

Figure 5.4 also clearly represents interaction plot of filler loading and speed for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural sstrength. It was also observed that from table 5.4, speed was significant after filler loading.

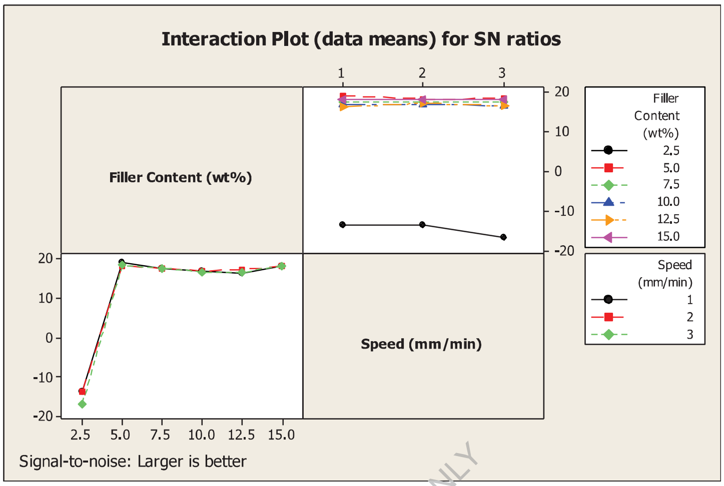

Figure 5.4 Interaction plot for S/N ratio on different percentage of weight of CSP/WSP epoxy based composites in flexural load.

Table 5.4 Response table of S/N ration for flexural load.

Level	Filler Content (wt%)	Speed (mm/min)
1	-14.81	12.38
2	18.54	12.35
3	17.56	11.70
4	16.80	-
5	16.65	-
6	18.11	-
Delta	33.35	0.68
Rank	1	2

5.1.2 Analysis of Variance of Flexural Property.

ANOVA is statistical tool, used to determine which design parameters importantly affect the quality attribute [41]. Analysis of variance was conducted on filler loading with parameter such as: : 2.5 wt%, 5 wt%, 7.5 wt%, 10 wt%, 12.5 wt% and 15 wt% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and speed with parameter such as: 1 mm/min 2 mm/min and 3 mm/min on experimental data using MINITAB 14. Table 5.5 and 5.6 represents analysis of variance for S/N_L ratios of mechanical maximum flexural strength and flexural load respectively. Analysis of variance is conducted for a level of confidence of significance of 95%.

The value of F was calculated for each design parameters. The second last column of the table 5.5 and 5.6 represents significance of F value. The F value of factor is more four (F>4), it means that factor more significant [51]. That factor effect more on the optimal characteristic. From table 5.5 and 5.6 observed that filler loading (A) was more significant and Speed (D) was less significant in each table.

Table 5.5 ANOVA analysis table for flexural strength.

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Filler Content (wt%)	5	212.214	212.214	42.443	4.720	0.018	68.007
Speed (mm/min)	2	9.851	9.851	4.925	0.550	0.595	3.157
Error	10	89.983	89.983	8.998			28.836
Total	17	312.047					

The third last column of the table 5.5 and 5.6 represents significance of P value. The P value of factor is less 0.05 (P< 0.05), it means that factor more significant [52]. That factor effect more on the optimal characteristic. From table 5.5 and 5.6 observed that filler loading (A) was more significant and Speed (B) was less significant in each table.

Table 5.6 ANOVA analysis table for flexural load.

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Filler Content (wt%)	5	141.966	141.966	28.393	372.190	0.000	99.424
Speed (mm/min)	2	0.060	0.060	0.030	0.400	0.683	0.042
Error	10	0.763	0.763	0.076			0.534
Total	17	142.789					

The last column of table 5.5 and 5.6 represents the percentage of contribution of each parameter on the whole variation, thus presenting the degree of impact on the outcome. From table 5.5, it might be noticed that filler loading (68.007%) had more significant impact on the maximum flexural strength of epoxy based composites while speed (3.157%) had less significant effect on it.

From table 5.6, it might be noticed that filler loading (99.424%) had more significant impact on the maximum flexural strength of epoxy based composites while speed (0.042%) had less significant effect on it.

5.1.3 Regression Analysis of Flexural Property.

Regression method is a statistical tool, using for approximating the relationships between parameters. It gives equation for understandarding how the dependent parameter changes when any one of the independent parameter is changed [41]. The main effects of the input parameters are plotted on graphs, which are shown in fgure 5.5 for normal propbability plot for flexural.

Regression equation for maximum flexural strength

Flexural Strength (N/mm^2) = 31.9 + 0.136 Filler Content (wt%) + 0.08 Speed (mm/min)

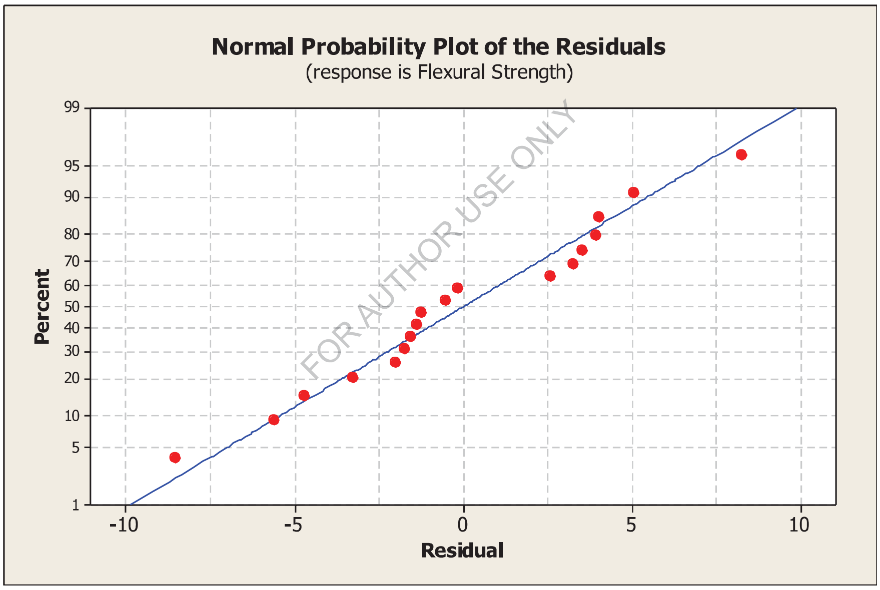

Figure 5.5 Normal propbability plot for flexural strength.

Regression equation for maximum flexural laod

Flexural Load (KN) = 3.10 + 0.385 Filler Content (wt%) - 0.071 Speed (mm/min)

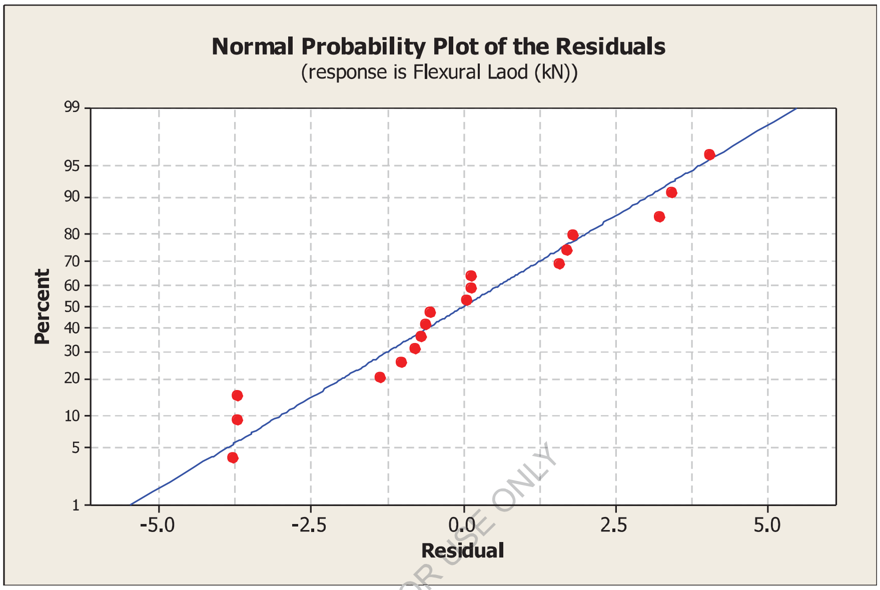

Figure 5.5 Normal propbability plot for flexural load.

Chapter 6

RESULTS AND CONCLUSIONS

The research report of this thesis consists of two parts: the first part has description of the physical characteristics and flammability characteristic of the composites, while the second part has observation of mechanical properties in impact test and flexural mode with different percentage of weight of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites respectively.

Part - I

6.1 Effect of Physical Properties on Coconut Shell Particle (CSP) and Walnut Shell Particle (WSP) (1:1) Reinforced Epoxy Composites.

6.1.1 Physical Properties

Experimental and analytical evaluation of physical properties on CSP/WSP (1:1) particulates reinforced epoxy composites have led to the following specific conclusions:

- CSP/WSP (1:1) particulates reinforced epoxy composites has maximum value of density 15.308 gm/cm^3 due to better bonding between epoxy resin and CSP/WSP as well as minimum voids formation.
- Table 6.1 and table 6.2 represent minimum and maximum values of percentage of MC, WA and LS for CSP/WSP (1:1) particulates reinforced epoxy based composites.

Table 6.1 Minimum values of percentage of physical properties of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites.

S. No.	Physical Properties	Designation	Composition	Minimum Value (%)
1	Moisture Content	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	0.418
2	Water Absorption	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	2.088
3	Thickness Swelling	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	2.811
4	Width Swelling	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	0.723
5	Length Swelling	A	Resin + 2.5 wt% CSP+ 2.5 wt% WSP	0.639

Table 6.2 Maximum Values of Percentage of Physical Properties of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites.

S. No.	Physical Properties	Designation	Composition	Maximum Value (%)
1	Moisture Content	F	Resin + 15 wt% CSP+ 15 wt% WSP	1.007
2	Water Absorption	F	Resin + 15 wt% CSP+ 15 wt% WSP	3.498
3	Thickness swelling	F	Resin + 15 wt% CSP+ 15 wt% WSP	16.254
4	Width swelling	F	Resin + 15 wt% CSP+ 15 wt% WSP	1.058
5	Length swelling	F	Resin + 15 wt% CSP+ 15 wt% WSP	1.101

6.1.2 Flammability Test

The burning of specimens in length per unit min is decreased with increase of particulates in epoxy based composites. It is found from experiment that 'F' specimen has the lowest burning rate in length per unit min.

Part- II

6.2 Effect of Mechanical Properties on Coconut Shell Particle (CSP) and Walnut Shell Particle (WSP) (1:1) Reinforced Epoxy Composites.

6.2.1 Properties in Impact Mode

Experimental and analytical evaluation of mechanical impact properties on CSP/WSP (1:1) particulates reinforced epoxy composites provides the following specific conclusions:

- Specimen E has minimum values of impact strength (12.700 J/m).
- Specimen B has maximum values of impact strength (18.760 J/m).

6.2.2 Properties in Flexural Mode

Experimental and analytical evaluation of mechanical flexural properties on coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites have led to the following specific conclusions:

- Response tables were obtained with help of MINITAB 14 using taguchi method for maximum flexural strength and flexural load by performing means of S/N ratios of each parameter to evaluate out the domination parameter.
- It was observed that filler loading (A) was more significant parameter because its rank one in each table.

- Table 6.3 represents optimum combination of design parameter with help of L_{18} orthogonal array mechanical flexural properties of CSP/WSP (1:1) particulates reinforced epoxy composites.

Table 6.3 Optimum combination of design parameter in flexural mode with help of L_{18} orthogonal array

S. No	Flexural properties	Optimum combination
1	Flexural strength	A6B2
2	Maximum flexural load	A2B1

- ANOVA is statistical tool, used to determine which design parameters importantly affect the quality attribute. Analysis of variance was conducted on filler loading and speed on experimental data using MINITAB 14.
- Table 6.4 represents the maximum percentage contribution of parameters (using ANOVA).
- Regression method is a statistical tool, using for approximating the relationships between parameters.

Table 6.4 Percentage contribution of parameters (using ANOVA).

S. No	Flexural properties	Source	Contribution (%)
1	Flexural strength	Filler Content (wt%)	68.007
		Speed (mm/min)	3.157
2	Maximum flexural load	Filler Content (wt%)	99.424
		Speed (mm/min)	0.042

6.3 Conclusions

This analytical and experimental investigation on coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) reinforced epoxy composites has led to the following specific conclusions:

- New classes of epoxy based composites reinforced with coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) have been fabricated advantageous in the laboratory for the development of value added products.
- Incorporation of the filler modifies physical characteristics and fire resistance (flammability test) of the epoxy based composites. However, while fabricating a composite of exact requirements, there is a need for the choice of appropriate filler material for optimizing the composite composition.
- Mechanical behaviour of CSP/WSP (1:1) particulates reinforced epoxy composites was studied under the variation of filler content. It was observed experimentally that the value of flexural strength and flexural load at 2.5 wt% of CSP/WSP (1:1) particulates reinforced epoxy composites have maximum value of 36.40 MPa and 0.207 kN at 1 mm/min. However research paper was observed experimentally that the value of flexural strength and flexural load at 5 wt% of WSP particulates reinforced epoxy composites have maximum value of 28.82 MPa and 0.17 kN respectively. As per experiment, 2.5 wt% of CSP/WSP (1:1) particulates reinforced epoxy composites has 26.30% and 15% more flexural strength and flexural load than 5 wt% of WSP particulates reinforced epoxy composites [4].
- It was examined by experimentally that the value of flexural strength at 15 wt% of CSP/WSP (1:1) particulates reinforced epoxy composites has maximum value of 42.50 MPa at 3 mm/min. However research paper was observed experimentally that the value of flexural strength at 25 wt% of CSP particulates reinforced epoxy composites has maximum value of 38.328 MPa. As per experiment, 15 wt% of CSP/WSP (1:1) particulates reinforced epoxy composites has 10.88% more flexural strength than 25 wt% of CSP particulates reinforced epoxy composites [20]. However research paper was observed experimentally that the value of flexural strength at 40 wt% of walnut shell flour (WSF) reinforced

polypropylene composites has maximum value of 41.0 MPa. As per experiment, 15 wt% of CSP/WSP (1:1) particulates reinforced epoxy composites has 3.65% more flexural strength than 40 wt% of WSP particulates reinforced epoxy composites [16]

6.4 Future Scope of Present Work

The present research work is having a wide scope for future investigators to explore many other aspects of such composites. Some recommendations for future research include:

- Investigations can be done for hardness, inter laminar shear strength and tensile characteristics.
- Use of other ceramics or metallic fillers in the development of new hybrid composites can be done.
- Polymeric resin can be used as a thermo plastic other than epoxy family.
- Possible combination of different types of natural fibers, glass fibers and carbon fibers can be used in the development of new hybrid composites.

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