4

Results and Discussion

The results obtained, analyses, and discussions pertinent to the findings are presented under each heading in this chapter.

4.1 Survey

The survey was conducted to aid the research, and the results are presented under the following headings:

4.1.1 General Information

Out of the 50 respondents surveyed, 84 per cent of them were male and 16 per cent of them were female (Figure 4a). As for the qualification of the respondents, the maximum of 70 per cent of the them were B.E qualified, followed by 14 per cent and 10 per cent of them who were Diploma and B.Tech holders respectively and only 6 per cent of them were architects (Figure 4b). As for the designation of respondents, about 66 per cent of them were supervisors, followed by 12 per cent and 6 per cent of them who were engineers and project managers, respectively. Other respondents were in various designations, namely architect, managing director and designer with an equal response of 4 per cent and safety engineer and quality controller, with an equal response of 2 per cent only. Some of the respondents were working for private companies, and some were running their own firms (Figure 4c).

4.1.2 Types of Jobs Undertaken

From Figure 5, it is clear that the types of jobs undertaken by the respondents were noted to be excavation, demolishing, site clearing, flooring works – tile laying, roofing, concrete work, carpentry work, making doors and windows, paintings and a few were involved in road works also. The works undertaken were expressed as 'always' for water proofing (80 per cent) cement tile laying (78 per cent) with highest responses for plastering (80 per cent), basement work (76 per cent), pavement/floor laying (76 per cent), concrete work (76 per cent), site clearing (74 per cent), excavation work (72 per cent) and other jobs undertaken were marble and granite cutting (70 per cent), partition jobs (70 percent), and responses for other jobs were rated to be 'always' by less than 70 per cent of the respondents though they were higher than the responses obtained for 'sometimes' (Figure 5).

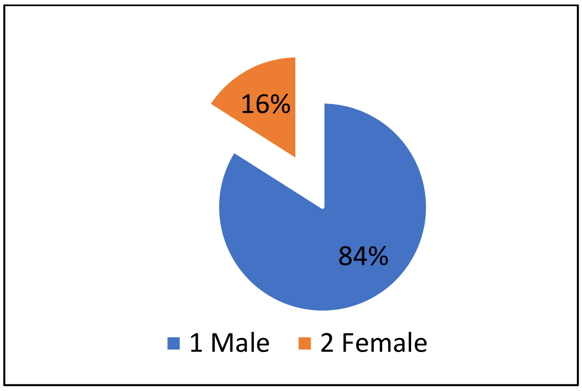


Figure 4a Gender of Respondents

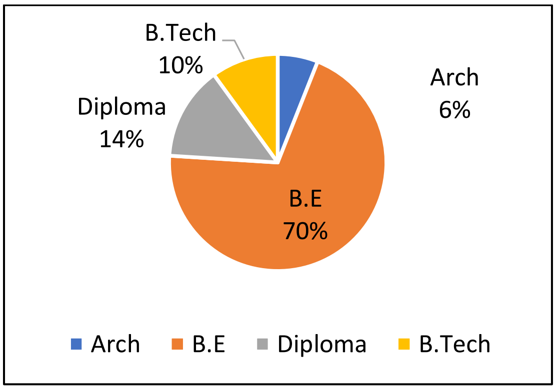


Figure 4b Qualification of Respondents

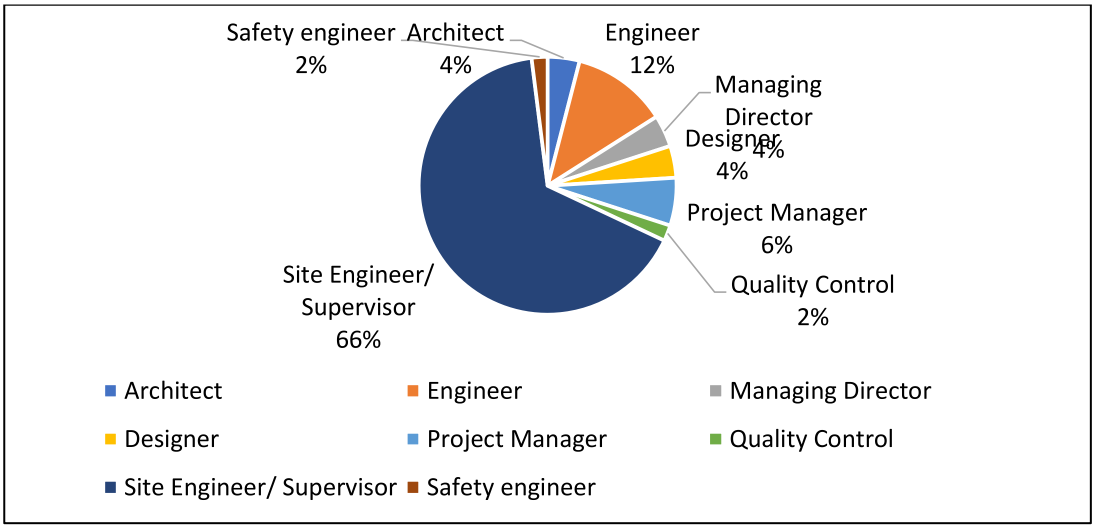


Figure 4c Desigination of the Respondents

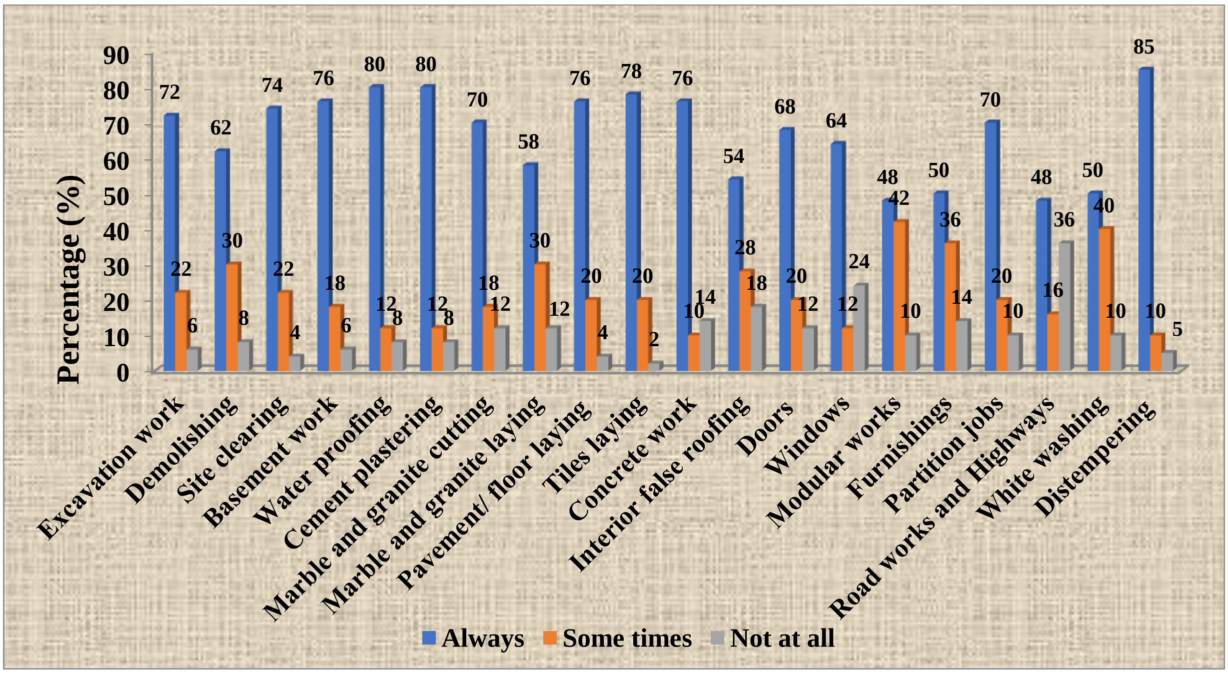


Figure 5 Jobs Undertaken

4.1.3 Type of Materials Used for Floor Construction

The results obtained for the type of materials used for construction is expressed in Figure 6

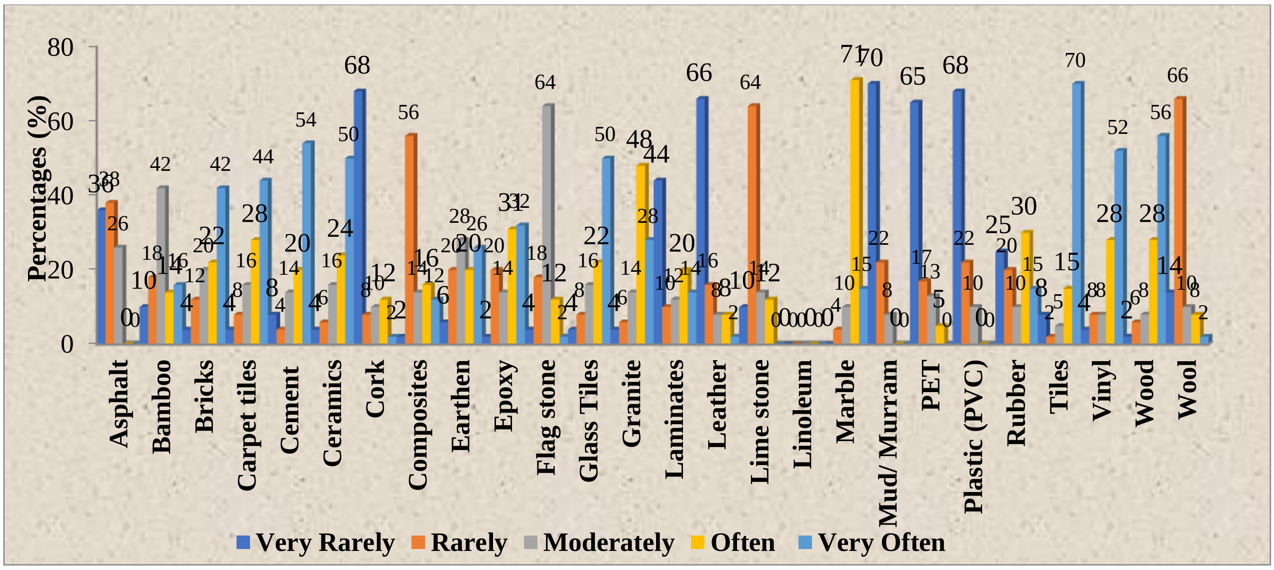


Figure 6 Materials Used for Floor Construction

From Figure 6, it is clear that the maximum number of respondents expressed that 'very often' used flooring material was Tiles (70 per cent) followed by wood (56 per cent) and cement (54 per cent) whereas the 'most often' used flooring material was marble, as expressed by 71 per cent of them. Hence, the most of them suggested ‘very often’ material was tiles.

4.1.4 Materials Used for Roofing

The results obtained for the materials used for roofing is expressed in Figure 7

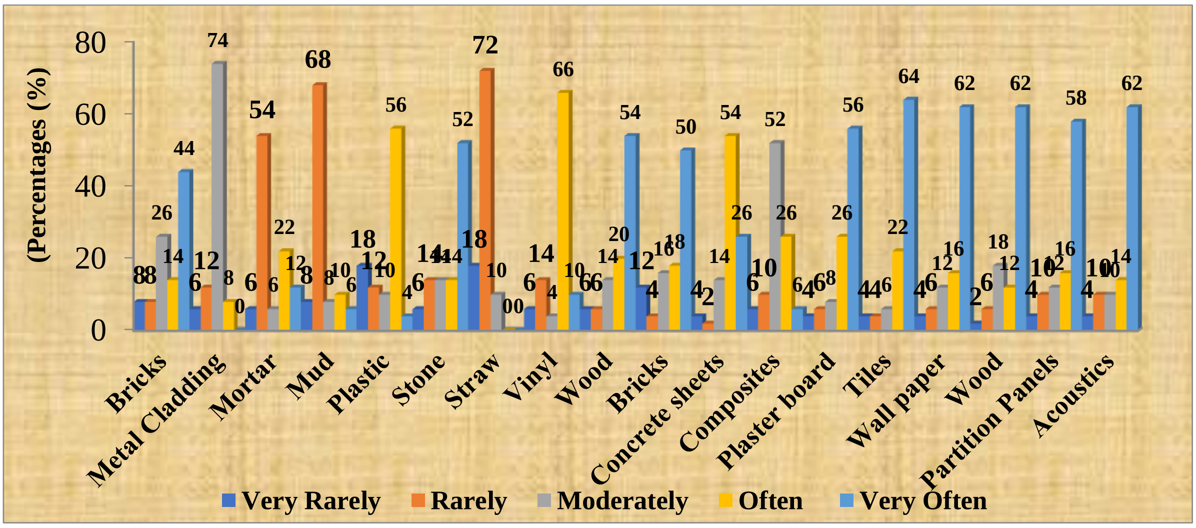


Figure 7 Materials Used for Roofing

From Figure 7, it is obvious that for roofing, the majority of respondents expressed that the material used very often was white cement (60 per cent) followed by cement (56 per cent) and ceramic tiles (52 per cent) whereas the material often used was metal sheets (62 per cent) as expressed by maximum of them, followed by wood shingle (48 per cent). Hence, very often used material for roofing was white cement, as expressed by the maximum respondents.

4.1.5 Materials used for Exterior Wall Covering

The results obtained used for wall covering materials is expressed in Figure 8

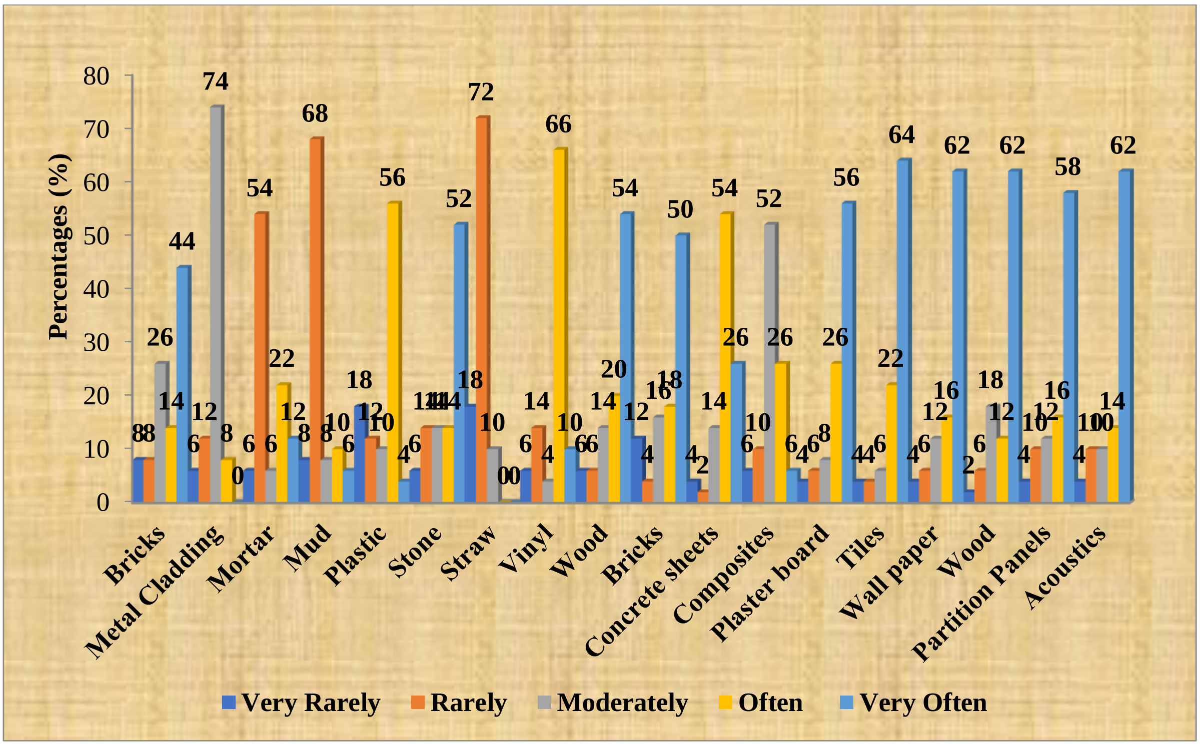


Figure 8 Materials Used for Exterior Wall Covering

From the Figure 8 it is clear that 'very often' used material for exterior wall covering was expressed as wood by 54 per cent of respondents, 'often' used material was vinyl as expressed by 66 per cent respondents, 'moderately' used was metal cladding (74 per cent) and 'rarely' used material was straw (72 per cent). Hence, 'very often' used wall covering material was wood, as expressed by the maximum of respondents.

4.1.6 Materials Used for Interior Wall Covering

The results obtained used for wall covering materials is expressed in Figure 9

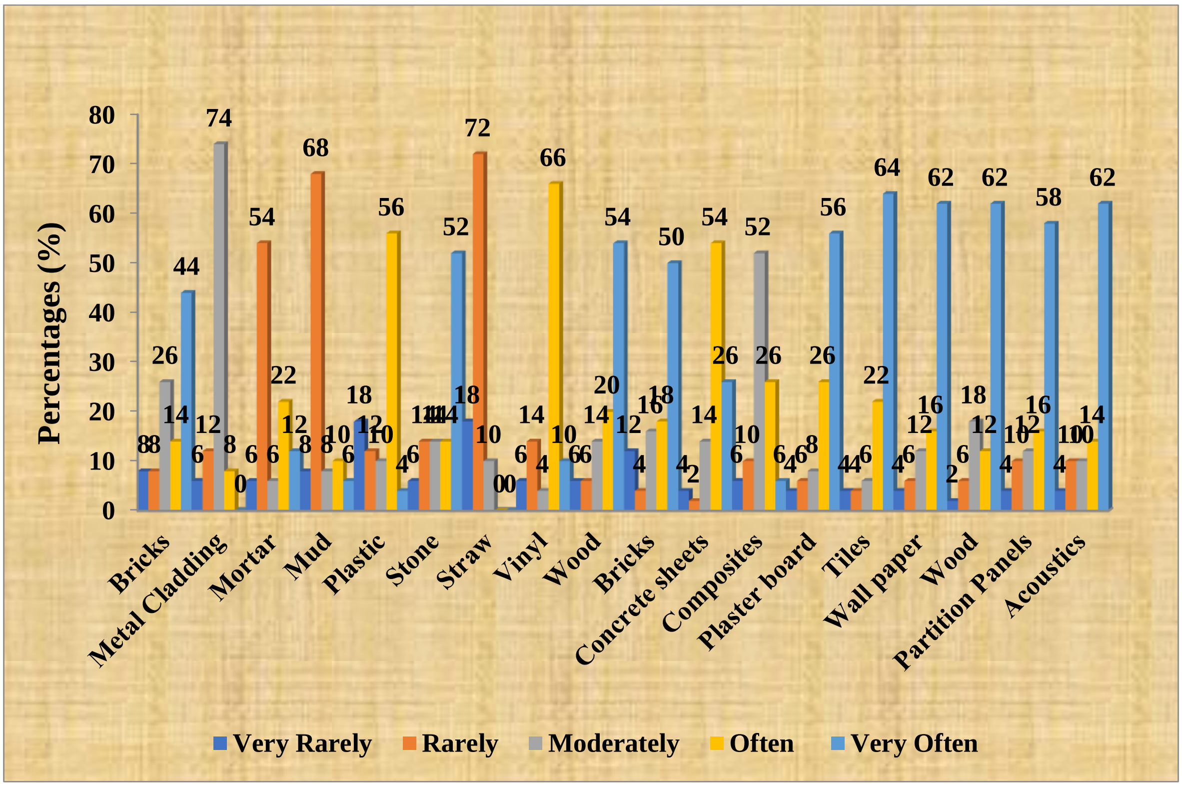


Figure 9 Materials Used for Interior Wall Covering

From Figure 9, it is clear that as for the materials used for wall interior, the 'very often' used material was tile, as expressed by 64 per cent of respondents, 'often' used material was concrete sheet (54 per cent) and the moderately used material was composite (52 per cent) as expressed by 52 per cent of them. Hence the maximum respondents expressed 'very often' used material for interior wall covering was tiles.

4.1.7 Materials Used for Water and Damp Proofing

The results obtained for materials used for water and damp proofing is presented in Figure 10

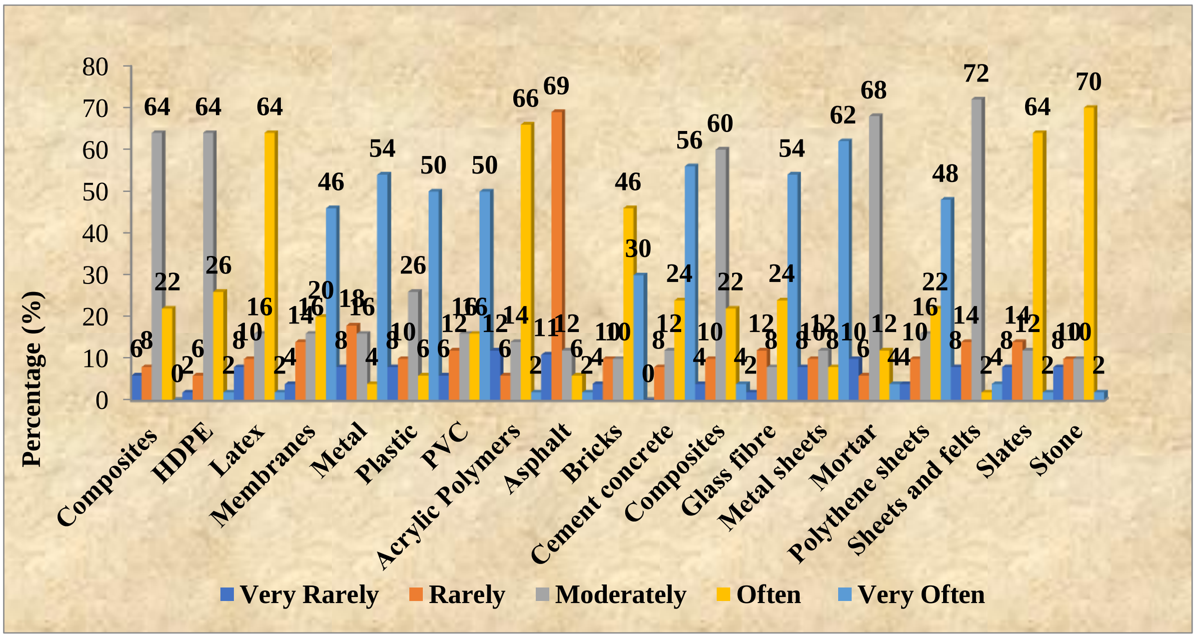


Figure 10 Material Used for Water and Damp Proofing

From Figure 10, it is obvious that the maximum respondents expressed that 'very often' used material was metal sheets (62 per cent) followed by cement (56 per cent). 'Often' used materials were stone (70 per cent) and acrylic polymers (66 per cent). Hence, 'often' used material for water damp proofing was stone, followed by acrylic polymers.

4.1.8 Factors Considered While Selecting Building Materials

The response obtained for factors considered while selecting the building materials is expressed in Figure 11

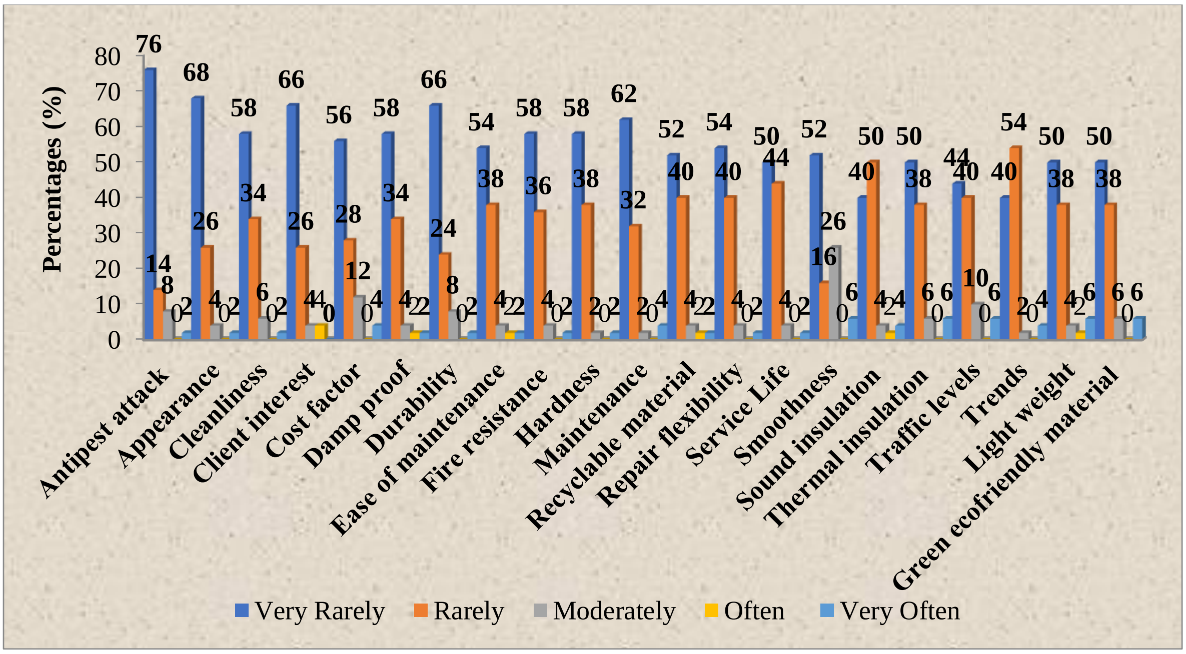


Figure 11 Factors Considered While Selecting Building Materials

From Figure 11 it is clear that out of several factors, the respondents strongly agreed for the factors to be considered for purchasing materials were the maximum for anti pest attack (76 per cent), followed by appearance (68 per cent) both client's interest and durability (66 per cent), maintenance (62 per cent), all four factors namely hardness, fire resistance, damp proof and cleanliness (58 per cent), cost (56 per cent) and, repair flexibility and maintenance (54 per cent). Hence, the predominant factors mainly considered while selecting building materials were anti pest attacks, appearance, and durability, as expressed by the respondents.

4.1.9 Utilization of other Fibres in Construction Field

The Figure 12 exhibits that the majority of respondents expressed that acrylic fibre (44 per cent) was used in construction field followed by fibres namely nylon (32 per cent), PET fibres (2 per cent), wool (2 per cent), polyethelene (PE) - 2 per cent) and others 22 percent). Hence, it was understood that the maximum utilization of fibres was with acrylic fibres.

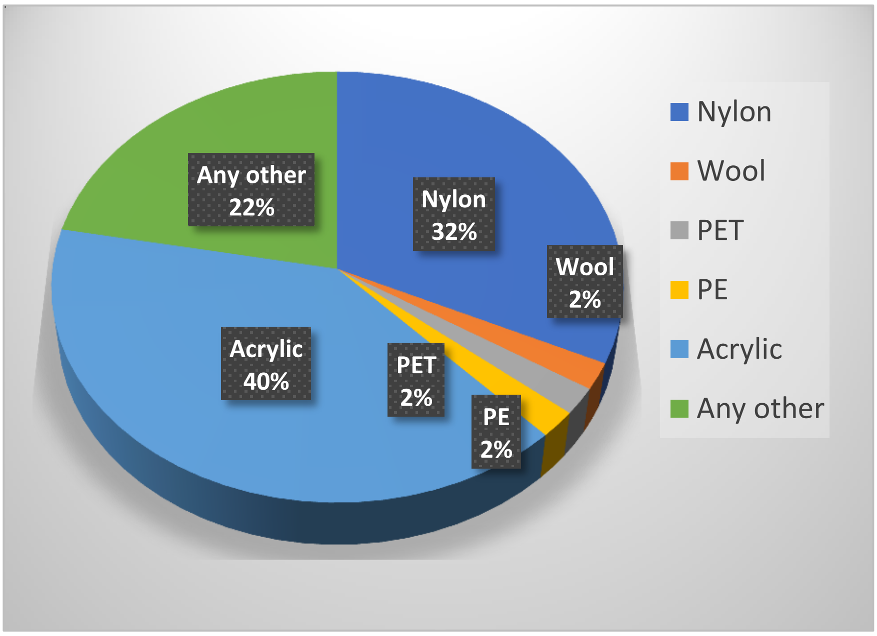


Figure 12 Utilization of Other Fibres in Construction Field

4.1.10 Awareness About Use of Natural Fibres in Construction Field

From Figure 13, it is clear that a maximum of 78 per cent of the respondents expressed an awareness of the use of natural fibres in construction field. And it was also understood that they were aware of glass, coir and jute fibres (22 per cent), as multiple responses, followed by glass alone (20 per cent) and coir (16 per cent) and, coir and jute together being 16 per cent of responses. Hence, the maximum respondents were aware of the use of natural fibres in the construction field.

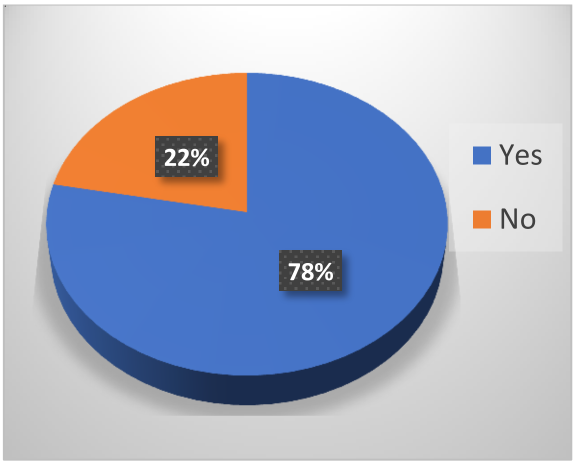


Figure 13 Awareness About Use of Natural Fibres in Construction Field

4.1.11 Application of Natural Fibres

From Figure 14, it is clear that a maximum of 26 per cent of them expressed that the natural fibres were used for the ceiling, followed by 20 per cent for both wall covering and ceiling, and 10 per cent for both flooring and wall covering.

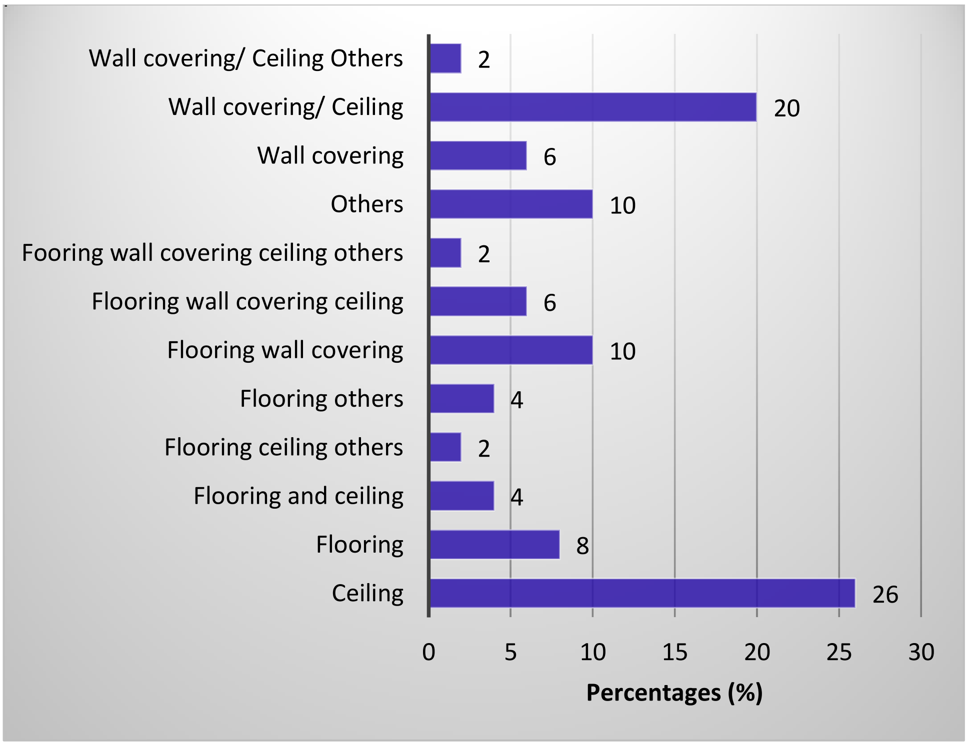


Figure 14 Application of Natural Fibres

4.1.12 Fabricated Structures Used for Buildings

From Figure 15, it is clear that the fabricated structure already used by the respondents was expressed to be the highest for nonwoven/composites/fibres as multiple response with 19 per cent followed by composites/woven materials with 15 per cent and both nonwoven/woven and nonwoven, woven/fibres as such with multiple respondents with 10 per cent. Hence, the maximum structures used for buildings were nonwovens, composite materials, and fibres.

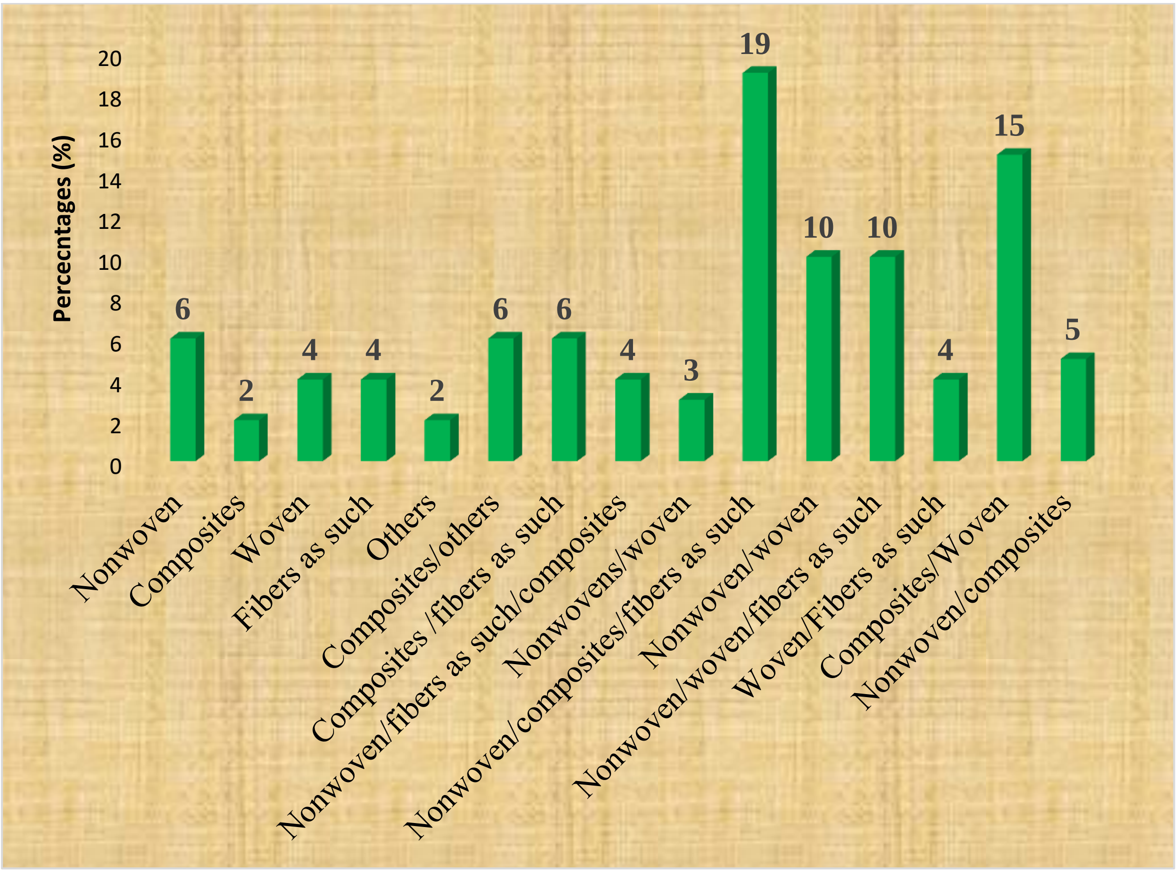


Figure 15 Fabricated Structures Used for Buildings

4.1.13 Suitability of Structure for Building /Interior Decoration /Construction

From Figure 16, it is clear that the maximum respondents expressed their vision on the suitability nonwoven/composites of structure for building interiors (21 per cent) followed by their multiple responses for nonwovens, composites/woven/fibres as such with 20 per cent. Hence for interior decorations, nonwoven and composite materials were suggested as suitable by the respondents.

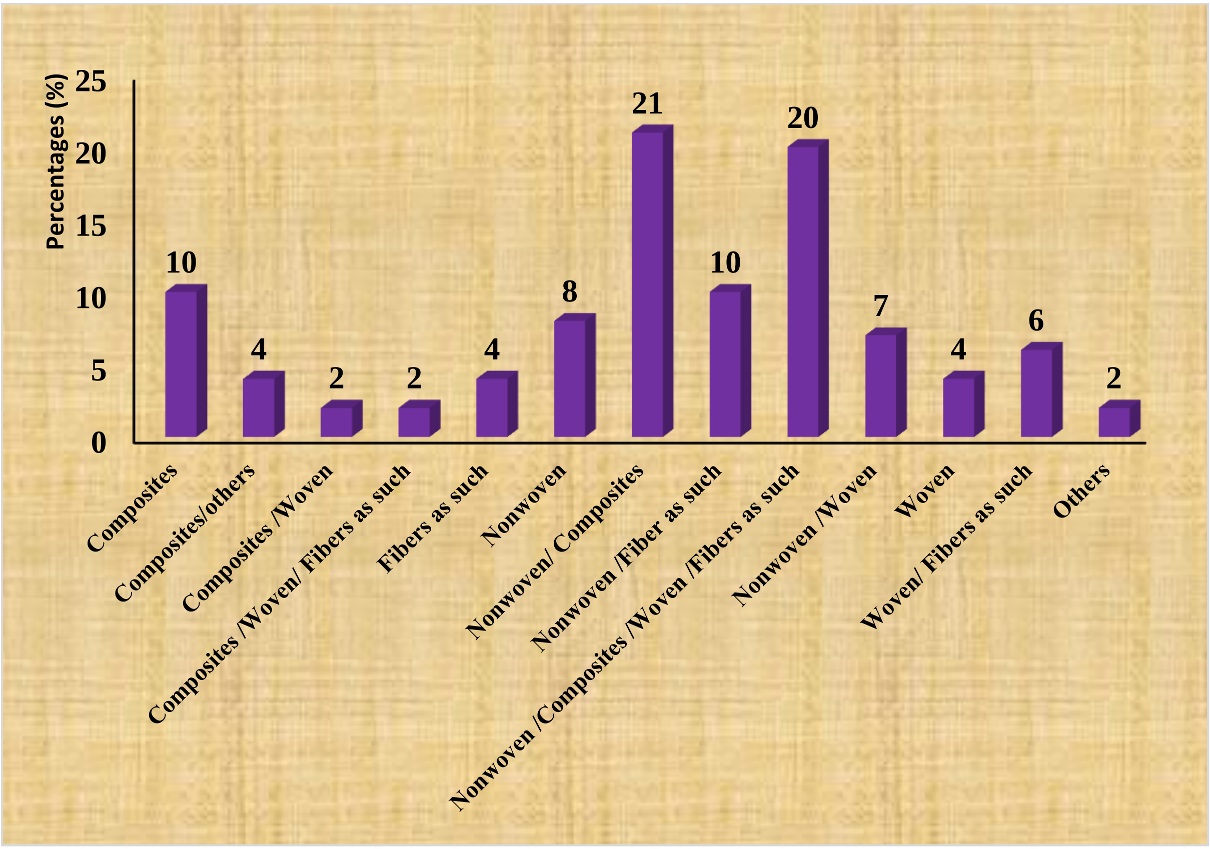


Figure 16 Suitability of Structure for Building /Interior Decoration /Construction

4.1.14. Preference for Eco friendly Products for Building Materials

Figure 17 shows that the maximum number of respondents (54 per cent) expressed their preference for eco-friendly products for building construction, followed by the most preferred (28 per cent) and somewhat preferred by 16 per cent of them. Hence, it was understood that the respondents preferred eco-friendly products for building construction.

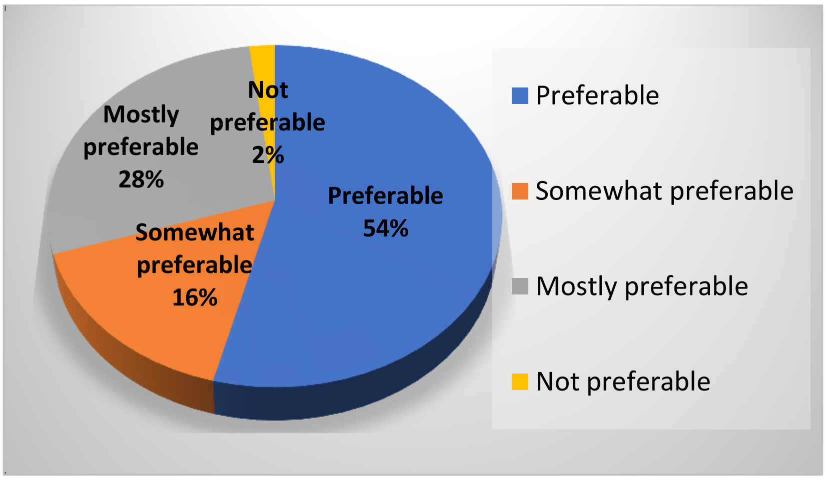


Figure 17 Preference for Ecofriendly Products for Building Materials

4.1.15 Application of Ecofriendly Materials in Building Construction

From Figure 18, it is clear that the majority of respondents expressed that eco-friendly materials were applied in buildings for flooring (18 per cent) followed by wall covering (9 per cent) and wall partition (12 per cent). There were multiple responses for flooring, wall coverings, false roofing, and partitions as well. Hence, eco-friendly materials found their applications in flooring.

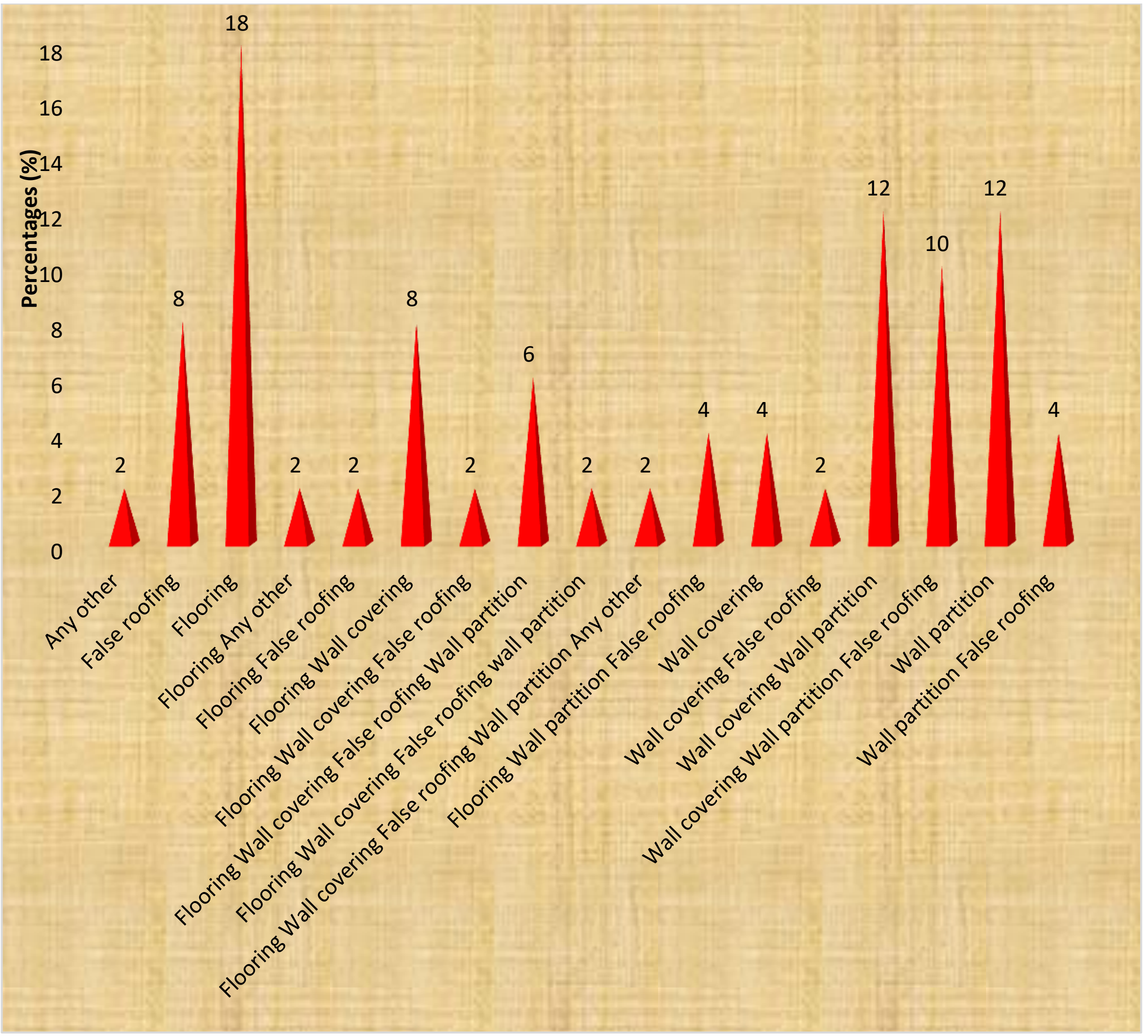


Figure 18 Application of Ecofriendly Materials in Building Construction

4.1.16 Preference for Reusable Materials

The Figure 19 shows that the preference for reusable materials was high among respondents (42 per cent) followed by 28 per cent for 'mostly preferable', 20 per cent for 'somewhat preferable' and 10 per cent for 'not preferable'. Hence, the respondent's maximum preference was noted for reusable materials for building construction.

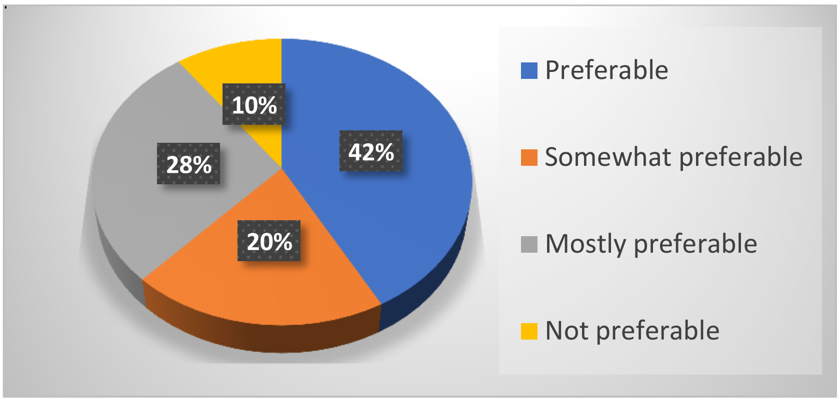


Figure 19 Preference for Reusable Materials

4.1.17 Satisfaction Level with Existing Building Materials and Their Supply

From Figure 20, it is vivid that the maximum of 54 per cent of the respondents expressed that they were very satisfied with the existing products for durability, followed by both aspects, namely ease of availability (38 per cent) and quality of the products (38 per cent). About 60 per cent of them expressed that they were somewhat satisfied with the ease of availability of natural products, whereas 26 per cent of them were neither satisfied nor dissatisfied with the service life of the products. Hence, the respondents were very satisfied about durability and somewhat satisfied about the labour and lack of availability of natural products as predominant aspects.

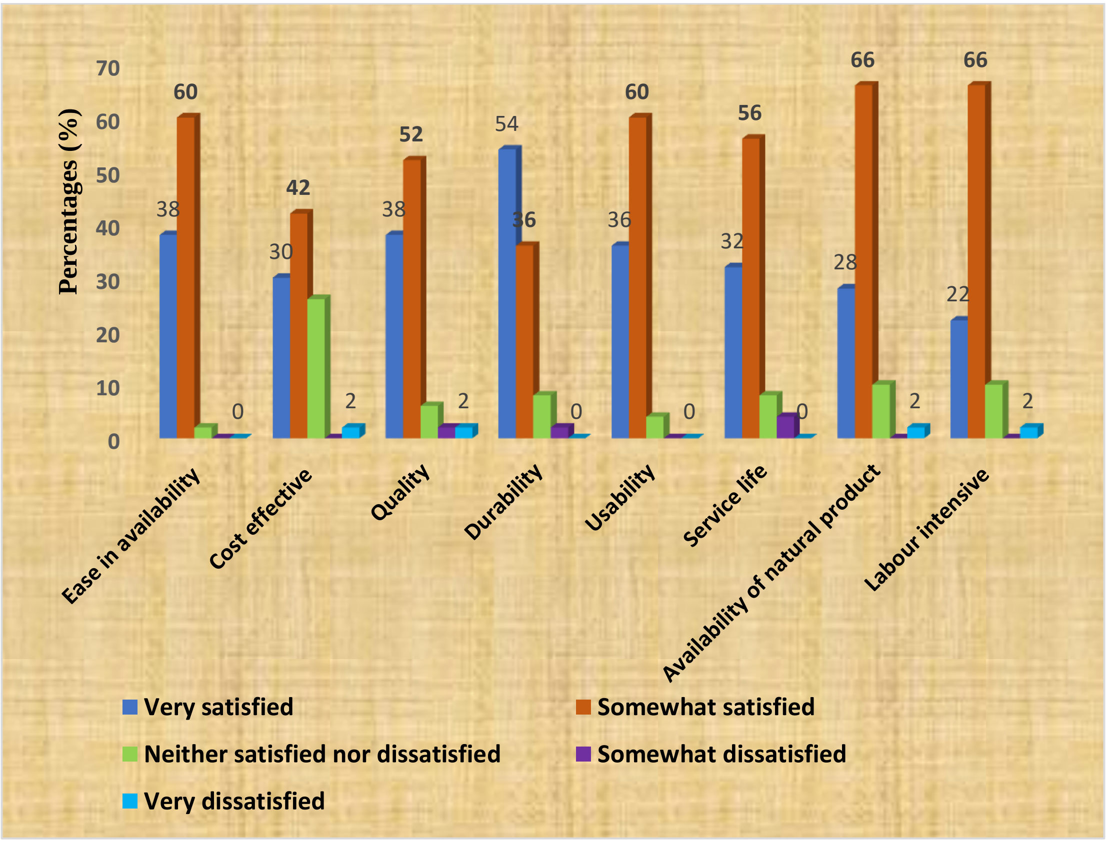


Figure 20 Satisfaction Level with Existing Building Materials and their Supply

4.1.18 Problems Faced in the Civil Field Regarding Building Materials

From Figure 21, in Pareto chart the expression for 'strongly agreed' problems by the respondents it is clear that a maximum of 46 per cent of the respondents had problems with the dismissal of building waste, 44 per cent of the respondents had challenges with the reclaim of building waste, and 34 per cent had problems with a lack of earthquake-resilient structures, which were 'strongly agreed' by the respondents for the problems faced in civil field. They 'agreed' the problems faced in indulging in green concepts (62 per cent), ageing of concrete (54 per cent) and satisfying client demands (40 per cent). They express that they 'moderately agree' with the lack of modern technology (42 per cent) and legal issues (42 per cent). The first eight problems, arranged in descending order in the pareto chart, need to be focused on in the future. Hence, it could be concluded that green building concepts could be initiated instead minimizing building material waste, which are aspects necessary for the study.

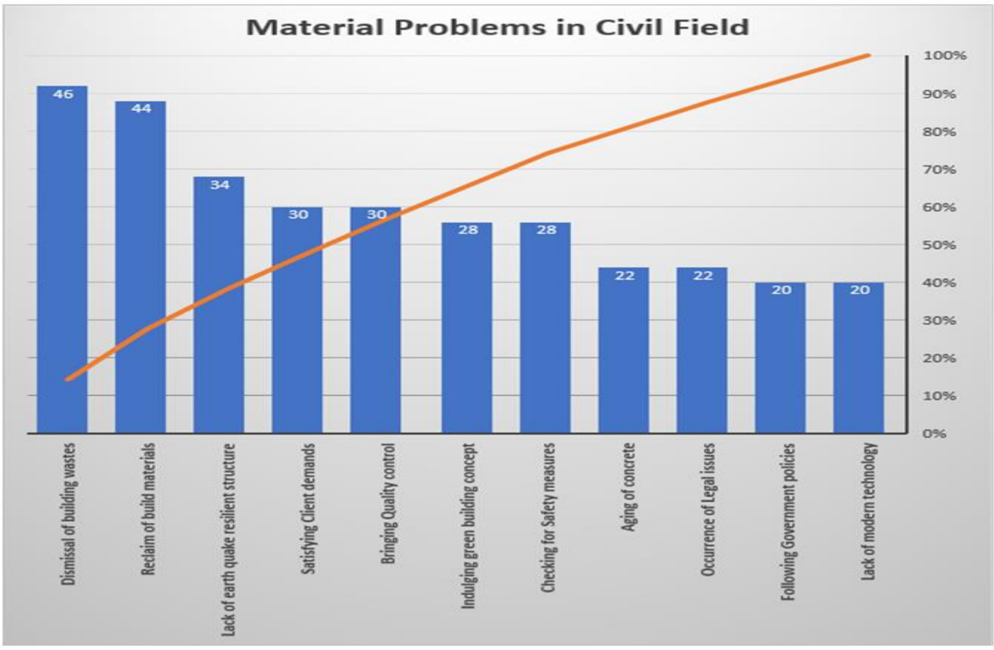


Figure 21 Problems Faced in Civil Field Regarding Materials

4.1.19 Common Problems Received from Customers About Existing Building

The problems encountered 'always' as expressed by the respondents in existing buildings are presented in Figure 22 in Pareto chart. It is obvious that the problems encountered by the respondents 'always' were cracks in walls, damage at door and window frames and floor damages 'always' (46 per cent), followed by wall cavities and water leakage with 42 per cent of them. The problem encountered as 'sometimes' was expressed by the maximum respondents for both microbial attacks and voids due to poor workmanship by 68 per cent followed by 66 per cent of them who expressed it for pests and termites and plaster crumbling (66 per cent). The first twelve problems expressed in the Pareto chart are faced by customers in existing buildings.

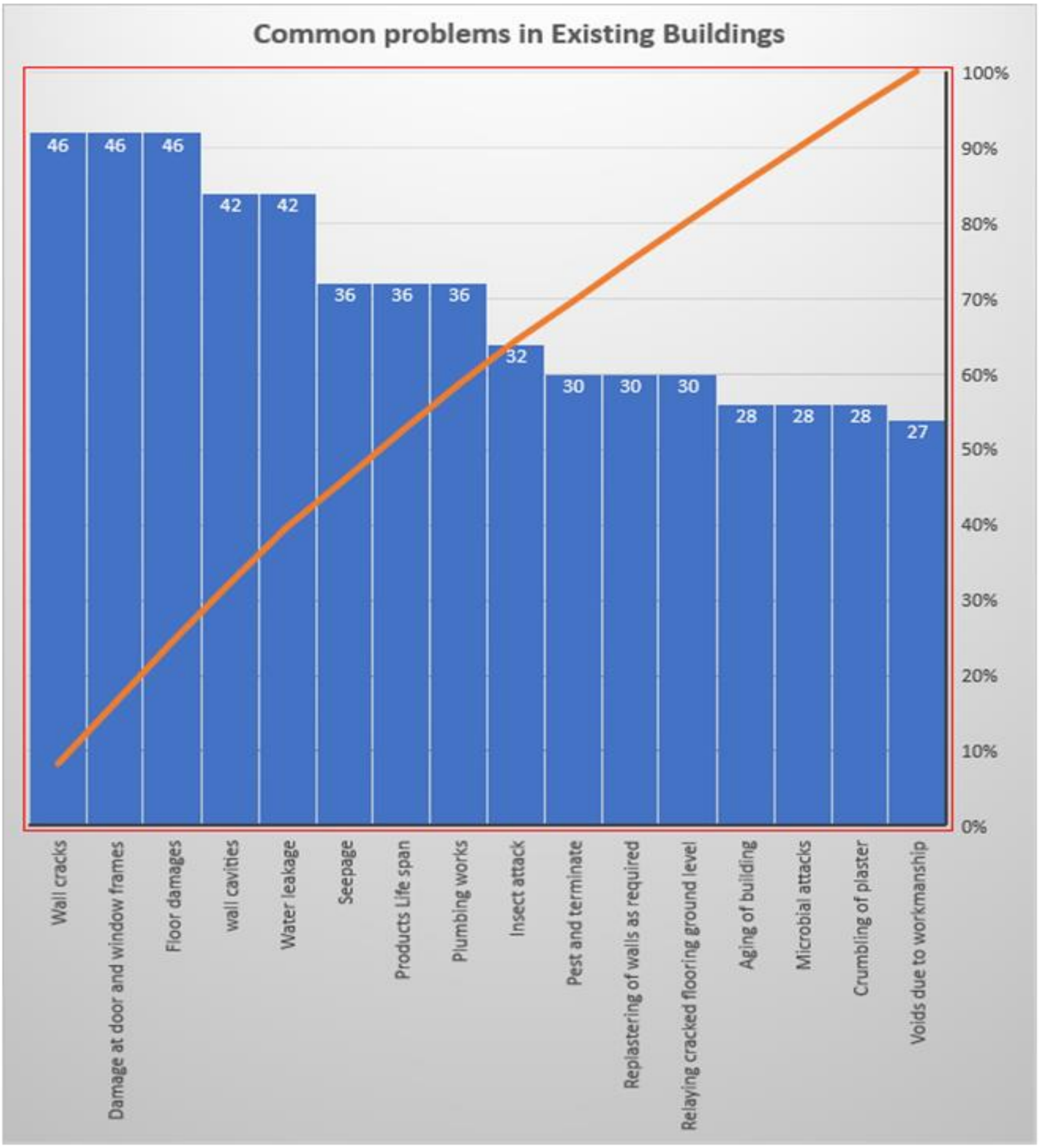


Figure 22 Common Problems Received from Customers about Existing Building

4.1.20 Need for Special Kind of Material for Building Construction

` From Figure 23, it is clear that 70 per cent of the respondents expressed that there is a need for special kinds of materials for building construction.

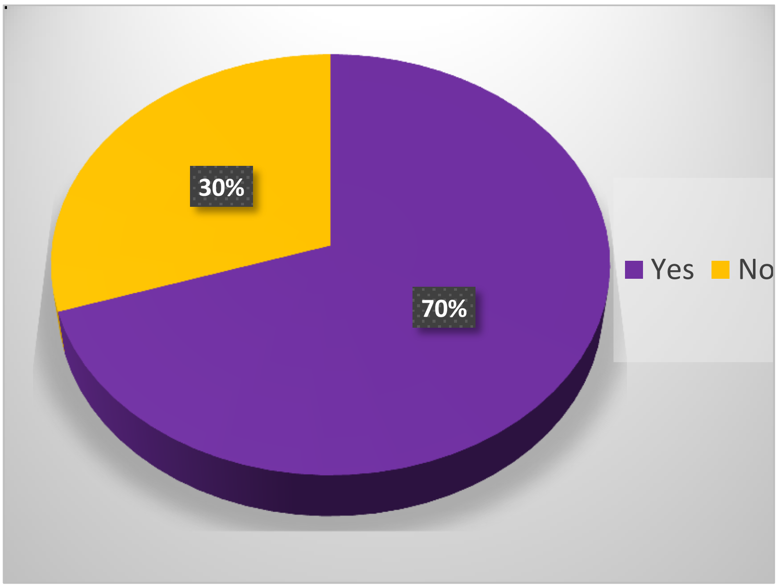


Figure 23 Need for Special Kind of Material for Building Construction

Hence it could be concluded that from the survey it is understood that green building concepts could be initiated and there may be high potential for eco-friendly building materials.

Thus the summary of the survey is that out of 50 respondents surveyed, 84 per cent of them were male and 16 per cent of them were female, of whom some were working in private companies and others were running their own firms. From the survey, it was understood that all types of building works were undertaken by them. The material very often used for roofing, wall covering and water proofing were white cement, wood, wood and stones respectively. The predominant factors considered by them while selecting building materials were anti pest attacks, appearance and durability. Acrylic fibres were maximum utilized and fabricated structures used for building were nonwovens, composite materials for interior decoration. They were aware of the use of natural fibres and also expressed the lack of availability of these in the construction field. Their preference for eco – friendly products and reusable materials for building was also high. Thus, from the survey, it was understood that green building concepts could be initiated as there was a problem of waste disposal. Hence, there may be high potential for eco – friendly building materials.

4.2. Evaluation of Fibres

The results obtained from subjective and objective assessments carried out for the untreated and treated fibres are presented under the following headings:

4.2.1 Visual Assessment

The results from the visual evaluation of the untreated and treated *Abutilon indicum, Agave americana, and Areca catechu* fibres are presented in Plate 12.

4.2.1.1 Visual Assessment of *Abutilon indicum* Fibres

The results obtained from the visual evaluation are presented in the Table V (Plate 12).

Table V

Visual Assessment of Fibre Samples

S. No	Sample	Colour (%)			Lustre (%)			Texture (%)			General appearance (%)		
		B	**M**	**D**	**G**	**F**	**P**	**S**	**C**	**V. C**	**G**	**F**	**P**
1	AUN	0	60	40	13	40	47	0	87	13	10	50	40
2	AC1	13	67	20	**73**	27	0	**78**	22	0	**67**	27	6
3	AC2	**70**	23	7	70	27	3	77	23	0	66	28	6
4	AC3	43	57	0	50	40	10	50	27	23	63	27	10
5	AE1	40	60	0	60	23	17	60	27	13	60	23	17
6	AE2	40	50	10	60	40	0	67	27	6	**87**	10	3
7	AE3	**100**	0	0	**93**	7	0	**73**	27	0	82	18	0

***B-Bright, M-Medium, D-Dull, G-Good, F-Fair, P-Poor, S-Soft, C-Coarse, V.V-Very Coarse**

From the Table V, it is clear that a maximum of 60 per cent of judges expressed that the sample AUN was medium in colour. The sample AC2 exhibited the highest value at 70 per cent. The sample AE3 was judged to have a bright colour by cent per cent of judges, which was the highest among enzyme treated samples. Hence, it could be concluded that brightness was highest in samples AC2 and AE3 by chemical and enzyme treatments, respectively, and was higher in the enzyme treated sample. As far as the lustre is concerned, sample AC1 was noted to have good lustre as judged by the maximum number of judges (73 per cent) followed by sample AC2 (70 per cent). In the enzyme treated samples, the maximum luster was noted in sample AE3 (93 per cent) followed by both samples AE2 and AE1 with 60 percent. Hence, it could be concluded that lustre was highest in samples AC1 and AE3 on chemical and enzyme treatments, respectively and was higher in enzyme treated fibre samples.

The texture of the sample AUN was coarse, as expressed by the maximum (87 per cent) of judges. This coarseness decreased in all the treated samples. It turned out to be soft as per the expression of 78 per cent of judges in sample AC1, followed by 77 per cent of judges in sample AC2 over the original sample. The enzyme treated samples were also noted to have a reduction in coarseness, as the fibre samples were assessed visually to be softer by the maximum of 73 per cent of judges in sample AE3. Hence, the softness of fibres increased on treatments and was the maximum in the samples AC1 and AE3 on chemical and enzyme treatments, respectively, which depicts the removal of unwanted materials adhering to the surface of fibres. The general appearance exhibited an improvement in all the treated samples of which it was judged to be good in samples AC1 (67 per cent) and AE2 (87 per cent) on chemical and enzyme treatments, respectively.

4.2.1.2 Visual Assessment of *Agave americana* Fibres

The results obtained from the visual evaluation are presented in the Table VI (Plate 12).

Table VI

Visual Assessment Fibre Samples

S. No.	Sample	Colour (%)			Lustre (%)			Texture (%)			General appearance (%)		
		B	M	D	G	F	P	S	C	V. C	G	F	P
1	BUN	17	83	0	0	83	17	0	67	33	0	83	17
2	BC1	0	**83**	17	17	33	50	**73**	17	10	17	67	16
3	BC2	23	77	0	30	**60**	10	67	23	10	**57**	40	3
4	BC3	20	70	10	43	17	40	53	27	20	20	60	20
5	BE1	73	27	0	70	23	7	50	23	27	**70**	30	0
6	BE2	0	77	23	57	30	13	25	53	22	27	73	0
7	BE3	**90**	10	0	**93**	7	0	**80**	20	0	60	40	0

***B-Bright, M-Medium, D-Dull, G-Good, F-Fair, P-Poor, S-Soft, C-Coarse, V.V-Very Coarse**

The Table VI reveals that the chemically treated samples BC1, BC2, and BC3 showed maximum values for medium color as expressed by the judges. Among the enzyme treated samples medium colour was reported by the maximum 77 per cent of judges in sample BE2 and bright by the maximum number (90 per cent) of judges in sample BE3. Hence, it could be concluded that the fibres turned bright in the enzyme treated sample BE3.

The luster was expressed as fair by the maximum of judges on chemical treatment in *A.americana* samples. Among the enzyme treated samples, good lustre was noted in sample BE3 by a maximum of 93 per cent of judges. Hence, the luster improved in all the treated samples with the highest ratings for the samples BC3 and BE3 on chemical and enzyme treatments, respectively.

The sample BUN was coarse as reported by 67 per cent of judges which turned to soft in sample BC1 as judged by 73 per cent of them. On enzyme treatment, the samples namely BE3 were judged to have a soft texture as expressed by 80 per cent of judges, followed by 50 per cent of judges for sample BE1. The sample BE2 exhibited coarseness as judged by 53 per cent of judges. Hence, it could be concluded that the texture turned soft in samples BC1 and BE3 on chemical and enzyme treatments respectively as expressed by the maximum number of judges, which was higher in sample BE3. The appearance of the sample BUN was fair, which turned out to be good in sample BC2 (57 per cent). On enzyme treatment, the samples turned out well in sample BE1 (70 per cent) of judges. Hence, samples BC2 and BE1 showed improvement in general appearance after chemical and enzyme treatments, respectively.

4.2.1.3 Visual Assessment of *Areca catechu* Fibres

The results from the visual evaluation are given in the Table VII (Plate 12)

Table VII

Visual Assessment of Fibre Samples

S. No.	Sample	Colour (%)			Lustre (%)			Texture (%)			General appearance (%)		
		B	**M**	**D**	**G**	**F**	**P**	**S**	**C**	**V. C**	**G**	**F**	**P**
1	CUN	0	20	80	0	0	100	0	80	20	0	70	30
2	CC1	0	63	37	0	**70**	30	0	**87**	13	0	**90**	10
3	CC2	0	**70**	30	0	57	43	0	63	37	0	63	37
4	CC3	0	50	50	0	63	37	0	57	43	0	77	23
5	CE1	0	70	30	0	53	47	0	63	37	0	63	37
6	CE2	0	**90**	10	7	**70**	23	0	**93**	7	7	**90**	3
7	CE3	**73**	27	-	17	67	**16**	23	67	**10**	17	67	16

***B-Bright, M-Medium, D-Dull, G-Good, F-Fair, P-Poor, S-Soft, C-Coarse, V.V-Very Coarse**

From Table VII, it is clear that the sample CUN exhibited a dull colour as expressed by 80 per cent of judges. There was improvement in colour as it was rated medium by the maximum of 70 per cent of judges in sample CC2, followed by sample CC1 as expressed by

63 per cent of judges among the chemically treated samples. Among the enzyme treated samples, sample CE2 was rated medium in colour as expressed by 90 per cent of judges followed by 70 per cent of them for sample CE1. The enzyme treated sample CE3 exhibited a bright colour as per the expression of 73 per cent of judges. The luster was noted to be very poor by the cent per cent of judges in sample CUN. Hence the luster was gained in chemically and enzyme treated samples namely CC1 and CE2.

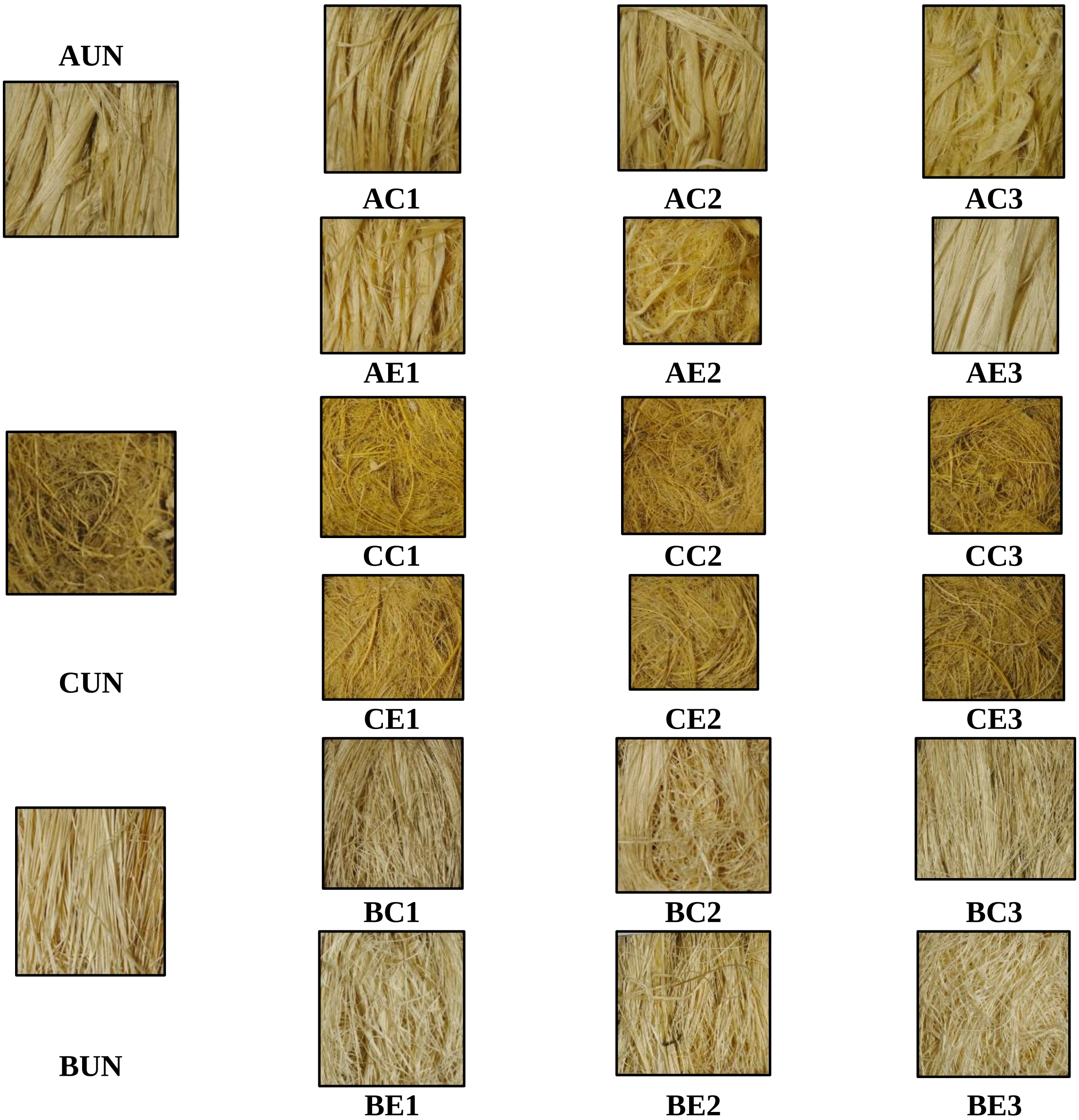


Plate 12 - Visual Assessment of Fibre Samples

Texture was observed to be very coarse in the sample CUN according to 80 per cent of judges. The chemical and enzyme treated samples namely CC1 (87 per cent) and CE2 (93 per cent) respectively were observed to have coarse texture by the maximum of judges.

The sample CE3 showed slight softness as expressed by 23 per cent of judges. General appearance was observed to be fair in sample CUN (70 per cent) and also the chemical and enzyme treated samples were rated to be fair in general appearance, with the maximum ratings for both samples CC1 and CE2 at 90 per cent. Hence, the general appearance was only fair in the fibre samples, even after treatments.

Hence, it could be concluded that a gain in brightness was observed in samples AC2 and AE3 on chemical and enzyme treatments, respectively, which was higher in the enzyme treated fibre sample. The *Agave americana* and *Areca catechu* fibres also showed the highest brightness on combined enzymatic treatments with pectinase and cellulase. The general appearance was good in samples BC2 and BE1 after chemical and enzyme treatments. The luster improved in chemical treated sample AC1 in the enzyme treated samples, namely AE3 and BE3. Texture improved to soft in chemical treated samples namely AC1 and BC1 and enzyme treated samples namely AE3 and BE3. The general appearance improved in chemical treated samples namely AC1 and BC2, and in enzyme treated samples namely AE2 and BE1.

4.2.2 Spectrophotometric Analysis

The results obtained from the spectrophotometric analysis for each of the untreated and treated fibre samples are presented under the following heads

4.2.2.1 Spectrophotometric Analysis of *Abutilon indicum* Fibres

The spectrophotometric analysis of untreated and treated *Abutilon indicum* fibre samples is presented in Table VIII.

Table VIII

Spectrophotometric Analysis of *Abutilon indicum* Fibres

S.No	Samples	Yellowness Index	Whiteness Index	Brightness Index
1	AUN	49.317	7.816	28.342
2	AC1	**55.562**	12.587	24.403
3	AC2	50.133	8.138	**27.014**
4	AC3	50.069	9.190	26.368
5	AE1	60.910	17.827	24.170
6	AE2	**69.900**	25.785	19.083
7	AE3	39.425	4.517	**37.989**

From the Table VIII, it is clear that the yellowness index increased drastically in sample AC1 (55.562), followed by samples AC2 (50.133) and AC3 (50.069), over the original sample AUN (49.317). The minimum whiteness index was observed in all the samples. The reduction in brightness was observed in all the treated samples over the untreated sample, and the brightness index was the highest in sample AC2 (27.014) followed by samples AC3 (26.368) and AC1 (24.403). Among the enzyme treated fibre samples the highest yellowness index was noted in sample AE2 (69.900) and the highest yellowness index in sample AE3 (37.989).

Hence, the sample AC1 exhibited the maximum yellowness index and the minimum brightness index. Among the chemical and enzyme treated *Abutilon indicum* fibre samples the brightness was highest in samples AC2 and AE3, respectively. The fibre treated with a combination of the enzymes' pectinase and cellulase exhibited the highest brightness among all the treated fibre samples.

4.2.2.2 Spectrophotometric Analysis of *Agave americana* Fibres

The results obtained for untreated and treated fibres are presented in the Table IX

Table IX

Spectrophotometric Analysis of *Agave americana* Fibres

S.No	Samples	Yellowness Index	Whiteness Index	Brightness Index
1	BUN	41.279	4.704	40.550
2	BC1	46.097	6.330	25.428
3	BC2	**46.482**	5.363	**30.306**
4	BC3	43.401	1.963	28.438
5	BE1	39.837	3.753	38.120
6	BE2	**45.650**	3.351	31.460
7	BE3	40.499	3.903	**40.207**

The Table IX reveals that the chemical treated samples increased in the yellowness index over the untreated sample BUN (41.279) of which it was the maximum in sample BC2 (46.482) followed by samples BC1 (46.097) and BC3 (43.401). Among the enzyme treated samples, an increase in yellowness index was observed in samples BE2 (45.650) and BE3 (40.499) but a slight decrease was noted in sample BE1 (39.837). The whiteness index was noted to be the minimum in sample BC1 and sample BE2 after chemical and enzyme treatments. The brightness index was observed to be at its maximum in sample BC2 (30.306) followed by sample BC3 (28.438). Among the enzyme treated samples the maximum brightness was noted in sample BE3 (40.207) followed by the sample BE1 (38.120). On Acetylation, the *Agave americana* fibres tend to increase in its yellowness and brightness over its original because of the chemical reaction. Pectinase enzyme treatment has increased the yellowness of *Agave americana* fibres due to the adherence and reaction of enzyme on the fibres. The brightness index of the *Agave americana* fibres has increased on cellulase and pectinase treated fibres has increased because of reactions occurred on fibre surface. Hence, it could be concluded that the chemical treated samples increased in yellowness index. Brightness index was higher in the enzyme treated samples than the chemical treated samples and was the highest in samples BE3.

4.2.2.3 Spectrophotometric Analysis of *Areca catechu* Fibres

The results obtained for untreated and treated fibres are expressed in the Table X

Table X

Spectrophotometric Analysis of *Areca catechu* Fibres

S.No	Samples	Yellowness Index	Whiteness Index	Brightness Index
1	CUN	66.262	13.539	9.155
2	CC1	64.250	17.702	13.235
3	CC2	41.939	3.673	**23.431**
4	CC3	**75.703**	23.241	10.918
5	CE1	71.862	22.187	**13.288**
6	CE2	**71.988**	19.450	11.220
7	CE3	67.559	17.199	12.295

From Table X, it is obvious that there was a reduction in the yellowness index in chemical treated fibre samples namely CC1 with 64.250 and CC2 with 41.939 but an increase in sample CC3 (75.703). Among the enzyme treated samples increase in yellowness index was noted in all three samples of which the maximum was noted in sample CE2 (71.988) followed by samples CE1 (71.862) and CE3 (67.559). The brightness index was noted to increase in chemical treated samples with the maximum increase in sample CC2 (23.431) followed by sample CC1 (13.235). Among the enzyme treated samples the maximum brightness index was observed in all the three samples of which the maximum was observed in sample CE1 (13.288) followed by the sample CE3 (12.295). Hence, it could be concluded that the yellowness index was the highest in samples CC3 and CE2 among chemical and enzyme treated samples respectively whereas, the brightness index was the highest in samples CC2 and CE1 among chemical and enzyme treated samples respectively.

4.2.3. Chemical Constituents

The results obtained and discussion of chemical constituents for the untreated and treated fibres are presented under the following headings (Appendix VIII a)

4.2.3.1 Chemical constituents of *Abutilon indicum* Fibres

The presence of chemical constituents, namely cellulose, lignin, wax and ash in treated and untreated fibres of *Abutilon indicum* is presented in Table XI.

Table XI

Chemical Constituents of *Abutilon indicum* Fibres

S. No	Fibre samples	Chemical constituents (%)											
		Cellulose				Lignin				Wax		Ash	
		Value (%)	Loss/ Gain (%)	Statistical Analyses		Value (%)	Loss/ Gain (%)	Statistical Analyses		Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)
				F-value	Significance			F-value	Significance				
1	AUN	67.95	-			24.17	-			0.18	-	2.2	-
2	AC1	64.3	5.37			22.81	5.62			0.11	38.8	3.11	41.36
3	AC2	**62.9**	7.43	1794.759	.000*	25.17	4.13	29959.333	.000*	0.29	61	0.52	76.36
4	AC3	65.03	4.29			22.55	6.70			0.17	5.55	1.48	32.72
5	AE1	61.25	9.86			26.16	8.23			0.44	144.44	1.06	51.81
6	AE2	70.72	4.07	508917.833	.000*	14.65	39.38	568683.333	.000*	0.33	83.33	1.24	43.63
7	AE3	60.43	11.06			25.24	4.4			0.22	22.22	1.27	42.27

*=Significance at 1% level

From the Table XI and Figure 24a-24d, it is clear that the cellulose content of sample AUN was noted to be 67.95 per cent which decreased in the samples AC3, AC1 and AC2 to 4.29 per cent, 5.37 per cent and 7.43 per cent respectively. The maximum reduction was noticed in sample AC2 among the chemical treated samples. The lignin content of the sample AUN was observed to be 24.17 per cent which was reduced in the samples AC1 and AC3 by 5.62 per cent and 6.70 per cent but an increase was noted in sample AC2 by 4.13 per cent. Among the chemical treated samples the wax content of the sample AUN was noted to be 0.18 per cent and this has been reduced in samples AC3 by 5.55 per cent and AC1 by 38.8 per cent, whereas a slight increase was noted in sample AC2 with 0.61 per cent. The ash content of the chemical treated samples showed a reduction in the sample AC2 (76.36 per cent) followed by the sample AC3 (32.72 per cent). But an increase was observed in the sample AC1 (41.36 per cent).

Among the enzyme treated *Abutilon indicum* fibre samples, the cellulose content of the fibres showed a decrease in both samples AE1 and AE3 with 9.86 and 11.06 percentages respectively, over the sample AUN. The lignin content in the fibres decreased in the sample AE2 by 39.38 per cent over the sample AUN. Both the samples AE1 and AE3 showed a slight increase in the lignin content by 8.23 and 4.4 percentages respectively. As for the wax content, all the enzyme treated samples showed an increase of 144.44 per cent, 83.33 per cent, and 22.22 per cent in the samples AE1, AE2 and AE3 respectively. The ash content was reduced in all the enzyme treated samples namely AE1 (51.81 per cent) AE2 (43.63 per cent) and sample AE3 (42.27 per cent). The statistical analysis of the interaction made between the untreated and treated fibre samples for cellulose and lignin contents showed a significant difference at the 1% level in both treated samples depicting the influence of chemical and enzymes. The chemical treatment alkalization partially removes the lignin, oil and wax that covers the outer part of the cell wall as it depolymerizes the cellulose in the fibres (Mohanty *et al.,* 2000). Hence, it could be concluded that there is an influence of chemical and biological treatments on the modification of chemical constituents in *Abutilon indicum* fibres.

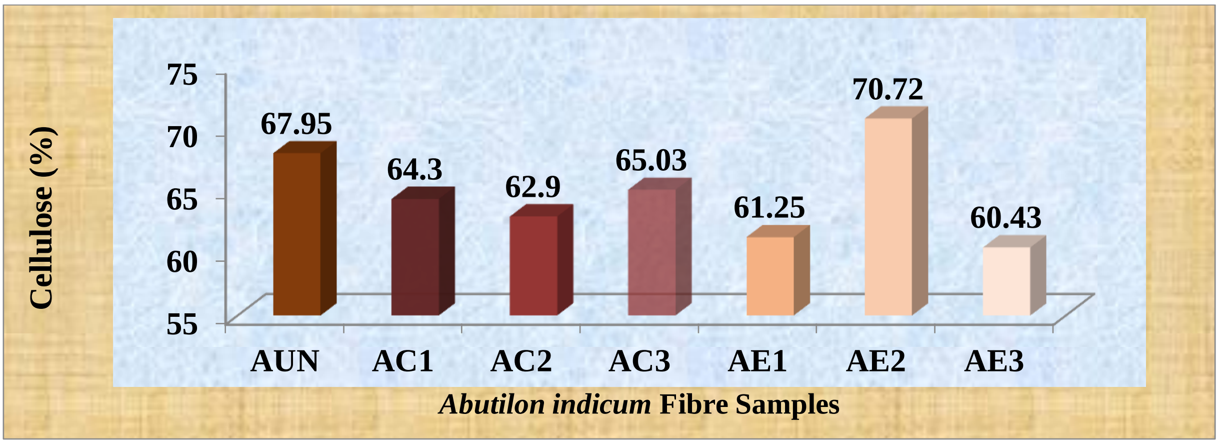


Figure 24a Cellulose

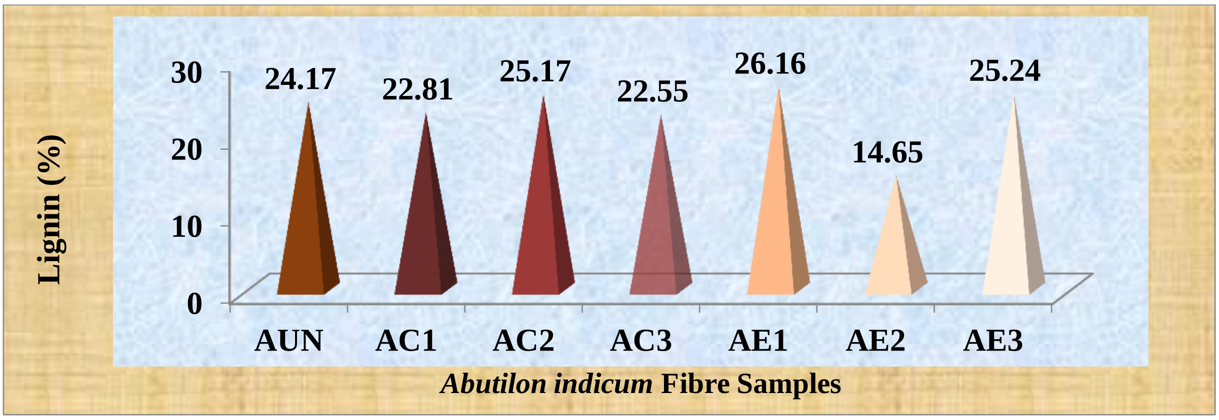


Figure 24b Lignin

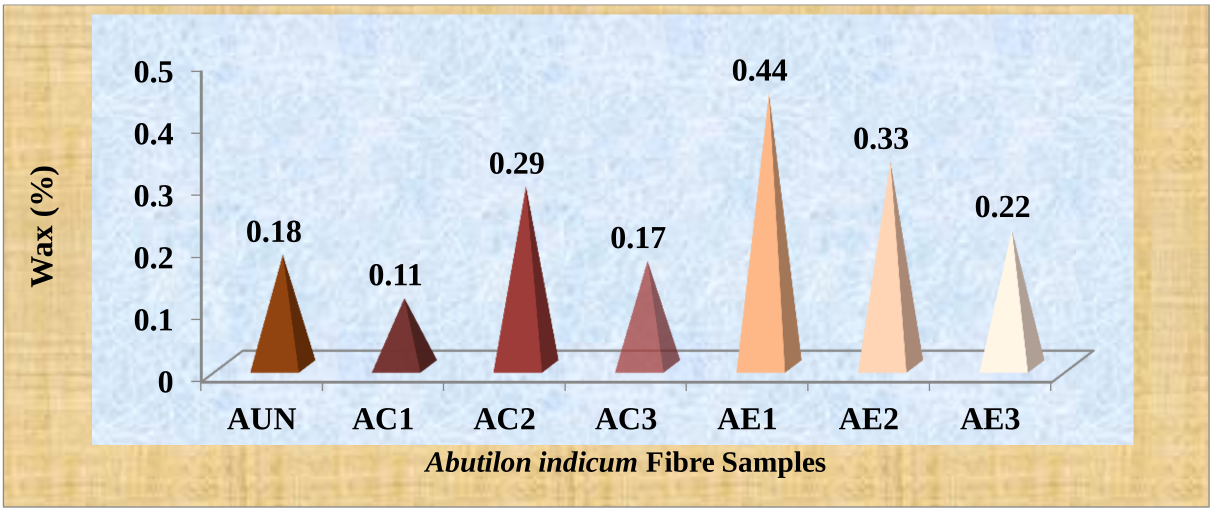


Figure 24c Wax

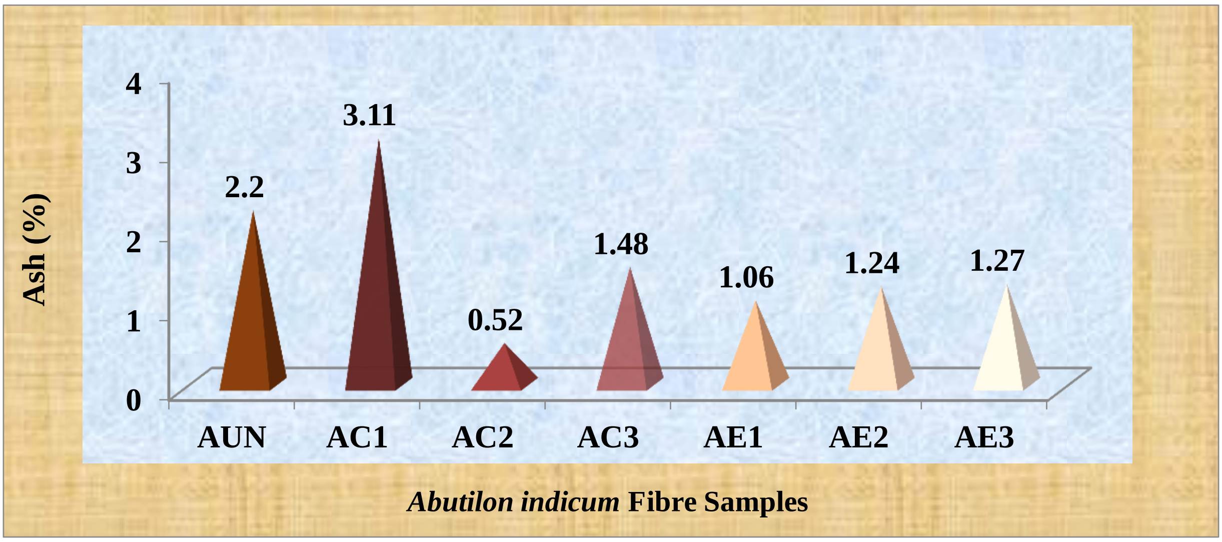


Figure 24d Ash

Figure 24 Chemical Constituents of *Abutilon indicum* Fibres

4.2.3.2 Chemical Constituents of *Agave americana* Fibres

The presence of chemical constituents namely cellulose, lignin, wax and ash for untreated and treated fibres are presented in Table XII and Figures 25a-25d.

Table XII
Chemical Constituents of *Agave americana* Fibres

S.No	Fibre samples	Chemical Constituents (%)											
		Cellulose				Lignin				Wax		Ash	
		Value (%)	Loss/ Gain (%)	Statistical Analyses: F-value	Statistical Analyses: Significance	Value (%)	Loss/ Gain (%)	Statistical Analyses: F-value	Statistical Analyses: Significance	Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)
1	BUN	70.77	-			13.59				0.29	-	3.1	-
2	BC1	87.95	24.27	21.51	.000*	13.46	0.95	167516.000	.000*	**0.21**	27.58	1.99	35.80
3	BC2	69.37	1.97			**10.86**	20.08			0.36	24.13	**1.13**	63.54
4	BC3	**68.3**	3.49			17.85	31.3			0.23	13.79	1.72	44.51
5	BE1	77.76	9.87	9900.557	.000*	9.96	26.71	70056.500	.000*	**0.27**	6.89	**1.05**	66.12
6	BE2	**73.85**	4.35			10.38	23.62			0.48	65.51	2.06	33.54
7	BE3	78.4	10.78			**9.44**	30.53			0.45	55.17	1.29	58.38

*=Significance at 1% level

From the Table XII and Figure 25a-25d, it is obvious that the cellulose content in sample BUN was 70.77 per cent which increased in sample BC1 by 24.27 per cent but decreased in both samples BC2 by 1.97 per cent and sample BC3 by 3.49 per cent. The reduction was higher in sample BC3 among the chemically treated samples. In the enzyme treated fibre samples a noticeable increase in cellulose content was observed over the untreated sample BUN (70.77 per cent) of which the maximum was in sample BE3 (10.78 per cent) followed by samples BE1 (9.87 per cent) and BE2 (4.35 per cent). Increased cellulose content observed in *Agave americana* fibres after enzymatic and chemical treatments has a potential to increase the composite strength and stiffness when weak polymeric substances in the fibres are replaced by strong matrixes like epoxy (Prez *et al.*, 2018). Hence, the cellulose content decreased to the maximum in chemical treated and enzyme treated samples, namely BC3 and BE2.

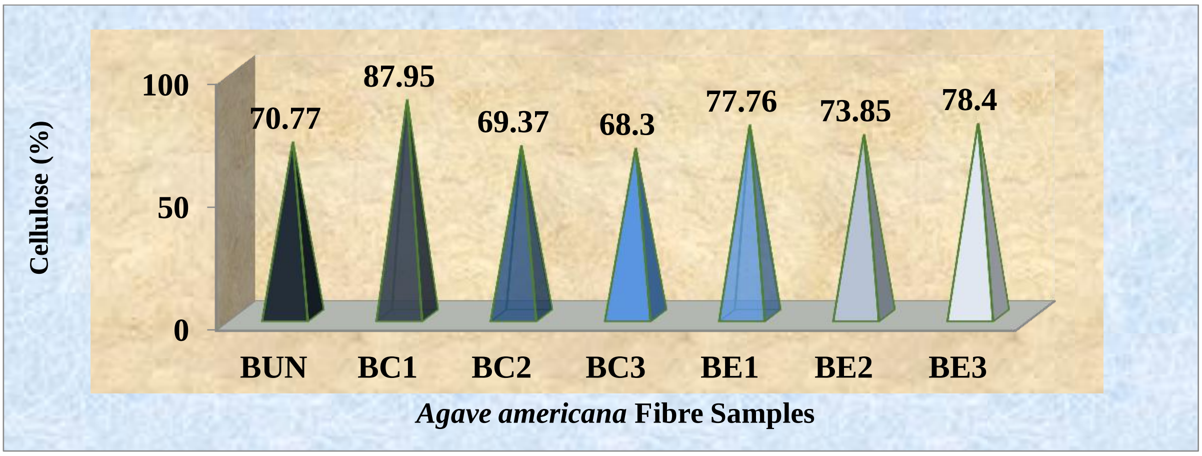


Figure 25a Cellulose

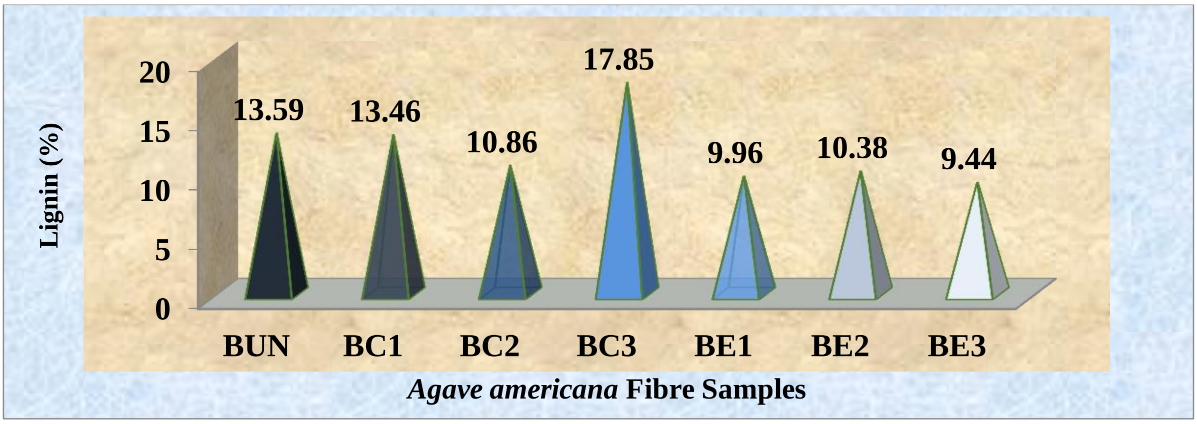


Figure 25b Lignin

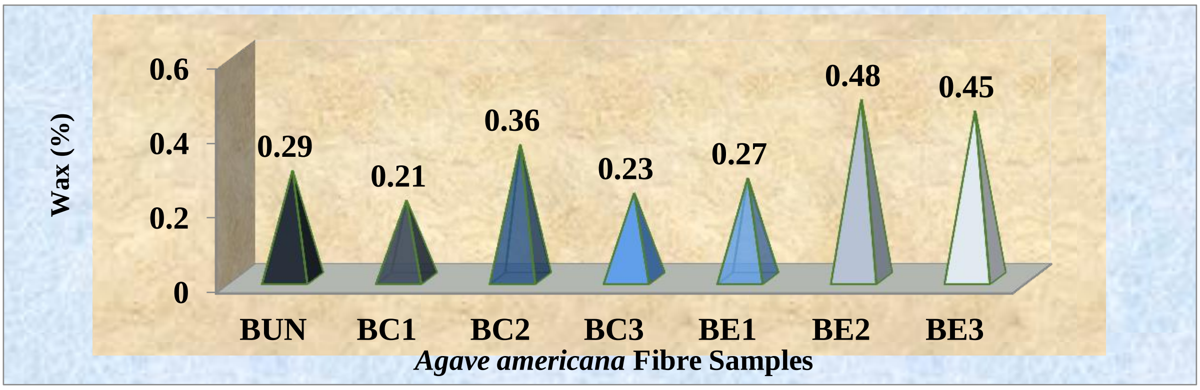


Figure 25c Wax

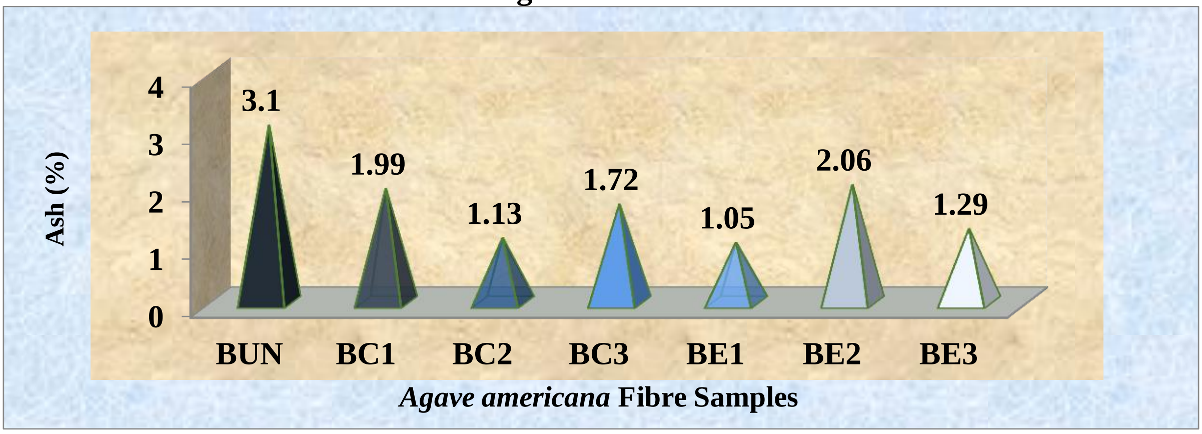


Figure 25d Ash

Figure 25 Chemical Constituents of *Agave americana* Fibres

The lignin content in sample BUN was 13.59 per cent. Among the chemically treated samples, it increased in sample BC3 with 31.3 per cent but decreased in both samples BC2 (20.08 per cent) and BC1 (0.95 per cent) of which the reduction was higher in sample BC2. Among the enzyme treated samples, the lignin content of fibres decreased in all three samples, with the maximum reduction in sample BE3 (30.53 per cent) followed by samples BE1 (26.71 per cent) and BE2 (23.62 per cent). Hence, the lignin content decreased to its maximum on chemical and enzyme treatments in samples BC2 and BE3 respectively. As for the wax content, it was 0.29 per cent in sample BUN. This was noted to reduce in samples BC1 (27.58 per cent) and BC3 (13.79 per cent) but an increase of 24.13 per cent was noted in sample BC2 among the chemical treated samples. In the enzyme treated samples, a reduction of wax content was noted in sample BE1 (6.89 per cent) whereas it increased in samples BE2 (65.51 per cent) and BE3 (55.17 per cent). Hence, the wax content was reduced to its maximum in the samples BC1 and BE1 on chemical and enzyme treatments. The ash content was observed to be 3.1 per cent in sample BUN which was reduced in all the chemical treated samples, with the maximum in sample BC2 at 63.54 per cent followed by samples BC3 at 44.51 per cent and BC1 at 35.80 per cent. Among the enzyme treated samples, also a reduction was observed, of which the maximum was in sample BE1 with 66.12 per cent followed by samples BE3 with 58.38 per cent and BE2 with 33.54 per cent. Hence, the chemical and enzyme treatments showed reduction in ash content, with the highest in samples BC2 and BE1 respectively. The statistical analysis by one-way ANOVA carried out between the chemically treated with untreated samples and the enzyme treated with untreated samples showed that there is a significant difference at the one per cent level. Hence, it could be concluded that the chemical and enzyme treatments altered the chemical constituents, namely cellulose, lignin, wax and ash in the *Agave americana* fibre samples which is also proved in statistical analysis.

4.2.3.3 Chemical Constituents of *Areca catechu* Fibres

The chemical constituents namely cellulose, lignin, wax and ash present in untreated and treated *Areca catechu* fibres are presented in Table XIII.

Table XIII

Chemical Constituents of *Areca catechu* Fibres

S.No	Fibre samples	Chemical Constituents (%)											
		Cellulose				Lignin				Wax		Ash	
		Value (%)	Loss/ Gain (%)	Statistical Analyses: F-value	Statistical Analyses: Significance	Value (%)	Loss/ Gain (%)	Statistical Analyses: F-value	Statistical Analyses: Significance	Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)
1	CUN	57.79	-			27.92	-			0.44	-	2.22	-
2	CC1	**52.9**	8.46	18094.207	.000*	31.78	13.82	271608.143	.000*	0.23	47.72	2.34	5.40
3	CC2	62.73	8.54			**23.03**	17.51			0.30	31.81	**1.07**	51.80
4	CC3	63.17	9.3			24.48	12.32			**0.18**	59.09	1.95	12.16
5	CE1	67.85	17.40	524173.833	.000*	20.73	25.75	10555479.17	.000*	**0.28**	36.36	1.57	29.27
6	CE2	**56.88**	1.57			**18.70**	153.22			0.35	20.45	**0.99**	55.40
7	CE3	58.39	1.03			26.94	3.51			0.39	11.36	1.87	15.76

*=Significance at 1% level

From the Table XIII and Figure 26a-26d, it is clear that the cellulose content of sample CUN was observed to be 57.79 per cent and this increased in samples CC3 and CC2 by 9.3 per cent and 8.54 per cent respectively, whereas it reduced in sample CC1 by 8.46

per cent over sample CUN. Among the enzyme treated samples CE2 showed a reduction of 1.57 per cent whereas an increase was observed in both samples CE3 and CE1 of 1.03 per cent and 17.40 per cent respectively.

The lignin content in sample CUN was noted to be 27.92 per cent which was reduced in both the samples CC3 and CC2 by 12.32 per cent and 17.51 per cent respectively. But the sample CC1 showed an increase of 13.82 per cent over the sample CUN among the chemically treated samples. Among enzyme treated samples, all the samples showed a decrease in lignin content, with the maximum decrease in sample CE2 (>100 per cent) followed by samples CE1 and CE3 with 25.75 per cent and 3.51 per cent respectively. Wax content was observed in sample CUN at 0.44 per cent which reduced in all the chemically treated samples, namely CC2 31.81 per cent, CC1 at 47.72 per cent, CC3 at 59.09 per cent of which the highest reduction was in sample CC3. All the enzyme treated samples also showed reductions in wax content, of which the highest was in sample CE1 with 36.36 per cent, followed by sample CE2 with 20.45 per cent and CE3 with 11.36 per cent.

Ash content was noted to be 2.22 per cent in sample CUN, which was reduced in both samples CC2 by 51.80 per cent and CC3 by 12.16 per cent, whereas it showed an increase in sample CC1 by 5.40 per cent. Among the enzyme treated samples, the ash content was reduced in all the samples namely CE2 by 55.40 per cent, CE1 by 29.27 per cent and CE3 by 15.76 per cent. Hence, the ash content of the chemical and enzyme samples showed the highest reduction in samples CC1 and CE2 respectively. The statistical analysis by One-way ANOVA carried out for the cellulose and lignin contents of the untreated and treated *Areca Catechu* fibre samples showed a significant difference at the 1% level. The chemical treatment enhanced the properties of fibre, namely alkalization in *Abutilon indicum, Areca catechu* and benzoylation in *Agave americana* because the strong polarization in cellulosic fibres is inherently less compatible with hydrophobic polymers (Ranakoti *et al.,* 2018). These fibres may have good compatibility with the polymer matrix when utilized.

Hence, it could be concluded that there was an alteration in both the treated samples as far as the chemical constituents were concerned, which is also statistically proved. In the *Areca catechu* fibre treated with chemicals and enzymes, cellulose content decreased in samples CC1 and CE2, lignin content decreased to the maximum in samples CC2 and CE2, and wax content was reduced in both the treated samples CC3 and CE1. A drastic reduction of ash content was seen in both treatments in samples CC2 and CE2. The structural composition of natural fibres allow moisture absorption from the environment which lead to poor bonding with the matrix materials. The reduction in ash content might lead to good adhesion between the matrix and reinforcement in composite making.

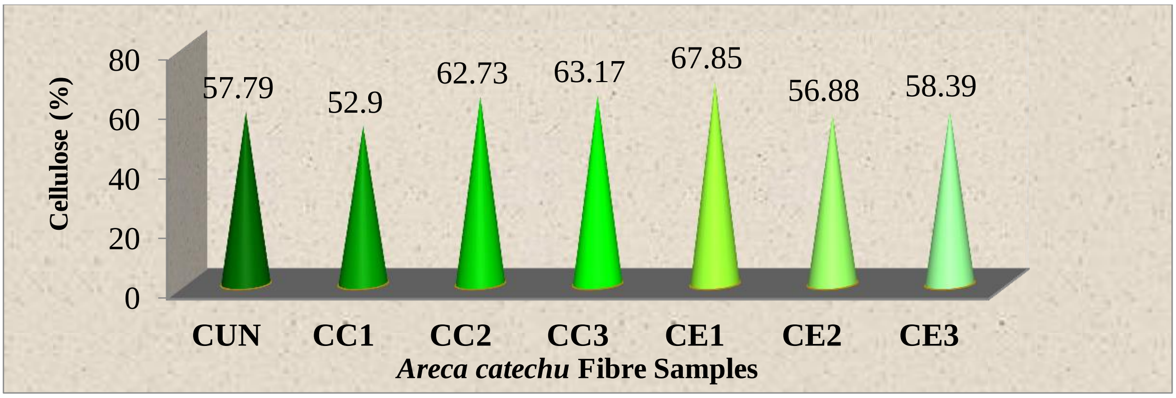


Figure 26a Cellulose

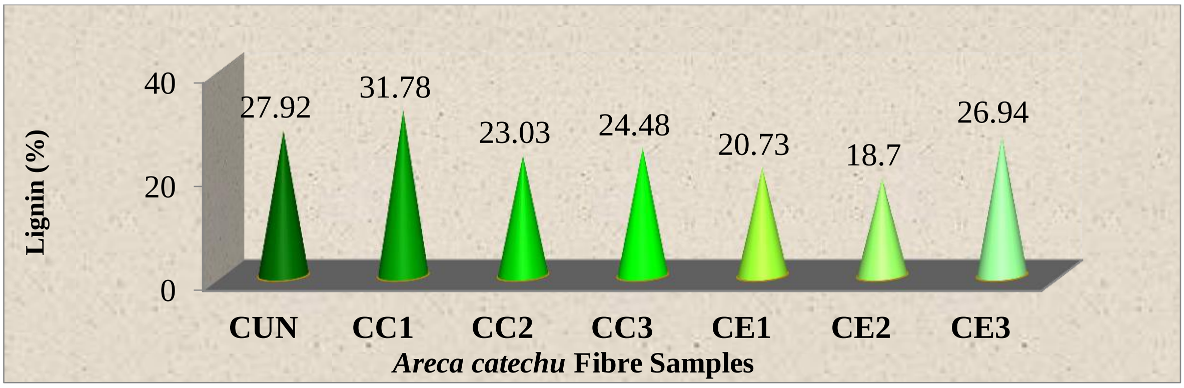


Figure 26b Lignin

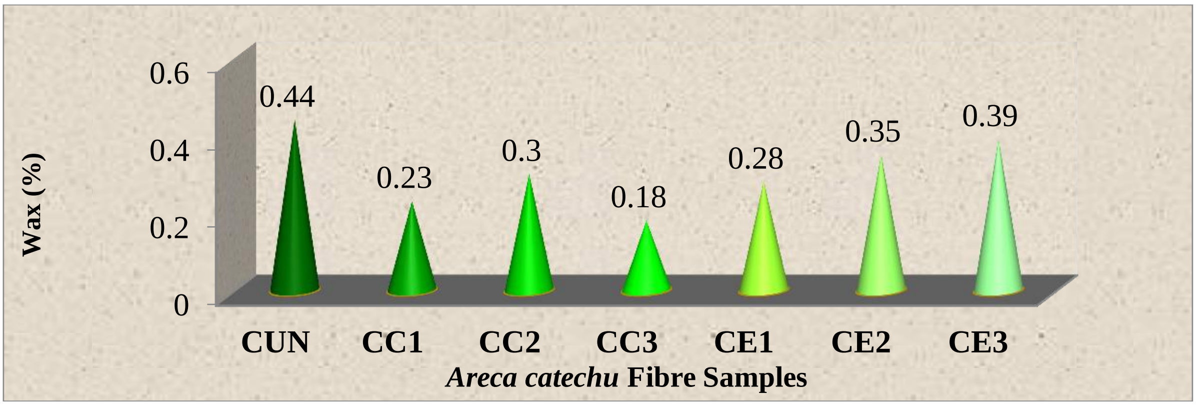


Figure 26c Wax

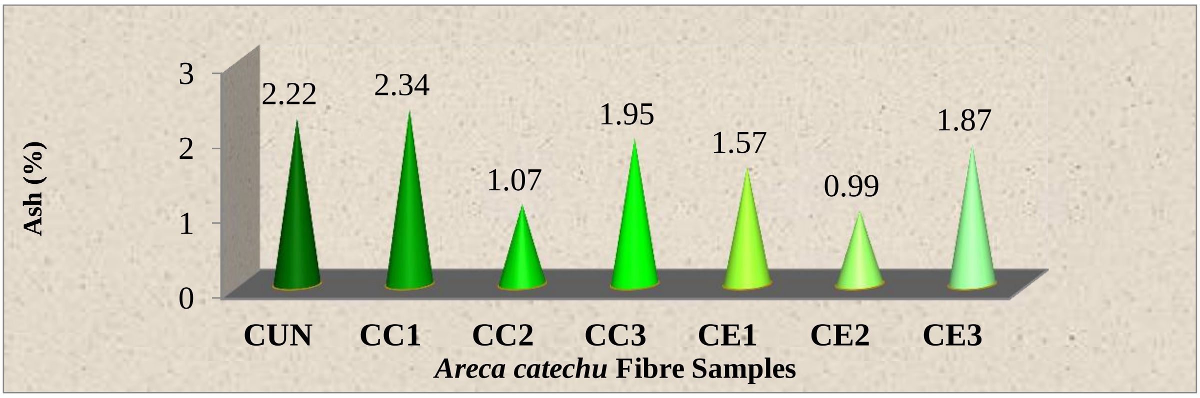


Figure 26d Ash

Figure 26 Chemical Constituents of *Areca catechu* fibres

4.2.4 Density, Moisture Content, Moisture Regain and Water Absorption

The results obtained for the untreated and treated fibres are presented with discussions under the following heads.

4.2.4.1 Density, Moisture Content, Moisture Regain and Water Absorption of *Abutilon indicum* Fibres

The density, moisture content, regain and water absorption of untreated and treated *Abutilon indicum fibres* are presented in Table XIV (Appendix VIIIb - VIIIe)

Table XIV

Density, Moisture Content, Regain and Water Absorption of *Abutilon indicum* Fibres

S. No	Fibre Samples	Density		Moisture Content		Moisture Regain				Water Absorption Rate		
		Value (g/cc)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)	Value (%)	Loss/Gain (%)	Statistical Analyses: F-Value	Statistical Analyses: Significance	Value (%)	Statistical Analyses: F-Value	Statistical Analyses: Significance
1	AUN	1.45	-	**12.10**	-	1.41	-			177.92		
2	AC1	1.45	0	11.6	4.13	**1.01**	28.36			258.03		
3	AC2	1.37	5.51	10.99	9.17	3.90	176.59	8582.026	0.000*	**169.19**	32984075.17	0.000*
4	AC3	**1.32**	8.96	10.56	12.72	4.03	185.81			187.47		
5	AE1	1.40	3.44	10.89	10	4.16	195.03			211.68		
6	AE2	**1.35**	6.89	**12.85**	6.1	**1.60**	13.47	60751.087	0.000*	111.42	59011810.64	0.000*
7	AE3	1.43	1.37	12.60	4.13	6.15	336.17			**104.41**		

*=Significance at 1% level

From the Table XIV and Figure 27a-27b, it is obvious that the density of the untreated fibre sample AUN was noted to be 1.45 g/cc. There was a reduction observed in the chemical treated samples, namely AC3 and AC2, by 8.96 per cent and 5.51 per cent respectively, but no change in density was observed in the sample AC1. Among the enzyme treated samples, there was a reduction noted in all the samples, of which the maximum reduction was in sample AE2 by 6.89 per cent followed by samples AE1 and AE3 by 3.44 per cent and 1.37 per cent respectively. The density loss may be due to the reduction in chemical constituents, namely cellulose, lignin, and wax in sample AC1, cellulose, wax, and ash in sample AC2, and cellulose, lignin, wax, and ash contents in sample AC3.

Moisture content of the sample AUN was noted to be 12.10 per cent which was reduced in samples AC1 (4.13 per cent), AC2 (9.17 per cent) and AC3 (12.72 per cent) and the maximum loss in moisture content was observed in the sample AC3 in the chemical treated samples. Among the enzyme treated samples, there was an increase noted in both samples AE2 (6 per cent) and AE3 (4.13 per cent) and a decrease in sample AE1 (10 per cent) over the sample AUN. The highest reduction was noted in sample AE1.

Moisture regain in the fibre sample AUN was noted to be 1.41 per cent. It decreased in sample AC1 by 28.3 per cent but increased in both samples AC3 (185.81 per cent) and AC2 (176.59 per cent) among the chemical treated samples. On enzyme treatment, the moisture regain increased in all three samples and was the minimum in sample AE2 (13.47 per cent). The statistical analysis also showed a significant difference at 1 per cent level in the interactions made between untreated and chemical treated samples, and between untreated and enzyme treated samples. This increase may be due to the increase in the hydrophilic property of the fibre due to Acetylation and Benzoylation. But due to Alkylation the hydrophobic property has been imparted to the *Abutilon Indicum* fibre samples.

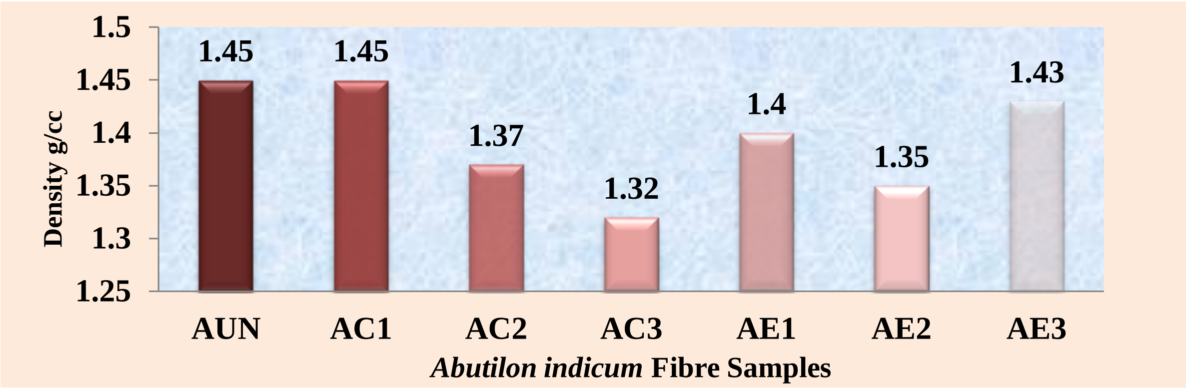


Figure 27a Density

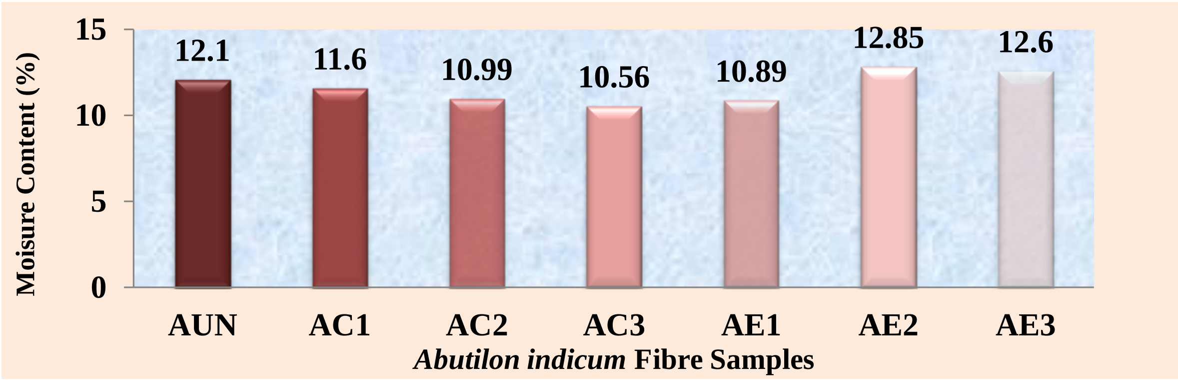


Figure 27b Moisture Content

Figure 27 Density and Moisture Content of *Abutilon indicum* Fibres

Water absorption of the sample AUN was noted to be 177.92 per cent by its own weight. This absorption capacity improved in the sample AC1 to 258.03 per cent followed by sample AC3 to 187.47 per cent whereas it was reduced in the sample AC2 by 169.19 per cent on chemical treatments. Among enzyme treated samples a decrease in water absorption was noted in samples AE2 and AE3 by 111.42 per cent and 104.41 per cent respectively. But it showed an increase in the sample AE1 to 211.68 per cent by its weight. Benzoylation reduces the hydrophobicity of the fibre as expressed by John and Anandjiwala 2008 which is also proved in this study as the sample AC3 exhibits higher water absorption than the sample AUN. Acetylation modifies the surface of natural fibers making it more hydrophobic than untreated as the chemical reacts with the hydroxyl groups (OH) of the fibre (Vishnu *et al*., 2016) which is exhibited in the sample AC2. The statistical analysis also showed a significant difference at 1 per cent level between the untreated and treated fibres.

4.2.4.2 Density, Moisture Content, Regain and Water Absorption of *Agave americana* Fibres

The density, moisture content, regain and water absorption of treated and untreated fibres are presented in Table XV

Table XV

Density, Moisture Content, Regain and Water Absorption of *Agave americana* Fibres

S.No	Fibre Samples	Density		Moisture Content		Moisture Regain				Water Absorption Rate		
		Value (g/cc)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)	Statistical Analyses		Value (%)	Statistical Analyses	
								F-Value	Significance		F-Value	Significance
1	BUN	1.370	-	12.02	-	0.60	-			224.60		
2	BC1	1.381	0.80	12.17	1.24	2.88	380	36572.000	.000*	208.86	20.155	0.000*
3	BC2	1.236	9.78	18.04	6.02	3.73	521.6			**176.35**		
4	BC3	1.414	3.21	**11.61**	0.41	1.83	205			254.64		
5	BE1	1.413	3.13	10.75	1.27	**0.40**	33.33	44495.003	.000*	**205.59**	7086956.000	0.000*
6	BE2	1.378	0.58	13.02	1.00	3.73	521.66			247.86		
7	BE3	**1.363**	0.51	**10.22**	1.80	2.04	240			211.11		

*=Significance at 1% level

From Table XV and Figure 28a-28b, it is clear that the density of the untreated sample BUN was noted to be 1.370 g/cc. This reduced BC2 in the sample to 9.78 per cent. This showed a slight increase in the samples BC1 and BC3, with 0.83 per cent and 3.21 per cent respectively. Among the enzyme treated samples, there was a gain in density observed in samples BE1 (3.13 per cent) and BE2 (0.58 per cent) whereas a slight loss was noted in samples BE3 (0.51 per cent) respectively.

The moisture content observed in sample BUN was 12.02 per cent which was reduced in sample BC3 by 0.41 percent, slightly increased in sample BC1 by 1.24 per cent and drastically increased in sample BC2 by 6.02 per cent. Among the enzyme treated samples, the greatest reduction in moisture content was observed in samples BE1 and BE3, with 1.27 per cent and 1.80 per cent respectively.

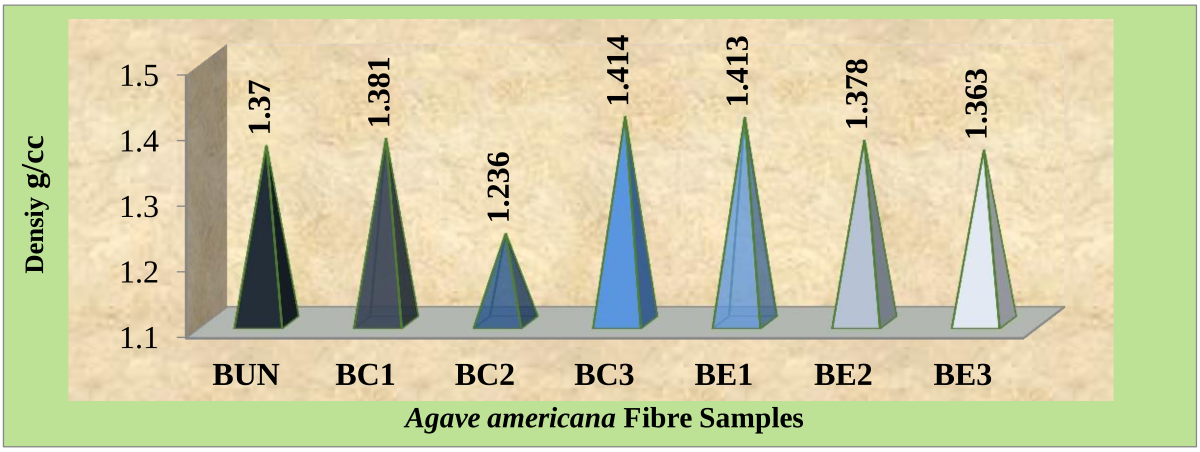


Figure 28a Density

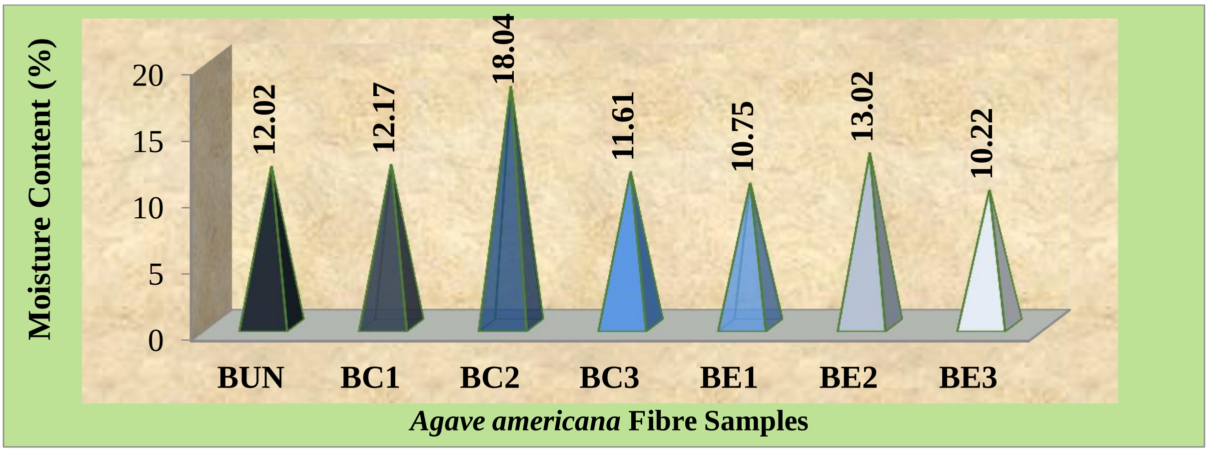


Figure 28b Density and Moisture Content of *Agave americana* Fibres

Moisture regain in the sample BUN was noted to be 0.60 per cent. The sample BC2 showed the highest moisture regain (3.73 per cent) among the chemical treated samples. All the chemical treated samples showed an increase in moisture regain, which was the highest in sample BC2 at 3.73 per cent. Among the enzyme treated samples, a decrease in moisture regain was observed in sample BE1 to 0.40 per cent whereas an increase was exhibited by samples BE2 (3.73 per cent) and BE3 (2.04 per cent). The Statistical analysis also proves there is a significant difference at the 1 per cent level in the interactions made between untreated and chemical treated samples, and untreated and enzyme treated *Agave americana* samples.

The water absorption of sample BUN was 224.60 per cent which increased drastically in sample BC3 to 254.64 per cent by weight. Statistical analysis by one way ANOVA also showed that there is a significant difference at the 1 per cent level in the interactions made between untreated samples.

Thus, the chemical and enzymatic treatments have altered the moisture absorption properties of the fibres, which would serve the purpose of composite preparation.

4.2.4.3 Density, Moisture Content, Regain and Water Absorption of *Areca catechu* Fibres

The density, moisture content, regain and water absorption of treated and untreated fibres *Areca catechu* fibres are presented in Table XVI

Table XVI

Density, Moisture Content, Regain and Water Absorption of *Areca catechu* Fibres

S.No	Fibre Samples	Density g/cc		Moisture Content		Moisture Regain				Water Absorption Rate		
								Statistical Analyses			Statistical Analyses	
		Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)	Value (%)	Loss/ Gain (%)	F-Value	Significance	Value (%)	F-Value	Significance
1	CUN	-	1.460	11.43	-	2.24	-			234.22		
2	CC1	14.93	**1.242**	10.99	3.84	2.45	9.37	9073.833	.000*	222.31	35778993.33	.000*
3	CC2	5.20	1.384	12.70	11.11	3.73	66.5			226.43		
4	CC3	24.65	1.820	**10.05**	12.07	3.09	37.94			**143.64**		
5	CE1	5.82	**1.375**	**9.38**	17.93	**1.01**	54.91	204.246	.000*	**149.16**	131796289.8	.000*
6	CE2	3.28	1.412	22.88	100.17	1.6	28.57			345.82		
7	CE3	2.73	1.420	12.21	6.82	1.41	37.05			222.59		

*Significance at 1% level

From the Table XVI, it is clear that the density of the sample CUN was observed to be 1.46 g/cc. The sample CC3 gained density with 24.65 per cent on chemical treatment, whereas there was a loss noted in the samples CC1 and CC2 with 14.93 per cent and 5.20 per cent. Among the enzyme treated samples, loss in density was also observed over the sample CUN in samples CE1, CE2 and CE3 with 5.82 per cent , 3.28 per cent and 2.73 per cent respectively.

Moisture content of sample CUN was noted to be 11.43 per cent which decreased in both the samples CC1 and CC3 to 3.84 per cent and 12.07 per cent respectively. Among the enzyme treatment samples, a drastic increase in moisture content was observed in sample CE2 with 100.17 per cent and slight increase in sample CE3 with 6.82 per cent and decrease in sample CE1 with 17.93 per cent.

Moisture regain in sample CUN was observed to be 2.24 per cent. This increased in all three chemical treated samples, of which the highest was sample CC2 at 66.2 per cent followed by samples CC3 at 37.95 per cent and CC1 at 9.37 per cent. All the enzyme treated samples exhibited a reduction in moisture regain to 20.57 per cent in sample CE2. Statistical analysis by one ANOVA also showed that there is a significant difference at 1 per cent level in the interactions made between untreated and chemical treated samples, and untreated and enzyme treated samples.

Water absorption was noted to be 234.22 per cent in the sample CUN. This reduced in all the chemical treated samples of which it was the maximum in the sample CC3 (143.64 per cent) followed by the samples CC1 (222.31 per cent) and CC2 (226.43 per cent). Among the enzyme treated samples, the reduction was observed in samples CE3 (222.59 per cent) and CE1 (149.16 per cent). Statistical analysis by ANOVA also showed that there is a significant difference at the 1 per cent level in the interactions made between untreated and chemical treated samples, and untreated and enzyme treated samples. Hence, it could be concluded that the chemical and enzymatic treatments have modified the moisture absorption properties of the *Areca catechu* fibres.

4.2.5 Tensile Strength and Elongation

The strength and elongation of the untreated and treated fibres are presented under the following heads (Appendix VIIIf)

4.2.5.1 Tensile Strength and Elongation of *Abutilon indicum* Fibres

The strength and elongation of the untreated and treated *Abutilon indicum* fibres are presented in Table XVII.

Table XVII

Tensile Strength and Elongation of *Abutilon indicum* Fibres

S.No	Fibre Samples	Breaking strength		Statistical analyses		Breaking Elongation (%)	Force (cN)
		Values (N mm)	Loss/ Gain (%)	F-value	Significance		
1	AUN	4.**02**	-			1.17	1.09
2	AC1	**6.01**	49.50	26571.333	.000*	**1.26**	1.88
3	AC2	3.86	3.98			1.20	1.09
4	AC3	3.41	15.17			1.10	0.97
5	AE1	3.55	11.69	15566.000	.000*	1.00	0.85
6	AE2	**5.56**	38.30			1.10	1.47
7	AE3	3.97	1.24			0.90	0.95

*Significance at 1% level

From the Table XVII, it is clear that the breaking strength was 4.02 in the sample AUN. This has improved in sample AC1 by 49.50 per cent whereas it decreased in both samples AC2 (3.98 per cent) and AC3 (15.17 per cent). Among the enzyme treated *Abutilon indicum* fibre samples, the sample AE2 showed a gain in strength of 38.30 per cent but the other two samples, AE3 and AE1, showed a reduction in strength of 1.24 per cent and 11.69 per cent respectively. Breaking elongation was observed to be 1.17 per cent in AUN, which increased in both samples AC1 to 1.26 per cent and AC2 to 1.20 per cent which decreased in sample AC3 to 1.10 per cent. The breaking elongation was observed to have a slight reduction in the samples AE1 (1.00 per cent), AE2 (1.10 per cent) and AE3 (0.90 per cent). The force required for the fibre breakage was observed to be 1.09 cN for sample AUN, which increased to 1.88 cN for sample AC1. Both the samples AC2 (1.09 cN) and AC3 (0.97 cN) required less force to break the fibre samples. The breaking force required for the enzyme treated samples was noted to have increased in the sample AE2 (1.47 cN) but decreased in both the samples AE1 (0.85 cN) and AE3 (0.95 cN) over the sample AUN. So single fibre strength exhibits an improvement of 49.50 percent in sample AC1 over sample AUN which is in line with the findings of earlier study (Vishnu *et al.*, 2016) that the strength increases due to alkali treatment. This may be due to the action of alkali on non-cellulosic content and its removal. The statistical analysis made using One-Way ANNOVA for the interaction between untreated and treated fibres showed a significant difference at the 1% level. Hence, it could be concluded that the strength of the *Abutilon indicum* fibers improved in the samples AC1 and AE2, which were chemical treated and enzymes treated samples, respectively, and elongation improved in the chemical treated samples AC1. The improved strength in *Abutilon indicum* fibers due to alkali and pectinase treatments would help in composite making.

4.2.5.2 Tensile Strength and Elongation of *Agave americana* Fibres

The Table XVIII reveals the Tensile Strength and Elongation of untreated and treated of *Agave Americana* fibres

Table XVIII

Tensile Strength and Elongation of *Agave americana* Fibres

S.No	Fibre Samples	Breaking Strength		Statistical Analyses		Breaking Elongation (%)	Force (cN)
		Values (N/mm)	Loss/gain (%)	F Value	Significant		
1	BUN	4.39	-			9.4	11.09
2	BC1	3.77	14.12	5157.333	.000*	10.1	9.65
3	BC2	4.11	6.37			9.3	9.30
4	BC3	**4.97**	13.21			9.2	12.16
5	BE1	3.69	15.94	4782.000	.000*	8.7	8.58
6	BE2	4.02	8.42			10.1	10.59
7	BE3	3.24	26.19			9.1	8.20

* Significance at 1% level

From the Table XVIII, it is noted that the sample BUN exhibited a breaking strength of 4.39 per cent. This increased in sample BC3 by 13.21 per cent but it reduced by 6.37 per cent in sample BC2 and 14.12 per cent in sample BC1 among the chemically treated samples. In the enzyme treated samples, all the samples showed a decrease in breaking strength, with the maximum in sample BE3 at 26.19 per cent followed by sample BE1 at 15.94 per cent.

The Breaking elongation was observed to be 9.4 per cent in sample BUN, which increased in sample BC1 (10.1 per cent). Among the enzyme treated samples, the sample BE2 showed an increase in breaking elongation of 10.1 per cent which was reduced in both the samples BE1 and BE3 to 8.7 per cent and 9.1 per cent respectively. The force required for the break of the fibre increased slightly in the sample BC3 to 12.16 cN. The statistical analysis done using one-way ANOVA showed a significant difference at the 1 per cent level in the interaction made between the untreated and chemical treated fibres for breaking strength. Hence, it could be concluded that the strength of *Agave americana* fibres improved in breaking strength and elongation on benzoylation, which can be selected for further study in composite making.

4.2.6 Thermogravimetric Analysis (TGA)

The Thermogravimetric Analysis for all the untreated and treated fibre samples are expressed under the following heads.

4.2.6.1 Thermogravimetric Analysis of *Abutilon indicum* Fibres

The results obtained from Thermogravimetric Analysis (TGA) for untreated and treated *Abutilon indicum* fibres are presented in Table XIX (Figures 29a – 29g).

Table XIX
TGA of *Abutilon indicum* Fibres

S.No	Fibre Sample	Stage 1		Stage 2		Final stage	
		Temp *(^{O}C)	Wt (%) *	Temp.*(^{O}C)	Wt (%)*	Temp.* (^{O}C)	Wt (%) *
1	AUN	390	107.7	-	-	-	-
2	AC1	280	19.5	430	69.1	450	**94.6**
3	AC2	340	36.5	450	95.3	-	-
4	AC3	325	35.6	375	97.3	-	-
5	AE1	400	101.8	-	-	-	-
6	AE2	480	103.3	-	-	-	-
7	AE3	380	**97.5**	-	-	-	-

*Temp. -Temperature, wt – Weight

From the Table XIX and Figure 29, it is clear that the untreated *Abutilon indicum* fibres exhibited one stage of thermal degradation at 390^{o}C weight loss of 107.7 per cent which is due to the release of moisture content from the fiber. In alkali-treated *Abutilon indicum* fibre, the first stage of thermal degradation took place at 280^{o}C with a weight loss of 19.5 per cent which corresponds to the vaporization of absorbed moisture content during treatment. The second stage is attributed to the degradation of hemicelluloses and lignin at

430°C and a weight loss of 69.1 per cent. The last stage of degradation occurred due to degradation of cellulose at 450°C with a loss in weight of 94.6 per cent. The TGA curve remains relatively flat until the temperature reaches 450°C which means slow decomposition of sample AC1. In the sample AC2, the initial stage of degradation occurred at 340 oC with weight loss of 36.5 per cent which was attributed to the elimination of moisture content from the fibre. The second stage of degradation took place at 450°C with a weight loss of 95.3 per cent due to the decomposition of hemicelluloses and lignin, and at the final stage of TGA, the curve remains flat. In sample AC3, the degradation starts at 325°C with a weight loss of 35.6 per cent and the second stage of degradation starts at 375°C with a weight loss of 97.3 per cent. The thermal stability improved in all the chemically treated fibres of *Abutilon indicum*, the highest being in sample AC1, which could withstand a higher temperature of 450°C with least weight loss. Among the enzyme treated samples, the highest degradation occurred in sample AE2 with 103.3 per cent weight loss at 480°C followed by samples AE1 with 101.8 per cent weight loss (400°C) and AE3 with 97.5 per cent weight loss (380°C). Hence, it could be concluded that thermal stability was the highest in sample AC1 which is due to the reaction of alkali on the fibres. This may be an added advantage in selecting the alkali treated Abutilon *Indicum* fibre for further study.

4.2.6.2 Thermogravimetric Analysis of *Agave americana* Fibres

The results obtained from the Thermogravimetric Analyses of untreated and treated *Agave americana* fibres are presented in Table XX and Figures 30a – 30g

Table XX
TGA of *Agave americana* Fibres

S.No	Fibre Sample	Stage 1		Stage 2		Final Stage	
		Temp. * (°C)	Wt (%) *	Temp. * (°C)	Wt (%) *	Temp. * (°C)	Wt (%)*
1	BUN	380	79.6	430	99	-	-
2	BC1	280	20.2	380	**95.7**	-	-
3	BC2	320	32	380	97.5	-	-
4	BC3	380	25.3	380	98.2	-	-
5	BE1	310	24.4	560	59.5	580	**86.5**
6	BE2	280	23.2	380	98.6	-	-
7	BE3	380	96.1	-	-	-	-

*Temp. -Temperature, wt – Weight

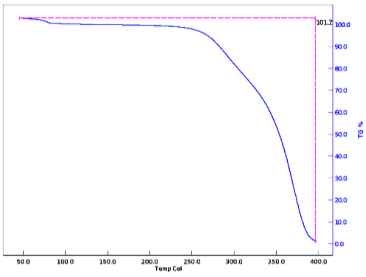


Figure 29a AUN

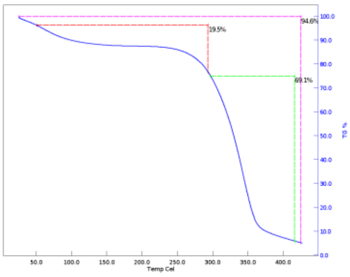


Figure 29b AC1

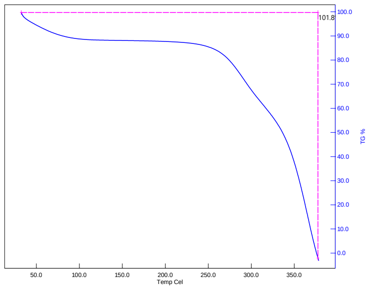


Figure 29e AE1

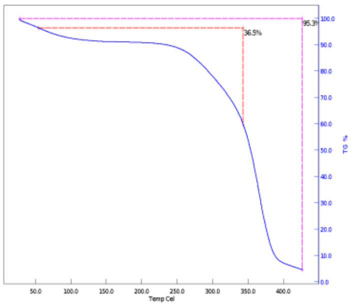


Figure 29c AC2

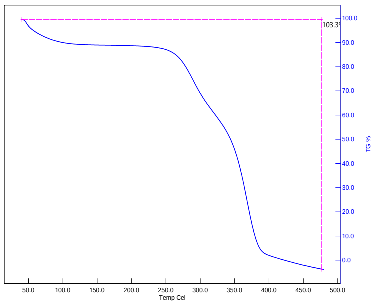


Figure 29f AE2

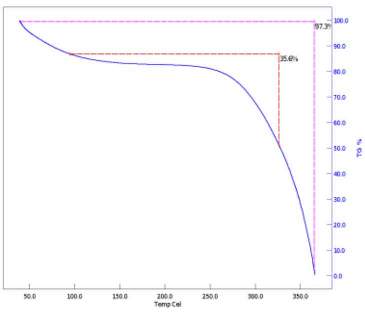


Figure 29d AC3

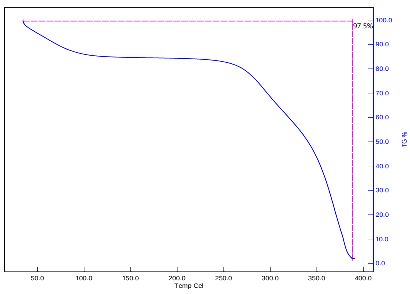


Figure 29g AE3

Figure 29 TGA of *Abutilon indicum* Fibres

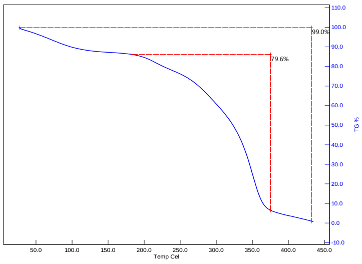


Figure 30a BUN

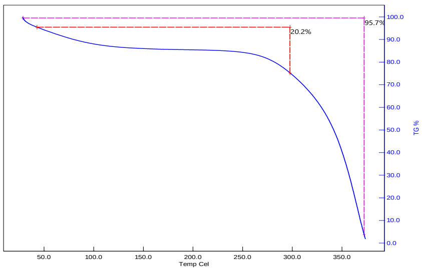


Figure 30b BC1

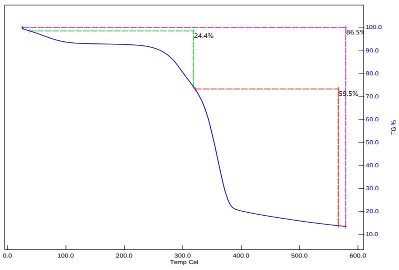


Figure 30e BE1

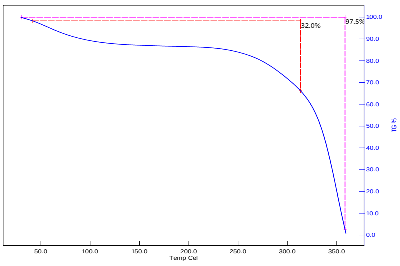


Figure 30c BC2

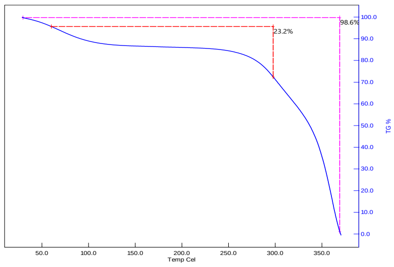


Figure 30f BE2

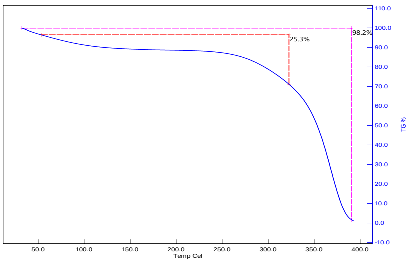


Figure 30d BC3

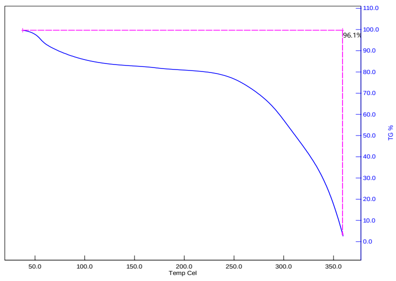


Figure 30g BE3

Figure 30 TGA of *Agave americana* Fibres

From the Table XX and Figure 30a–30g, it is clear that the sample BUN showed two stage degradation at temperatures of 380°C and 430°C with weight loss of 79.6 per cent and 99 per cent respectively. Among the chemical treated fibre samples, the maximum decomposition was noted in sample BC3 with a weight loss of 98.2 per cent at 380°C followed by sample BC2 with 97.5 per cent and sample BC1 with 95.7 per cent at 380°C temperature. Among the enzyme treated samples, BE3 underwent only one stage of decomposition with 96.1 per cent weight loss at 380°C. The maximum degradation was observed in sample BE2, with a weight loss of 98.6 per cent at 380^oC. The sample BE1 underwent three stages of degradation, with an 86.5 percentage at 580^oC. The sample BE1 withstand high temperature with least degradation on enzymatic treatment. On alkali treatment also *Agave americana* fibre showed least degradation. These may be due to the reason that the cell wall has not been removed completely from the fibre structure. And the changes that occurred in the chemical constituents by various treatments (Abdullah et al., 2018). The decomposition of the untreated fibres was noted to be 99.9 per cent at 430^oC. Hence, it could be concluded that the chemical treated fibre sample BC1 showed the highest thermal stability (95.7 per cent) at 380^oC among the other chemically treated fibre samples. The fibre sample BE1 showed the highest thermal stability, with a minimum weight loss of 86.5 per cent even at a very high temperature of 580^oC. The treatments by alkali and cellulase on *Agave americana* fibres have improved the thermal stability.

4.2.6.3 Thermogravimetric Analysis of *Areca catechu* Fibres

The results obtained from the thermogravimetric analysis of untreated and treated *Areca catechu* fibres are presented in Table XXI and (Figures 31a-31g).

Table XXI
TGA of *Areca catechu* Fibres

S.No	Fibre Sample	Stage 1		Stage 2		Final Stage	
		Temp. * (^OC)	Wt (%) *	Temp. * (^OC)	Wt (%) *	Temp. * (^OC)	Wt (%) *
1	CUN	480	104.9	-	-	-	-
2	CC1	280	17.9	480	69.3	480	**91.0**
3	CC2	380	97.1	-	-	-	-
4	CC3	320	22.6	480	101.8	-	-
5	CE1	380	97.8	-	-	-	-
6	CE2	310	26.2	480	103.1	-	-
7	CE3	390	98.8	-	-	-	-

*Temp. -Temperature, wt – Weight

From Table XXI, it is clear that the sample CUN underwent only one stage of decomposition, with 104.9 per cent at 480^OC depicting the lesser thermal stability in the sample. Among the chemically treated samples, the sample CC1 underwent three stages of decomposition with 91 per cent at 480^{O}C whereas the sample CC3 underwent two stages of decomposition with 101.8 per cent decomposition at 480^{O}C and sample CC2 with 97.1 per cent weight loss at 380^{O}C.

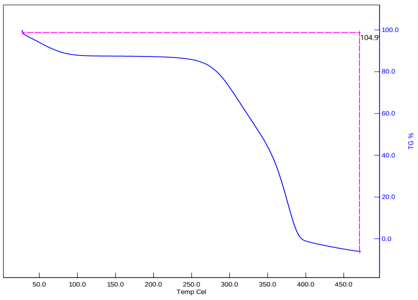


Figure 31a CUN

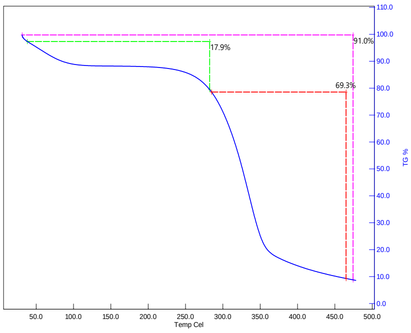


Figure 31b CC1

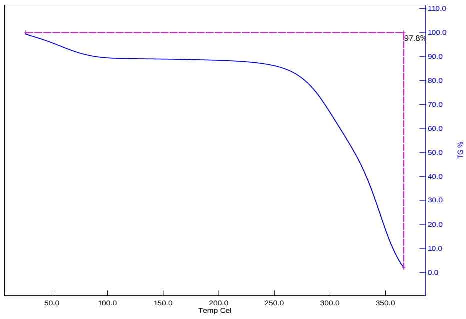


Figure 31e CE1

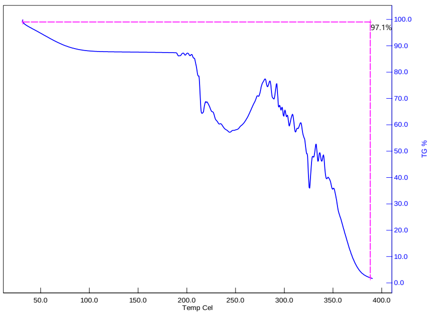


Figure 31c CC2

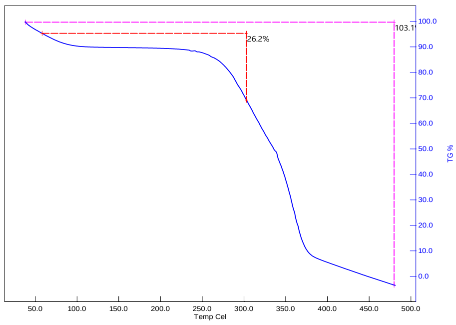


Figure 31f CE2

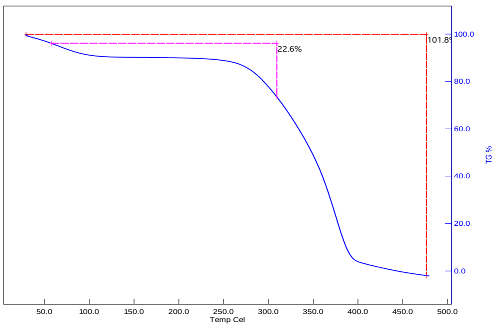


Figure 31d CC3

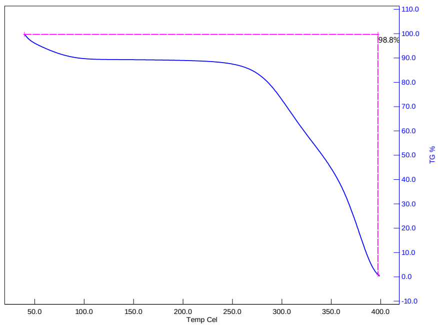


Figure 31g CE3

Figure 31 TGA of *Areca catechu* Fibres

Among enzyme treated samples, sample CE2 showed two stage decomposition with 103.1 per cent decomposition at 480^{O}C and sample CE3 with 98.8 per cent decomposition at 390^{O}C and sample CE1 with 97.8 per cent weight loss at 380^{o}C. Hence, it could be concluded that the highest thermal stability was observed in sample CC1 among the chemical treated samples, as the weight loss was minimum at high temperatures. This thermal stability of the alkali treated *Areca catechu* fibers will be an advantage in future studies when incorporated into composite making**.**

4.2.7 Scanning Electron Microscopic Appearance (SEM)

The images obtained from the Scanning electron microscope and pertinent interpretations are presented under the following heads.

4.2.7.1 SEM Appearance of *Abutilon indicum* Fibres

The SEM study of untreated and treated *Abutilon indicum* fibres are presented in (Plates 13a-13g)

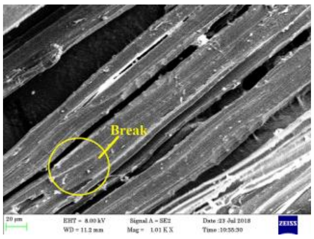


Plate 13a AUN

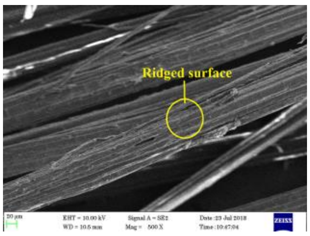


Plate 13b AC1

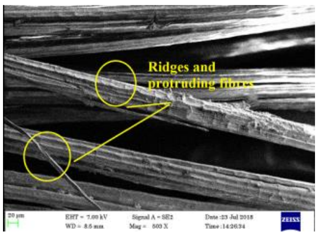


Plate 13e AE1

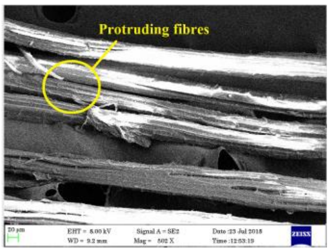


Plate 13c AC2

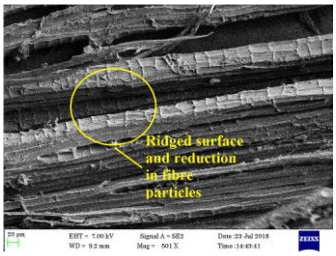


Plate 13f AE2

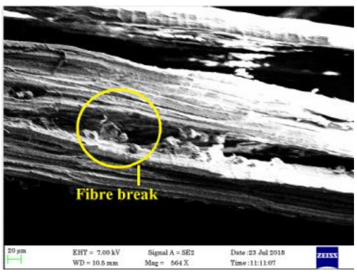


Plate 13d AC3
Chemical treatment

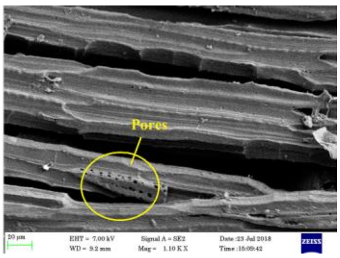


Plate 13g AE3
Biological treatment

Plate 13 SEM Appearance of *Abutilon indicum* Fibres

From Plates 13a–13g, it is obvious that the sample AUN exhibited fibre bundles with breaks on the surface. The sample AC1 exhibited a ridged and clear fibre surface. Protruding fibre and breaks were noted in sample AC2. The sample AC3 exhibited fibre breakage and gaps. The sample AE1 showed slight ridges and protruding fibres on the sides of the fibres. The sample AE2 exhibited more ridges on the surface, and there was a reduction in adhering fibre particles. Some fibre particles adhering to the surface were also observed. The sample AE3 showed a smoother surface than the sample AUN, and pores were observed in one region. Hence, it could be concluded that the surface of the fibres turned rougher due to the presence of ridges and breaks, especially in the samples of *Abutilon indicum* fibres treated with pectinase (AE2) and *Abutilon indicum* fibres treated with alkali (AC1). This induced surface roughness would assist in matrix absorption of the fibres leading to better compatibility and enhancing the mechanical properties.

4.2.7.2 SEM appearance of *Agave Americana* Fibres

The images of untreated and treated obtained from the SEM analyses are presented in Plates (14a-14g)

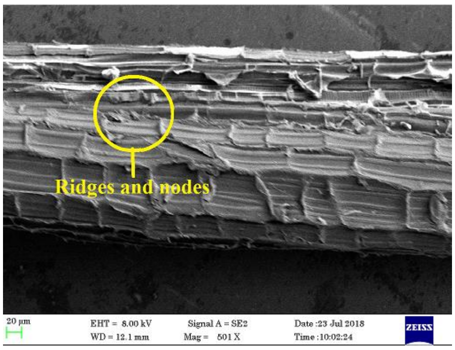


Plate 14a BUN

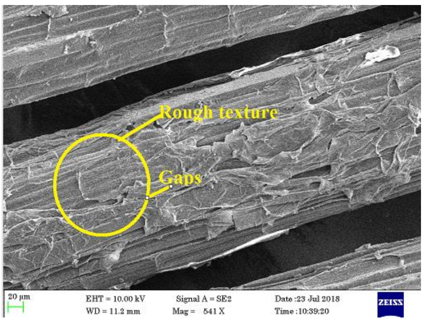


Plate 14b BC1

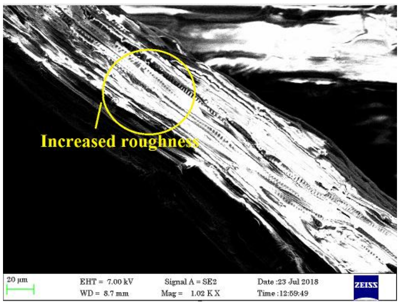


Plate 14e BE1

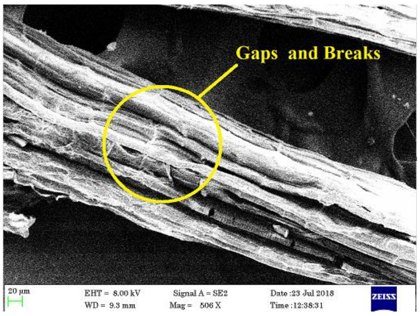


Plate 14c BC2

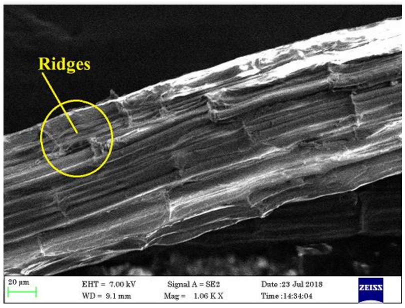


Plate 14f BE2

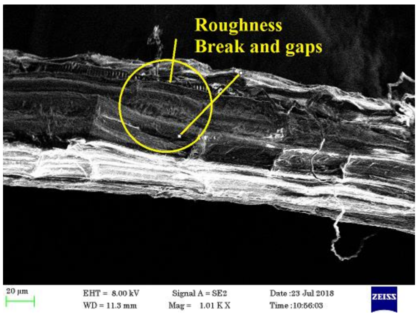


Plate 14d BC3

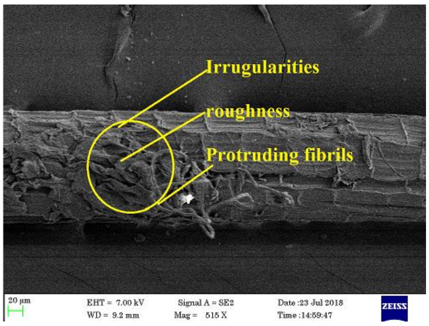


Plate 14g BE3

Chemical treatment **Biological treatment**

Plate 14 SEM Appearance of *Agave americana* Fibres

From Plates 14a–14g, it is expressed that the sample BUN showed ridges and nodes on the surface. The sample BC1 showed a reduction in irregularities, where only small gaps were observed on the surface. The sample BC2 showed reduced ridges with tiny gaps and breaks. A higher degree of roughness was observed with breaks and gaps in sample BC3. The sample BE1 exhibited small gaps in longitude manner. Ridges and irregularities were observed in samples BE2 and BE3, making the surface rougher. Hence, it could be concluded that the chemical treatment showed a high degree of roughness in *Agave americana* fibre which underwent benzoylation. This roughness will help with resin uptake during composite preparation.

4.2.7.3 SEM Appearance of *Areca catechu* Fibres

The images obtained from SEM analyses of untreated and treated *Areca catechu* fibres are expressed in the Plates (15a-15g)

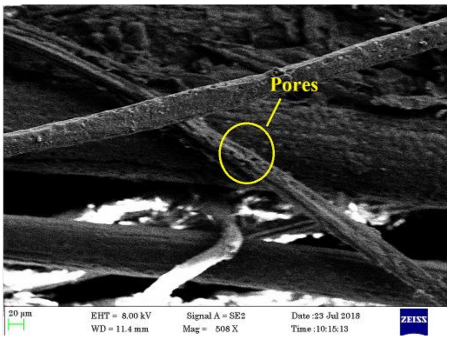


Plate 15a CUN

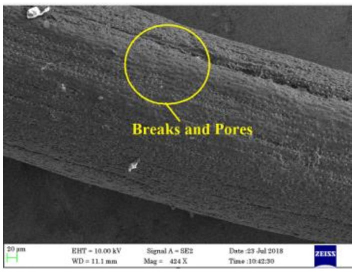


Plate 15b CC1

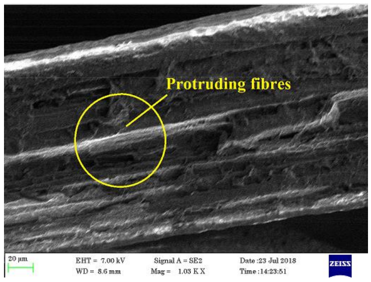


Plate 15e CE1

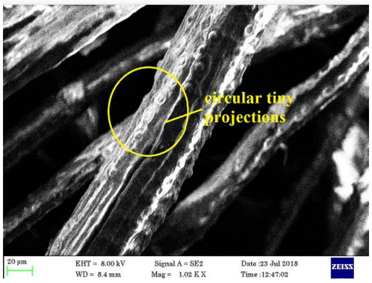


Plate 15c CC2

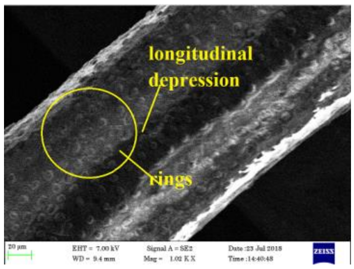


Plate 15f CE2

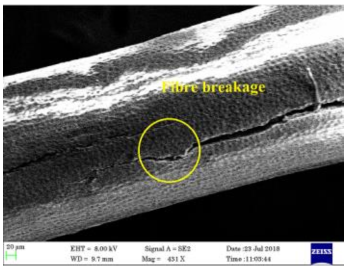


Plate 15d CC3

Chemical treatment

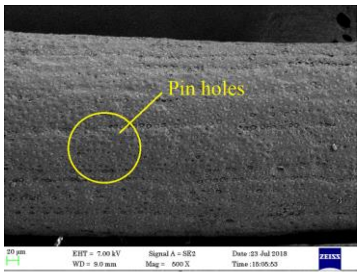


Plate 15g CE3

Biological treatment

Plate 15 SEM Appearance of *Areca catechu* Fibres

From the Plates 15a–15g, it is clear that there were pores noted on the surface of the fibre. The sample CC1 showed many pores and breaks, making the fibre rougher. The sample CC2 showed a rougher surface with protruding fibre on the sides and tiny circular projections. The sample CC3 showed slight roughness due to the protruding effects and fibre breakage. Protruding fibres were noted on the surface of the fibres in sample CE1. The sample CE2 showed a small longitudinal depression and circular rings on the surface. The sample CE3 exhibited a smoother surface with small pores on the fibres. Hence, it could be concluded that the treated samples (CC1) and (CE2) turned rougher than the untreated samples. These fibres with surface modifications, would assist in composite making.

4.2.8 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR was the technique used for analyzing the functional groups present in the untreated and treated fibres. So FTIR was done for all fibre samples to obtain the stretching peaks and the functional groups present in the samples (Appendix IXa – IXc)

4.2.8.1 FTIR of *Abutilon indicum* Fibres

The FTIR of untreated and treated *Abutilon indicum* fibres is presented in Figures. The presence of functional groups for both untreated and treated fibres obtained from FTIR results is presented in Appendix IXa (Figures 32a -32g)

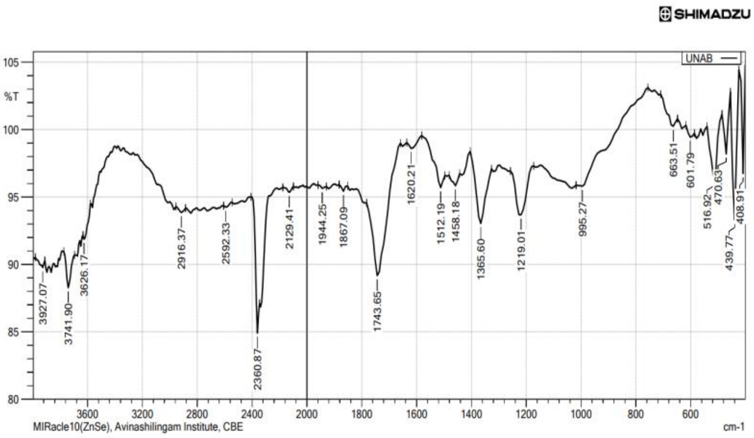


Figure 32a AUN

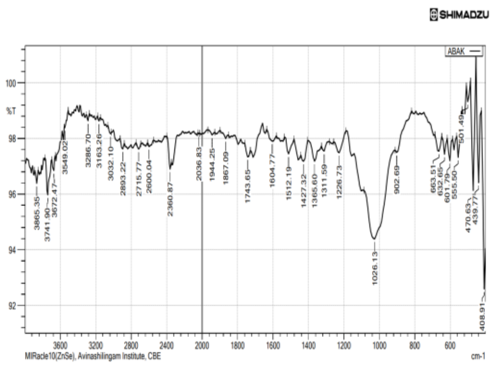


Figure 32b AC1

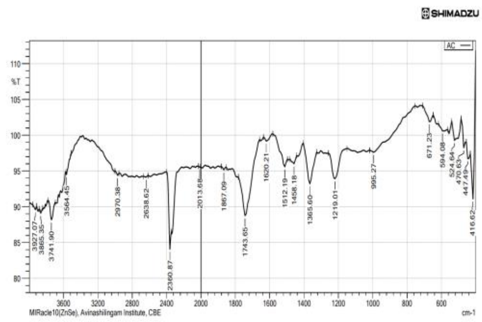


Figure 32e AE1

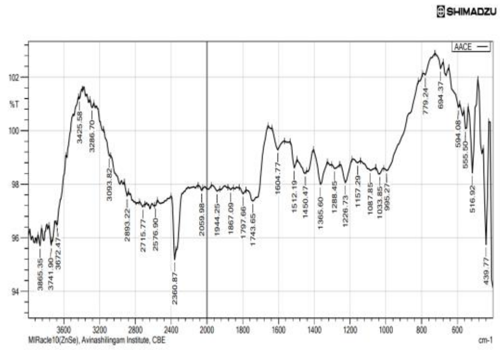


Figure 32c AC2

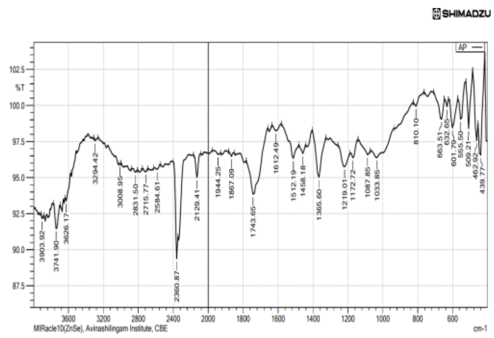


Figure 32f AE2

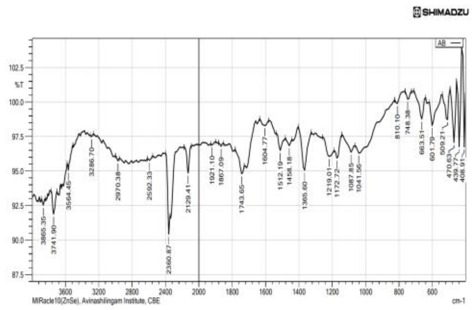


Figure 32d AC3

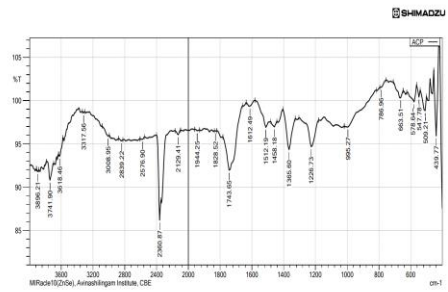


Figure 32g AE3

Chemical Treated Fibres

Enzyme Treated Fibres

Figure 32 FTIR of *Abutilon indicum* Fibres

From the Figure 32, it is vivid that the untreated and treated *Abutilon indicum* fibre samples AUN exhibited peaks in FTIR depicting the presence of Hydroxyl groups, carbon dioxide, and ester functional groups. The same functional groups were observed in the treated fibre samples as well. In addition, Alkene was present in the chemically treated sample AC2. The fluoro compound (C-F stretch) was observed in both the enzyme treated samples, namely AE2 and AE3.

4.2.8.2 FTIR of *Agave americana* Fibres

The FTIR of untreated and treated *Agave americana* fibres is presented in Figures. The presence of functional groups for both untreated and treated fibres obtained from FTIR results is presented in Appendix IXb (Figure 33a – 33g)

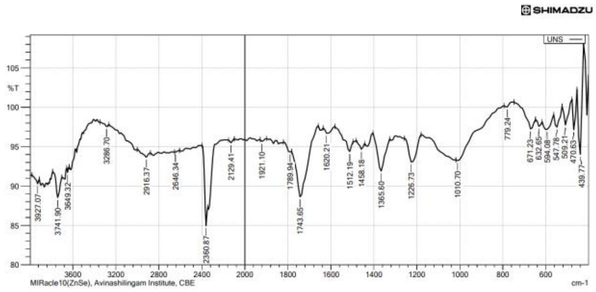


Figure 33a BUN

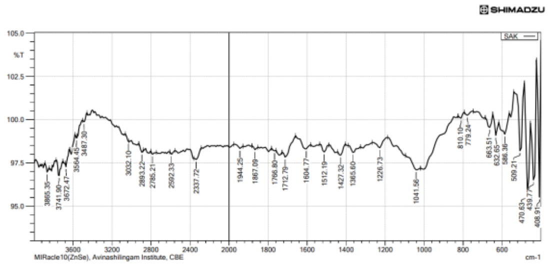


Figure 33b BC1

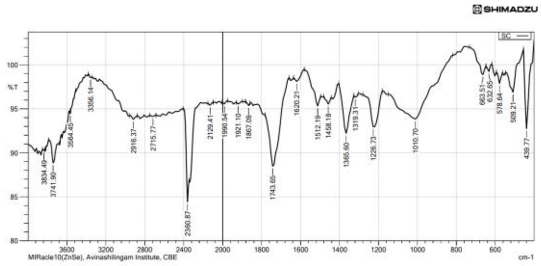


Figure 33e BE1

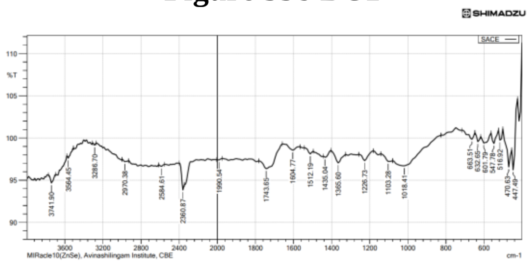


Figure 33c BC2

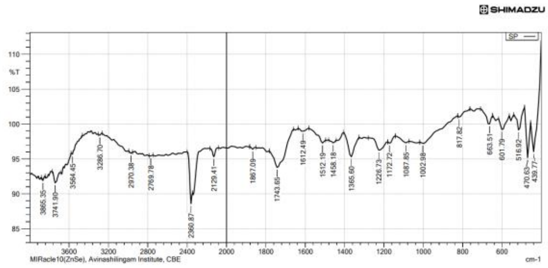


Figure 33f BE2

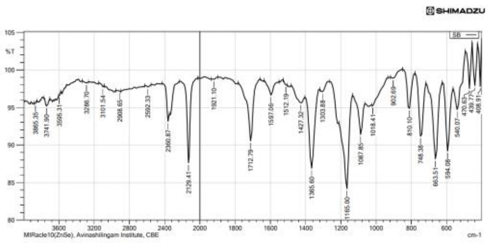


Figure 33d BC3

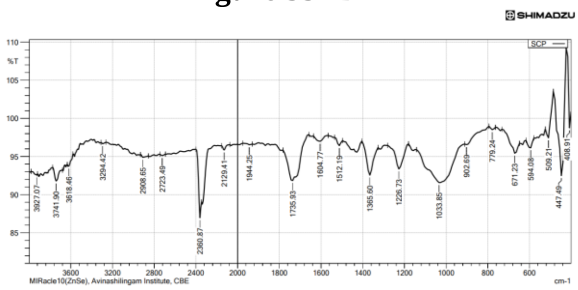


Figure 33g BE3

Chemical Treated Fibres **Enzyme Treated Fibres**

Figure 33 FTIR of *Agave americana* Fibres

The FTIR results of the untreated fibre BUN showed the presence of the Hydroxyl group, carbon dioxide, and esters. The same functional groups were present in the chemical treated samples, whereas in addition, the presence of fluoro compounds was observed in the samples BC2 and BC3. The enzyme treated samples exhibited the same peaks as BUN, but in addition, there was the presence of fluoro compounds (C-F stretch) and nitro compounds (N-O stretch) in sample BE1 (Figure 33a – 33g)

4.2.8.3 FTIR of *Areca catechu* Fibres

The FTIR of untreated and treated *Areca catechu* fibres is presented in the figures. The presence of functional groups for both untreated and treated fibres obtained from FTIR results is presented in Appendix IXc (Figure 34)

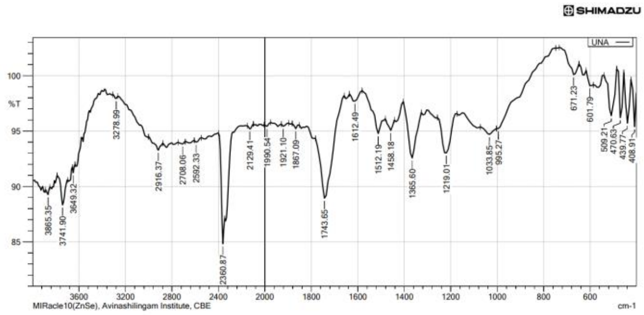


Figure 34a CUN

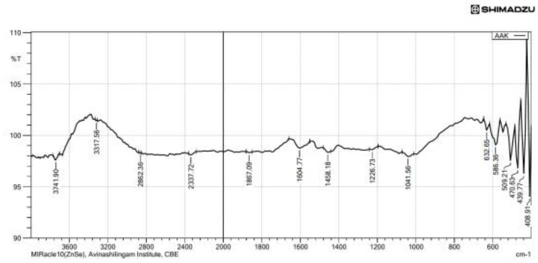


Figure 34b CC1

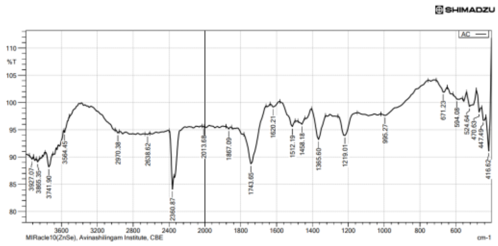


Figure 34e CE1

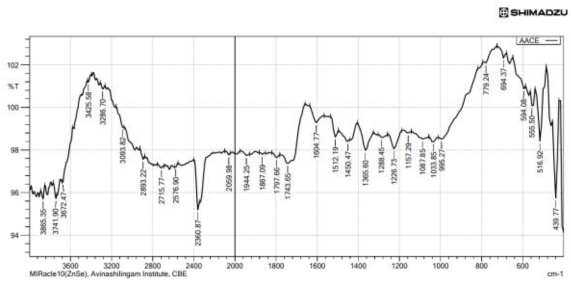


Figure 34c CC2

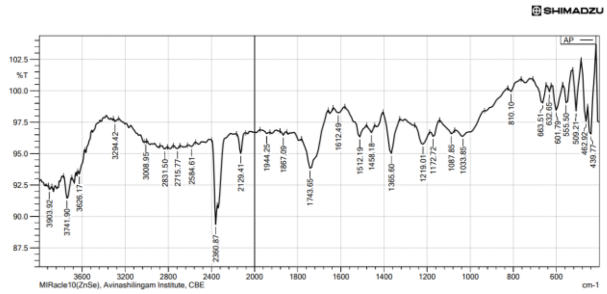


Figure 34f CE2

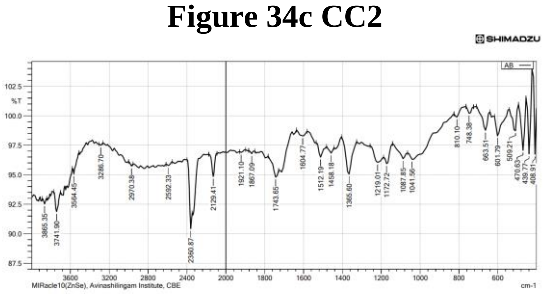


Figure 34d CC3

Chemical Treated Fibres

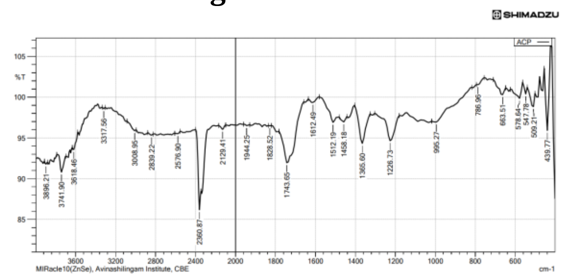


Figure 34g CE3

Enzyme Treated Fibres

Figure 34 FTIR of *Areca catechu* Fibres

From the Figure 34, it is noted that the sample CUN exhibited Hydroxyl groups, Carbon dioxide, and Aromatic compounds. The chemically treated samples, namely CC1, CC2, and CC3, exhibited Alkane and Fluoro compounds. The enzyme treated samples CE1, AP, and CE3 showed the presence of ester (C=O) and fluorocompound (C-F stretch) in sample CE1. The aromatic compound (C-O stretch) was absent in all the treated samples except sample CC1. Hence, it could be concluded that there was a modification in the functional group present in treated fibre samples over the untreated fibres (Figure 34a – 34g)

4.3. Evaluation of Nonwoven Structures

The result obtained from the evaluation of nonwoven structures are expressed under the following heads.

4.3.1 Thickness

The thickness of nonwoven fabric samples is presented in Table XXII

Table XXII

Thickness of Nonwoven Samples

S.No	Samples		Thickness (mm)	F-value	Significant
1	I	UNAS	5.95	49777.545	.000*
2		ENAS	**8.09**		
3		CHAS	7.08		
4	II	UNAAB	5.25		
5		ENAAB	**7.50**		
6		CHAAB	5.09		
7	III	UNABS	4.06		
8		ENABS	7.05		
9		CHABS	**7.30**		
10	IV	UNAABS	5.86		
11		ENAABS	4.35		
12		CHAABS	**6.20**		

***= Significant at 1% level**

From the Table XXII, it is clear that among the I set of samples, the sample ENAS was the thickest with 8.09 mm, followed by the sample CHAS with 7.08 mm, and the sample UNAS with 5.95 mm. Among II set of samples, UNAAB, ENAAB, and CHAAB, the maximum thickness of 7.50 mm was observed in the sample ENAAB, followed by the samples UNAAB and CHAAB with 5.25 mm and 5.09 mm respectively. The sample CHABS was observed to have the maximum thickness of 7.30 mm followed by the samples ENABS and UNABS with 7.05 mm and 4.06 mm respectively. Among the samples UNAABS, ENAABS and CHAABS in the IV set, the thickness of the sample CHAABS was the highest with 6.20 mm followed by the samples UNAABS and ENAABS with 5.86 mm and 4.35 mm respectively. The statistical analysis for thickness among all the samples exhibited 1% level significance. Hence, the nonwoven structures prepared from the treated fibres exhibited more thickness (ENAS) than the untreated fibre utilized in fabric samples.

4.3.2 Weight

The results obtained for weight of nonwoven fabric samples are expressed in Table XXIII

Table XXIII

Weight of Nonwoven Samples

S.No	Samples		Weight (GSM)	F-value	Significant
1	I	UNAS	724	51999.182	.000*
2		ENAS	**922**		
3		CHAS	781		
4	II	UNAAB	603		
5		ENAAB	**641**		
6		CHAAB	508		
7	III	UNABS	567		
8		ENABS	710		
9		CHABS	**826**		
10	IV	UNAABS	662		
11		ENAABS	472		
12		CHAABS	**746**		

***= Significant at 1% level**

From the Table XXIII, it is clear that the weight of the sample ENAS was the highest with 922 GSM in the comparison made between the samples in I set, followed by the sample CHAS with 781 GSM and the sample UNAS (724 GSM). Among the samples in

II set of comparisons, the maximum weight of 641 GSM was observed in the sample ENAAB followed by the samples UNAAB and CHAAB with 603 GSM and 508 GSM, respectively. The sample CHABS was observed to have the maximum weight of 826 GSM followed by the samples ENABS and UNABS with 710 GSM and 567 GSM respectively. Among the IV set of samples, the weight of the sample CHAABS was the highest with 786 GSM followed by the samples UNAABS and ENAABS with 662 GSM and 472 GSM respectively. The statistical analysis exhibited a significant difference at the 1% level. Hence, the nonwoven structures prepared from treated fibres exhibited more weight than the untreated fibre induced nonwoven fabric samples, with the highest weight in sample ENAS.

4.3.3 Bulk Density

The results of bulk density of nonwoven samples are presented in the Table XXIV

Table XXIV

Bulk Density of Nonwoven Samples

S.No	Sample		Bulk Density (g/cc)
1	I	UNAS	**0.121**
2		ENAS	0.113
3		CHAS	0.110
4	II	UNAAB	0.114
5		ENAAB	**0.854**
6		CHAAB	0.101
7	III	UNABS	**0.139**
8		ENABS	0.100
9		CHABS	0.113
10	IV	UNAABS	0.112
11		ENAABS	0.108
12		CHAABS	**0.120**

From the Table XXIV, it is obvious that among the I set of samples, sample UNAS showed the highest bulk density, followed by samples ENAS and CHAS with 0.113 and 0.110 g/cc, respectively. Among the II set of samples, the sample ENAAB showed the highest bulk density of 0.854 g/cc followed by the sample UNAAB (0.114 g/cc). Among the III set of samples, sample UNABS showed the highest density of 0.139 g/cc followed by sample CHABS (0.113 g/cc) Among the IV set, the sample CHAABS showed the highest bulk density of 0.120 g/cc followed by the samples UNAABS (0.112 g/cc) and ENAABS (0.108 grams per cubic centimeter). Hence, the highest bulk density was observed in the sample ENAAB, followed by the samples UNABS, UNAS, and CHAABS. The weight and thickness of the samples ENAAB and CHAABS were the highest with their respective sets of comparisons, which is also reflected in the bulk density.

4.3.4 Breaking Strength and Elongation

The results obtained for these properties of nonwoven samples are given in Table XXV

Table XXV

Breaking Strength and Elongation of Nonwoven Samples

S.No	**Sample**		**Breaking Strength (Kgf)**		**Elongation (%)**		**Time (Seconds)**	
			MD	CD	MD	CD	MD	CD
1	I	UNAS	35.40	34.90	23.50	22.35	27.90	26.82
2		ENAS	36.00	8.40	46.70	30.65	56.04	36.78
3		CHAS	**44.90**	**49.25**	**50.60**	**45.65**	**60.72**	**54.78**
4	II	UNAAB	27.80	3.90	8.05	12.40	9.66	14.88
5		ENAAB	13.30	**9.65**	**31.80**	25.45	**38.16**	30.54
6		CHAAB	**29.25**	6.80	17.87	**55.27**	21.45	**66.33**
7	III	UNABS	34.50	29.20	25.45	32.68	30.54	39.22
8		ENABS	**39.90**	**56.20**	16.92	19.05	20.31	22.86
9		CHABS	29.30	41.00	**34.85**	**34.55**	**41.82**	**41.46**
10	IV	UNAABS	5.90	**30.55**	**29.77**	15.35	**35.73**	18.42
11		ENAABS	26.90	11.40	25.90	20.92	31.08	**50.22**
12		CHAABS	**31.55**	7.55	17.57	**28.05**	21.09	33.66
Breaking Strength (MD) - F-value - 377600.246 **Significant -** .000* (1% level) **Breaking Strength (CD) - F-value -** 275057.506 **Significant -**.000*(1% level)								

The Table XXV reveals that the samples among the I set of sample comparisons UNAS showed 35.40 kgf, breaking force in machine direction, which showed an increase in sample CHAS with 44.90 kgf. Among II set of nonwoven samples, the sample UNAAB showed a 27.80 kgf breaking force, which increased in the sample CHAAB to 29.25 kgf, followed by the sample ENAAB (13.30 kgf). In the III set of comparison samples, the sample ENAABS showed the highest tensile strength of 39.9 kgf followed by the samples UNABS (34.50 kgf) and CHABS (29.30 kgf). In the IV set of samples, the maximum strength was observed in sample CHAABS with 31.55 kgf followed by samples ENAABS (26.90 kgf) and UNAABS (5.90 kgf). In cross-direction, among the I set of samples, the sample CHAS exhibited the highest breaking force of 49.25 kgf followed by the samples UNAS (34.90 kgf) and ENAS (8.40 kgf). In the II set, the sample ENAAB exhibited the highest breaking force of 9.65 kgf followed by the sample CHAAB (6.8 kgf). In the III set, the sample ENABS exhibited the highest breaking force of 56.20 kgf followed by the samples CHABS (41.00 kgf) and UNABS (29.20 kgf). Among the IV set of samples, UNAABS showed the highest strength of 30.55 kgf followed by ENAABS (11.41 kgf) and CHAABS (7.55 kgf). The statistical analysis proved that a level of significance of one per cent was observed in the statistical analysis in both machine and cross directions. Hence, it could be concluded that among all the samples, CHAS showed the highest strength in machine direction. The high strength of the nonwoven structures would result in better mechanical properties when utilized for composite making.

As for the elongation, the sample CHAS exhibited the maximum elongation in machine direction with 50.60 per cent followed by the sample ENAS (46.70 per cent). In the II set of samples, the sample ENAAB exhibited the highest elongation of 31.80 per cent followed by the samples CHAAB and UNAAB with 17.87 and 8.05 percentages respectively. In the III, the highest elongation was exhibited by sample CHABS (34.85 per cent) followed by samples UNABS (25.45 per cent) and (ENABS 16.92 percent). Among the IV set of samples, the sample UNAABS showed the highest elongation of 29.77 per cent followed by the sample ENAABS (25.90 percent). In cross direction, the sample CHAS showed the highest elongation of 45.65 per cent followed by the sample ENAS (30.65 per cent). In the comparison made among the II set of samples, the sample CHAAB showed the highest elongation of 55.27. In the III set of comparisons, the sample CHABS showed the highest elongation of 34.55. And in the IV set of samples, the sample CHAABS showed the highest elongation of 28.05 per cent. The time taken for the break of the samples was the highest in sample CHAS in machine direction (60.72 seconds) and in cross direction (54.78 seconds). The sample CHAAB has taken the highest time in cross direction (66.33 seconds), followed by the sample ENAAB (30.54 seconds). The sample CHABS has taken the maximum time of 41.82 seconds and 41.46 seconds for breaks in machine and cross directions respectively. The sample ENAABS had taken the longest time in the cross direction (50.22 seconds) to break. Hence, it could be concluded that the time taken for a break in machine direction was the highest in sample CHAS and in sample CHAAB in cross direction. The time taken for the break of the sample also implies the strength of the sample as exhibited in ENAABS.

4.3.5 Abrasion Resistance

The results obtained for resistance for abrasion of nonwoven fabrics are presented in Table XXVI (Figure 35)

Table XXVI
Abrasion Resistance of Nonwoven Samples

S.No	Sample		Abrasion Resistance (%)
1	I	UNAS	12.5
2		ENAS	**9.09**
3		CHAS	14.28
4	II	UNAAB	12.5
5		ENAAB	**4.76**
6		CHAAB	23.07
7	III	UNABS	9.09
8		ENABS	14.28
9		CHABS	**4.34**
10	IV	UNAABS	21.87
11		ENAABS	**9.09**
12		CHAABS	14.28

From Table XXVI, it is obvious that loss percent was the minimum in sample ENAS with 9.09 per cent whereas the samples UNAS and CHAS showed 12.5 and 14.28 percentages respectively. Among the II set of samples, the sample ENAAB showed the minimum loss with 4.76 per cent proving highest abrasion resistance whereas the samples UNAAB and CHAAB showed 12.5 and 23.07 percentages respectively. Among the III set of samples, the sample CHABS showed the minimum loss with 4.34 per cent and among the other samples. In the IV set the least loss was noted in sample ENAABS with 9.09 per cent depicting least abrasion resistance.

Hence, it could be concluded that the samples ENAS, ENAAB, CHABS and ENAABS showed the best results for abrasion resistance when compared with their respective sets of samples.

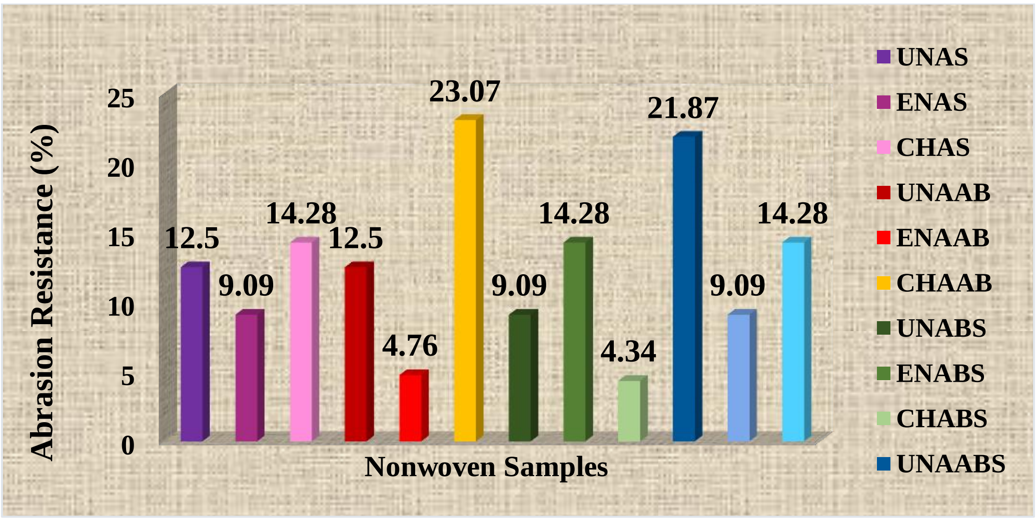


Figure 35 Abrasion Resistance

4.3.6 Moisture Regain

The results obtained for moisture regain in nonwoven samples are presented in Table XXVII.

Table XXVII

Moisture Regain of Nonwoven Samples

S.No	Samples		Moisture regain (%)
1	I	UNAS	**6.80**
2		ENAS	4.04
3		CHAS	6.04
4	II	UNAAB	**6.10**
5		ENAAB	4.83
6		CHAAB	5.20
7	III	UNABS	2.04
8		ENABS	**6.16**
9		CHABS	2.04
10	IV	UNAABS	4.71
11		ENAABS	5.14
12		CHAABS	**6.07**

The Table XXVII reveals that in the I set of samples, UNAS showed the highest moisture regain, followed by CHAS and ENAS with 6.04 and 4.04 percentages, respectively. Among II set of samples, the highest moisture regain was observed in sample UNAAB (6.1 per cent) followed by the samples CHAAB (5.20 per cent) and ENAAB (4.83 per cent). Among the III set of samples, the highest moisture regain was noted in the sample ENABS (6.16 per cent) followed by both the samples UNABS and CHABS with 2.04 per cent. Among the IV set of samples, the maximum regain was noted in the sample CHAABS (6.07 per cent) followed by the sample ENAABS (5.14 percent). The samples UNABS and CHABS showed least moisture regain among other nonwoven samples. The reason may be due to the combination of the untreated or treated fibres with minimum moisture regain individually. This has been explained under 4.2.4. The sample UNABS is a constituent of untreated *Abutilon indicum* and untreated *Agave americana* fibres with 1.41 per cent and 0.60 per cent of moisture regain respectively which also showed less moisture regain individually. In case of sample CHABS the fibre samples namely *Abutilon indicum* and *Agave americana* which underwent the chemical treatments namely alkalization and benzoylation respectively were combined. These two treated fibres showed 1.01 per cent and 1.83 per cent of moisture regain individually. Hence, it could be concluded that the samples UNABS and CHABS showed the least moisture regain among the other samples. This may be due to the fibre present in the nonwoven material and the interlocking compactness of the fibres. This would also aid in composite fabrication.

4.3.7 Air Permeability

The result obtained for air permeability of nonwoven structure fibre samples are presented in Table XXVIII (Appendix X)

Table XXVIII

Air Permeability of Nonwoven Samples

S.No	Samples		$cc/s/cm^2$	F-value	Significance
1	I	UNAS	88.33	155674.818	.000*
2		ENAS	89.44		
3		CHAS	90.56		
4	II	UNAAB	88.33		
5		ENAAB	92.22		
6		CHAAB	92.78		
7	III	UNABS	88.89		
8		ENABS	92.78		
9		CHABS	**87.22**		
10	IV	UNAABS	85.56		
11		ENAABS	87.78		
12		CHAABS	88.89		

***= Significance - 1% level**

The Table XXVIII reveals that the sample CHAS showed the highest air permeability of 90.56 cc/s/cm2, followed by the samples ENAS and UNAS with 89.44 $cc/s/cm^2$ and 88.33 $cc/s/cm^2$ respectively, among the I set of samples. In the II set, the sample CHAAB showed the highest air permeability of 92.78 $cc/s/cm^2$ followed by the sample ENAAB (92.22 $cc/s/cm^2$). Among the III set, the sample ENABS showed the highest air permeability of 92.78 $cc/s/cm^2$ followed by the samples UNABS (88.89 $cc/s/cm^2$) and CHABS (87.22 $cc/s/cm^2$). Among the IV set of samples, the highest air permeability was observed in the sample CHAABS (88.89 $cc/s/cm^2$) followed by the samples ENAABS (87.78 $cc/s/cm^2$) and UNAABS (85.56 $cc/s/cm^2$). The air permeability of fabric decreases with an increase in mass per unit area (Cincik and Koc 2011), which is the case for samples ENAS, ENAABS and CHABS. The level of significance was 1% as per the statistical analysis. Hence, among all the samples, the air permeability was the lowest in the sample UNAABS, followed by the sample CHABS, and highest in the two samples CHAAB and ENABS. Among the treated samples in the IV set, it was the least in sample ENAABS.

4.3.8 Absorbency Tests

The results obtained for absorbency tests of nonwoven samples are expressed under the following headings.

4.3.8.1 Water Absorption

The result obtained for water absorption behaviour of nonwoven fabric samples are presented in Table XXIX (Figure 36)

Table XXIX
Water Absorbency of Nonwoven Samples

S.No	Samples		Water absorption after 24hrs (%)	F-value	Sig
1	I	UNAS	**420.77**	137973479.4	.000*
2		ENAS	398.33		
3		CHAS	351.89		
4	II	UNAAB	**486.76**		
5		ENAAB	430.15		
6		CHAAB	360.54		
7	III	UNABS	**463.33**		
8		ENABS	269.56		
9		CHABS	347.91		
10	IV	UNAABS	**367.56**		
11		ENAABS	354.54		
12		CHAABS	267.40		

***= Significance - 1% level**

From the Table XXIX, it is clear that the sample UNAS showed the highest water absorption after twenty-four hours (420.77 per cent) followed by the samples ENAS (398.33 per cent) and CHAS (351.89 per cent) in the I set. In the II set of samples, UNAAB showed the highest absorbency (486.76 per cent) followed by the samples ENAAB and CHAAB with 430.15 per cent and 360.54 per cent respectively. In the III set of samples, the sample UNABS showed the highest water absorption of 463.33 per cent followed by the samples CHABS (347.91 per cent) and ENABS (269.56 per cent). Among the IV sets, the sample UNAABS showed the maximum water absorbency (367.56 per cent) followed by the samples ENAABS (354.54 per cent) and CHAABS (267.40 percent). The statistical analysis for water absorption among all the samples showed that there was a significant difference at the 1% level between the nonwoven samples due to variation in the fibre blends. Hence, it could be concluded that all the treated samples showed lesser absorbency, and the least was noted in the samples CHAABS followed by the ENABS.

4.3.8.2 Sinking

Findings of the sinking test of Nonwoven fabric samples are presented in Table XXX (Figure 37)

Table XXX

Sinking Test of Nonwoven Samples

S.No	Samples		Sinking (Seconds)
1	I	UNAS	**584**
2		ENAS	566
3		CHAS	491
4	II	UNAAB	335
5		ENAAB	**577**
6		CHAAB	240
7	III	UNABS	445
8		ENABS	**582**
9		CHABS	384
10	IV	UNAABS	578
11		ENAABS	**629**
12		CHAABS	568

Table XXX reveals it is clear that all the nonwoven samples crossed sixty seconds depicting poor absorbency of the samples towards water. The sample UNAS had taken the maximum time of 584 seconds which was noted to have reduced in the samples ENAS (566 seconds) and CHAS (491 seconds). Among the II set of samples, the maximum time taken for sinking was by sample ENAAB (577 seconds) followed by the samples UNAAB (335 seconds) and CHAAB (240 seconds). In the III set of comparison of samples, the longest time taken for sinking was by the sample ENABS (582 seconds) followed by the samples UNABS (445 seconds) and CHABS (384 seconds). In the IV set of samples, the sample ENAABS showed the highest sinking time of 629 seconds followed by the samples UNAABS (578 seconds) and CHAABS (568 seconds). Hence it could be concluded that all the chemical treated samples CHAS, CHAAB, CHABS and CHAABS had taken minimum sinking time of which the least was shown by the sample CHAAB depicting highest absorbency. The highest time was taken by the sample ENAABS depicting poor absorbency.

4.3.8.3 Wicking

The wicking test results of nonwoven fabric samples are presented in Table XXXI (Figure 38)

Table XXXI

Wicking Test of Nonwoven Samples

S.No	Samples		Wicking (cm)
1	I	UNAS	1.5
2		ENAS	1.7
3		CHAS	**1.8**
4	II	UNAAB	1.7
5		ENAAB	1.6
6		CHAAB	**1.9**
7	III	UNABS	1.7
8		ENABS	1.6
9		CHABS	**1.8**
10	IV	UNAABS	1.7
11		ENAABS	1.6
12		CHAABS	**1.9**

From the Table XXXI, it is clear that the wicking was to the maximum height in sample CHAS with 1.8 cm, followed by samples ENAS and UNAS with 1.7 cm and 1.5 cm respectively. Among the II set of comparisons, the sample CHAAB showed a maximum height of 1.9 cm followed by the samples UNAAB (1.7 cm) and ENAAB (1.6 cm). Among the III set of samples, the sample CHABS showed the highest absorbency of capillary rise with 1.8cm height, followed by the samples UNABS (1.7 cm) and ENABS (1.6 cm). In the IV set of samples, the sample CHAABS showed the highest wicking of 1.9 cm followed by the samples UNAABS (1.7 cm) and ENAABS (1.6 cm). Wicking is the spontaneous transfer of a liquid in to a porous structure caused by capillary forces (Mallick and Sekhar 2022). It enables the characterization of textile structures, their porosity resulting from the capillaries formed by the inter filament spaces in which the liquid flows (Liu. 2008). Hence, it could be concluded that the chemically treated fibre used in nonwoven samples showed the highest capillary movement of water in the samples, indicating more absorbency. It was noted to be the highest in the samples CHAAB and CHAABS with their respective comparisons. The least amount of wicking was exhibited by the sample UNAS. The good absorbency of the nonwoven fabric samples might assist in the uptake of resin while preparing composites.

4.3.8.4 Spray Test

The results of spray test for nonwoven fabrics are expressed in the Table XXXII

Table XXXII

Spray Test of Nonwoven Samples

S.No	Sample		Standard (Rating)
1	I	UNAS	70
2		ENAS	70
3		CHAS	50
4	II	UNAAB	70
5		ENAAB	70
6		CHAAB	70
7	III	UNABS	50
8		ENABS	70
9		CHABS	50
10	IV	UNAABS	70
11		ENAABS	70
12		CHAABS	50

From the Table XXXII, it is clear that the rating as per the standard chart was noted to be 70, depicting partial wetting of the specimen beyond the spray points, for all the nonwoven samples except the samples CHAS, UNABS, CHABS, and CHAABS, which showed a rating of 50, depicting complete wetting of the entire face beyond the spray points. Hence, it could be concluded from the spray test that the highest absorbency on spraying was only fifty ratings in a few samples among all the nonwoven fabric samples.

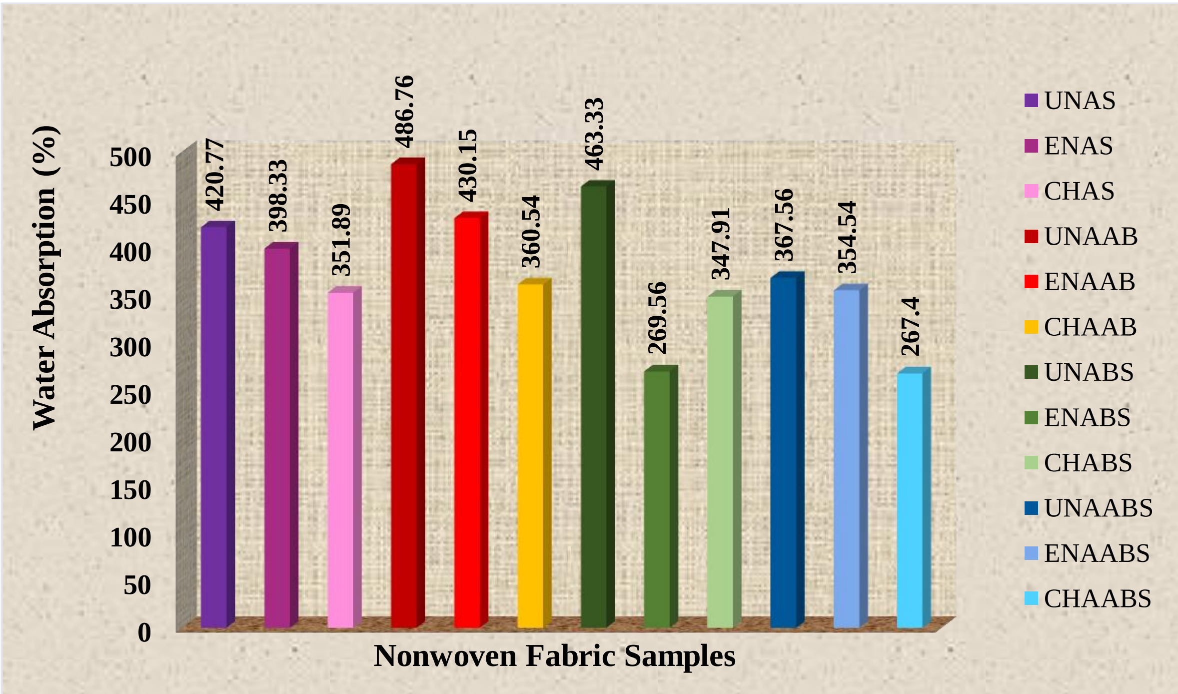


Figure 36 Water Absorption of Nonwoven Fabric Samples

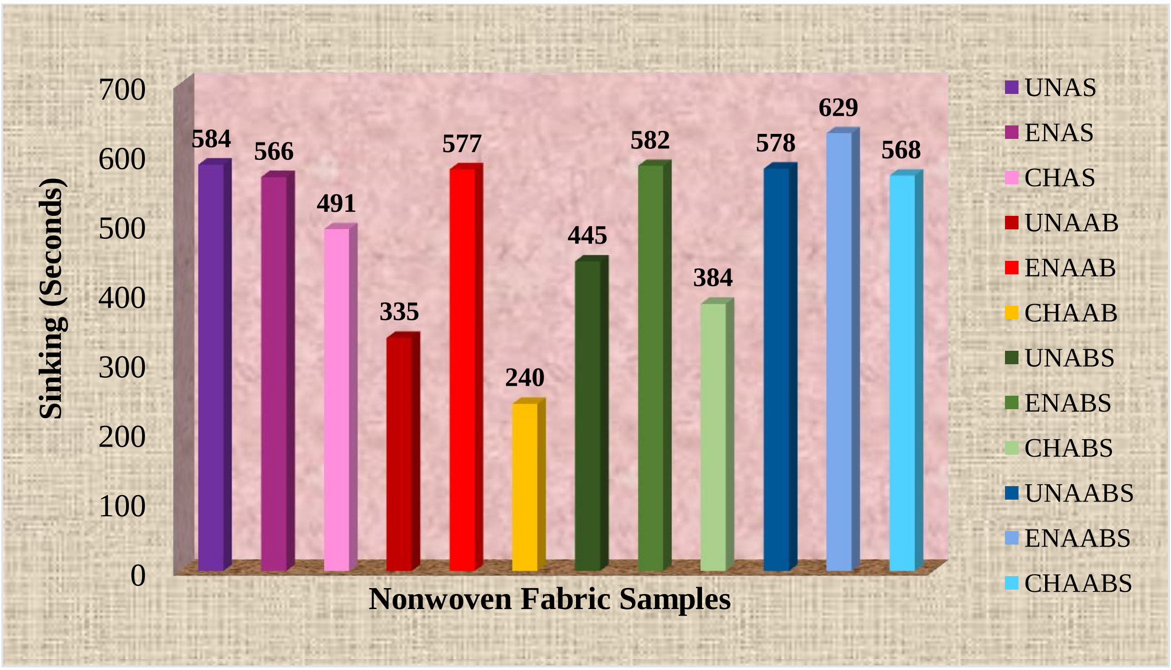


Figure 37 Sinking Test of Nonwoven Fabric Samples

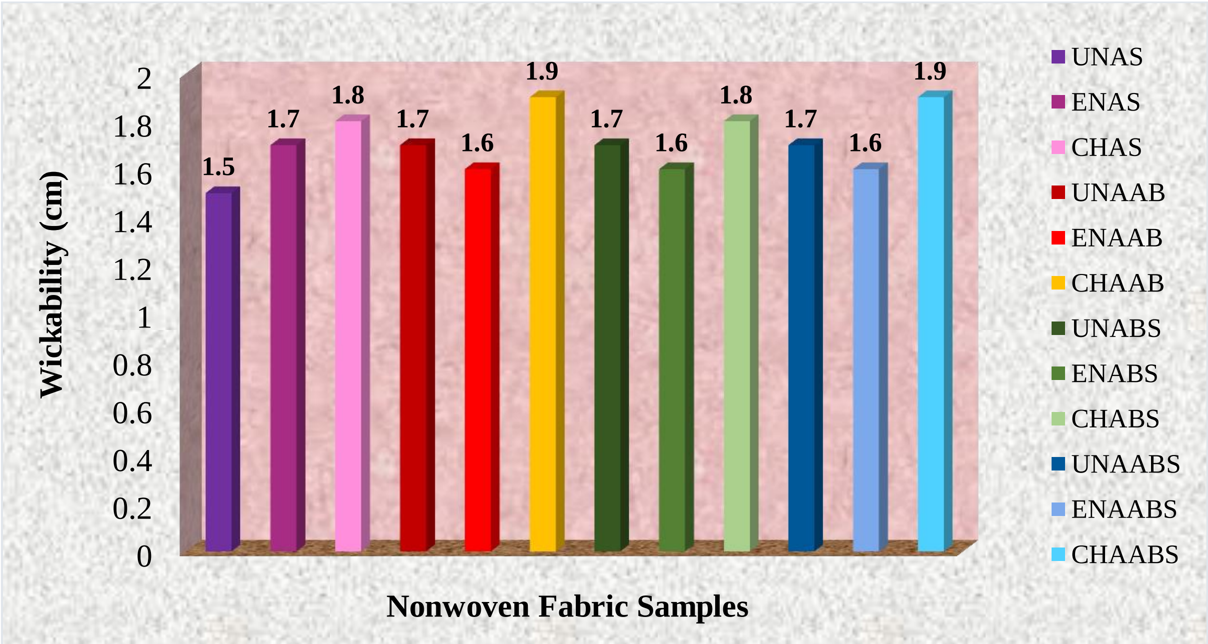


Figure 38 Wickability of Nonwoven Fabric Samples

4.3.9 Thermal Conductivity

The thermal behaviour of the nonwoven samples analysed by thermal conductivity is presented in Table XXXIII

Table XXXIII

Thermal Conductivity of Nonwoven Samples

S.No	Samples		Thermal Conductivity(W/mk)
1	I	UNAS	0.56
2		ENAS	**0.49**
3		CHAS	0.51
4	II	UNAAB	**0.43**
5		ENAAB	0.45
6		CHAAB	0.47
7	III	UNABS	0.59
8		ENABS	0.55
9		CHABS	**0.48**
10	IV	UNAABS	**0.38**
11		ENAABS	0.40
12		CHAABS	0.45

The Table XXXIII reveals that in the I set of samples, the thermal conductivity was the lowest in the sample ENAS with 0.49 W/mk. Among the II set of samples, it was least in sample UNAAB (0.43 W/mk), followed by sample ENAAB (0.45 W/mk), and in the III set, the least thermal conductivity was noted in the sample CHABS and in the IV set in UNAABS. Lower air permeability in the sample shows better thermal insulation (Ilango 2018). This is proved in the comparisons made in the II, III, and IV sets of samples, where the lowest air permeability in samples UNAAB, CHABS and UNAABS showed the highest thermal resistance, as thermal conductivity is inversely proportional to thermal resistance. Hence, it could be concluded that the samples CHAS, UNAAB, CHABS and UNAABS had the lowest thermal conductivity among each set of comparisons.

4.3.10 Thermogravimetric Analysis (TGA)

The Thermogravimetric results for the Nonwoven Samples are presented in the Table XXXIV (Figures 39 and 40)

Table XXXIV

TGA of Nonwoven Samples

S.No	Fibre Sample		Stages of Degradation					
			1st		2nd		3rd	
			Temp. (^{O}C)	Wt. (%)	Temp. (^{O}C)	Wt. (%)	Temp. (^{O}C)	Wt. (%)
1	UNAS	Set I	340	26.8	520	47.4	980	92.2
2	ENAS		480	79.1	980	90.2	-	-
3	CHAS		480	74.5	980	**86.8**	-	-
4	UNAAB	Set II	350	20.8	980	55.2	980	92.0
5	ENAAB		490	78.6	980	92.6	-	-
6	CHAAB		360	45.9	480	**78.0**	-	-
7	UNABS	Set III	490	78.6	970	90.5	-	-
8	ENABS		490	82.1	980	92.1	-	-
9	CHABS		320	27.1	590	47.7	970	**87.6**
10	UNAABS	Set IV	510	82.9	970	93.9	-	-
11	ENAABS		430	98.0	990	116.2	-	-
12	CHAABS		350	43.5	540	24.7	970	**84.7**

From the Table XXXIV, it is clear that among the I set of nonwoven fabric sample structures, the thermal degradation occurred at three stages in the untreated sample UNAS with maximum temperature of 980^{o}C with 92.2 per cent weight loss, whereas the sample ENAS showed two stages of degradation with a maximum temperature of 980^{o}C and a weight loss of 90.2 per cent followed by the sample CHAS, which degraded to 86.8 percent at 980°C. Among II set of samples, the untreated sample UNAAB had three stages of thermal degradation, followed by sample CHAAB, which showed two stages of degradation with a minimum weight loss of 780 per cent at 480 °C. The sample CHABS in the III set of samples exhibited a decomposition at the third stage of 87.6 per cent at 970°C followed by sample ENABS with a degradation of 92.1 per cent at 980°C and sample UNABS with a 90.5 per cent degradation at 970°C

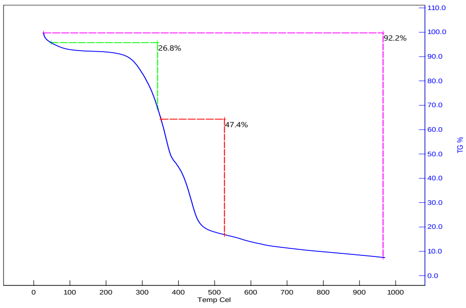


Figure 39a UNAS

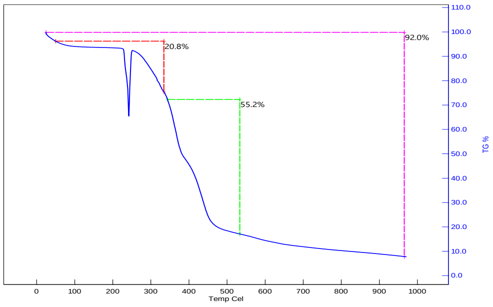


Figure39d UNAAB

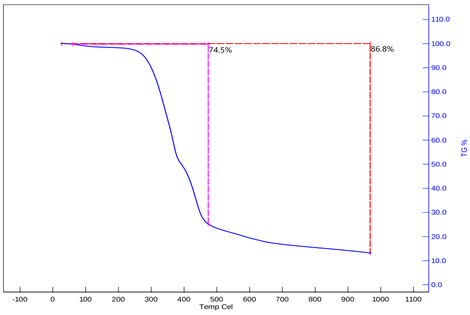


Figure 39b CHAS

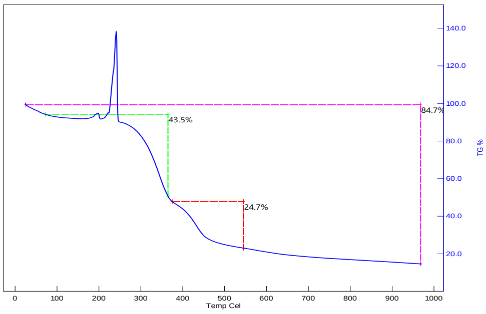


Figure 39e CHAAB

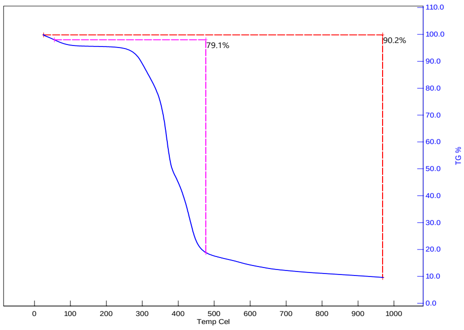


Figure 39c ENAS

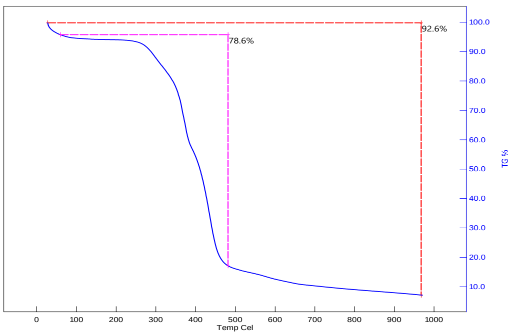


Figure 39f ENAAB

Figure 39 TGA of Nonwoven Samples (Set I and Set II)

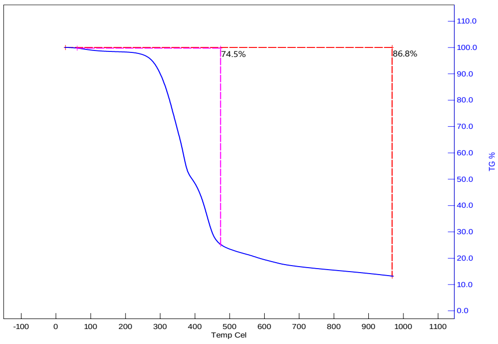


Figure 40a UNABS

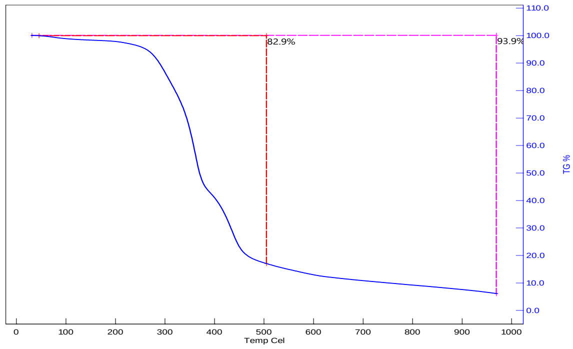


Figure 40d UNAABS

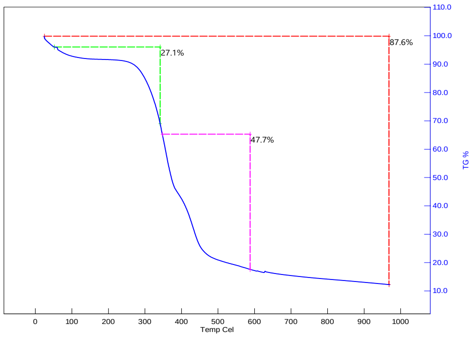


Figure 40b CHABS

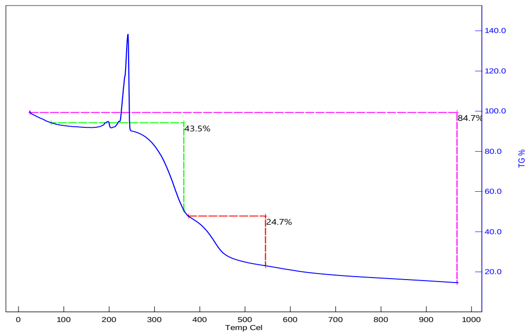


Figure 40e CHAABS

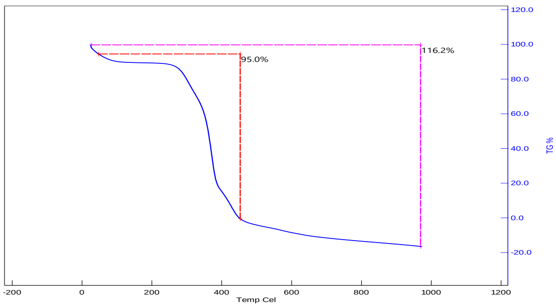


Figure 40c ENABS

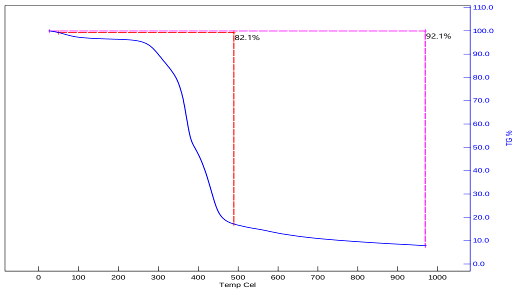


Figure 40f ENAABS

Figure 40 TGA of Nonwoven Samples (Set III and Set IV)

Among the IV set of samples, the chemically treated fabric sample (CHAABS) degraded at the third stage by 84.7 per cent at 970 ^{o}C whereas the enzyme treated fabric sample underwent a weight loss of 116.0 percent at 990^{o}C followed by the sample UNAABS with a weight loss of 93.9 per cent at 970^{o}C. Hence, the sample CHAABS showed the least weight loss among all the samples. The thermal stability with minimum weight loss at high temperatures among the respective sets of comparison in samples CHAS, CHAAB, CHABS and CHAABS may help in maintaining the thermal stability even after resin coating.

4.3.11 Scanning Electron Microscopic Appearance (SEM)

The SEM appearance of the nonwoven structures is presented in Plate 16

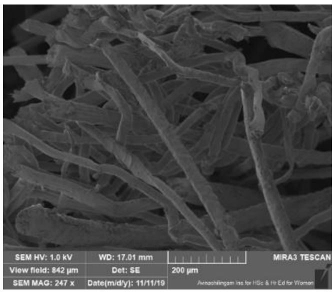


Plate 16a UNAS

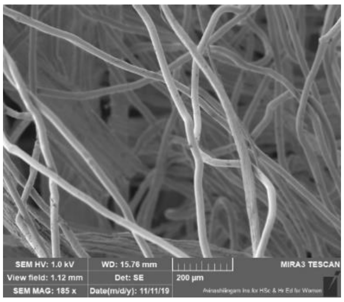


Plate 16b CHAS

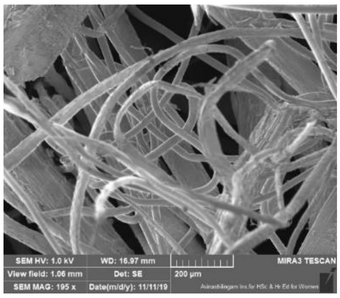


Plate 16c ENAS

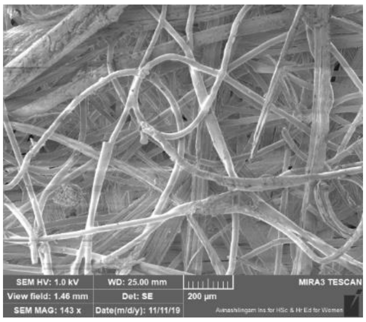


Plate 16d UNAAB

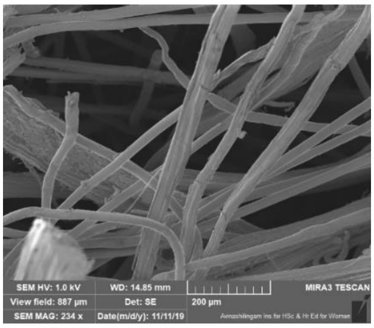


Plate 16e CHAAB

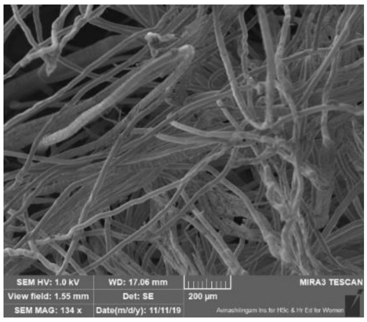


Plate 16f ENAAB

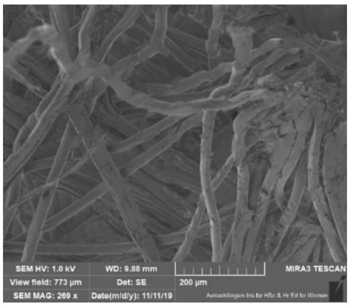


Plate 16g UNABS

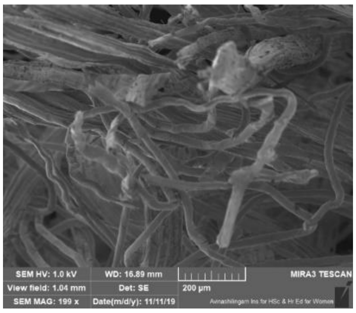


Plate 16h CHABS

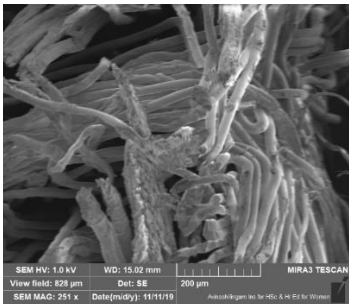


Plate 16I ENABS

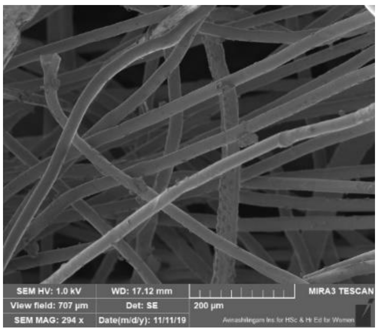


Plate 16j UNAABS

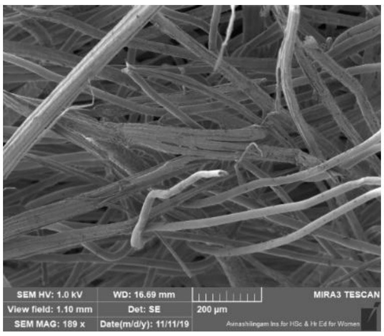


Plate 16k CHAABS

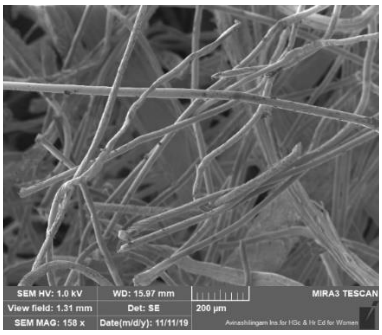


Plate 16l ENAABS

Plate 16 SEM Appearance of Nonwoven Samples

The SEM appearance of the nonwoven fabric sample UNAS exhibited the interlocking of the fibres which is vivid in the samples CHAS and ENAS. The entanglement is very high as per the SEM view in the sample ENAS, which has improved the compactness and, in turn, the thickness which may be the reason for the increase in acoustic properties. This same trend was observed in the comparison made between the samples UNABS, CHABS and ENABS. Due to better interlocking of fibres the thickness was also higher in both treated fibre interlocked nonwoven structures when compared with the untreated fibre interlocked sample. Among the samples UNAAB, CHAAB and ENAAB, the sample ENAAB showed the highest interlocking in SEM appearance. In the comparison made between the samples in the IV set, the interlocking of the fibres was also greater in the nonwoven structures CHAABS and ENAABS than in the sample UNAABS. Hence, it could be concluded that the fibres gained softness and flexibility for aiding in the fabric formation during needle punching and thermal bonding processes, which is reflected in the interlocking of the fibres during nonwoven preparation.

4.3.12 Acoustics

The results obtained for acoustic property and the nonwoven structures with respect to sound absorbent, and co efficient and noise reduction, properties are presented in the following heads.

4.3.12.1 Sound Absorption Coefficient (α) for Set I Samples

The result obtained for Sound Absorption Coefficient (α) for samples in set I are expressed in the Table XXXV and Figure 41a.

The Table XXXV reveals that the sample UNAS showed the highest SAC values at frequencies 2000, 2800, 3600, and 4000 Hz with 0.244107, 0.29981, 0.384944, and 0.602844 dB, respectively, whereas the sample CHAS showed the highest SAC at 200, 400, 1000, 1400, 2400, 3000, and 3200 Hz frequencies with 0.379473, 0.19638, 0.142565, 0.163213, 0.641331, 0.383772, and 0.365486. Among the treated fibre utilized in nonwoven structures, the sample ENAS showed higher SAC values at ten points at frequencies namely 600, 800, 1200, 1600, 1800, 2200, 2600, 3400, and 3800 Hz with 0.115598, 0.140807, 0.272622, 0.352905, 0.285286, 0.49304, 0.638364, and 0.758349.

Table XXXV

Sound Absorbency Coefficient (α) of UNAS Vs CHAS Vs ENAS

S.No	Frequency (Hz)	Sound Absorbency Coefficient (α)		
		UNAS	CHAS	ENAS
1	200	0.228583	**0.379473**	0.05245
2	400	0.12925	**0.19638**	0.08458
3	600	0.038618	0.08991	**0.115598**
4	800	0.088813	0.130049	**0.140807**
5	1000	0.092381	**0.142565**	0.110618
6	1200	0.224747	0.240168	**0.272622**
7	1400	0.142022	**0.163213**	0.142817
8	1600	0.257763	0.280658	**0.352905**
9	1800	0.227377	0.277618	**0.285286**
10	2000	**0.244107**	0.242312	0.243659
11	2200	0.06565	0.06866	**0.07941**
12	2400	0.400691	**0.641331**	0.239984
13	2600	0.328182	0.458273	**0.49304**
14	2800	**0.29981**	0.257343	0.178065
15	3000	0.334417	**0.383772**	0.37837
16	3200	0.264848	**0.365486**	0.350966
17	3400	0.277623	0.57295	**0.638364**
18	3600	**0.384944**	0.359089	0.310691
19	3800	0.444152	0.694028	**0.758349**
20	4000	**0.602844**	0.415341	0.00464
Average		**0.2538411**	**0.31793095**	**0.26166105**

The sample ENAS showed the best SAC results at nine points when compared with other samples, which may be due to the thickness of the sample. The average value of SAC was the highest in sample CHAS with 0.31793095, followed by sample ENAS with 0.26166105. Hence, it could be concluded that sample ENAS showed the highest SAC values at nine different frequency points, and sample CHAS showed the highest average SAC value.

4.3.12.2 Sound Absorption Coefficient (SAC) (α) for Set II Samples

The Sound absorption coefficient (SAC) (α) results obtained for samples set II are presented in Table XXXVI and Figure 41b

Table XXXVI

Sound Absorbency Coefficient (SAC) (α) of UNAAB Vs CHAAB Vs ENAAB

S.No	Frequency (Hz)	Sound Absorbency Coefficient (α)		
		UNAAB	CHAAB	ENAAB
1	200	**0.490929**	0.194397	0.6944
2	400	0.11327	0.13593	**0.17007**
3	600	0.00472	0.055159	**0.060522**
4	800	**0.122677**	0.099869	0.093064
5	1000	0.062333	0.075888	**0.08049**
6	1200	0.189966	0.211629	**0.244597**
7	1400	0.063767	**0.12822**	0.113745
8	1600	0.205962	**0.238233**	0.222336
9	1800	0.180781	0.20995	**0.2266**
10	2000	0.141542	**0.198009**	0.18583
11	2200	**0.10054**	0.0621	0.06613
12	2400	0.280683	**0.502199**	0.230957
13	2600	0.360997	0.475643	**0.617325**
14	2800	0.043996	**0.203668**	0.04256
15	3000	0.229067	0.292817	**0.360741**
16	3200	0.111457	0.239516	**0.275244**
17	3400	0.340293	0.35644	**0.63113**
18	3600	0.138013	**0.247244**	0.187074
19	3800	0.513025	0.381246	**0.680771**
20	4000	0.307853	0.13906	**1.51245**
	Average	**0.20009**	**0.22236**	**0.3348**

From Table XXXVI and Figure 41b, it is vivid that the sample UNAAB showed the highest SAC at the lower frequency three points, namely 200, 800, and 2,200 Hz, with 0.490929, 0.122677, and 0.10054, but the treated samples exhibited better results than the sample UNAAB, of which it was higher in sample ENAAB as it exhibited better SAC values at lower as well as higher frequency points, namely 400, 600, 1000, 1200, 1800, 2600, 3000, 3200, 3400, 3800, and 4000 Hz with 0.17007, 0.060522, 0.08049, 0.244597, 0.222336, 0.617325, 0.360741, 0.275244, 0.63113, and 0.680771 respectively. The sample CHAAB exhibited the best results in SAC at 1400, 1600, 2000, 2400, 2800, and 3600 Hz with 0.12822, 0.238233, 0.198009, 0.502199, 0.203668, and 0.247244, respectively. The fibres with low density exhibit better absorption (Nandanwar *et al*., 2017) which may be the reason for the samples blended with *Agave americana* fibres exhibiting a better sound absorption coefficient when compared with other blends. The density of the fibres is *Agave americana* 1.46g/cc, *Abutilon indicum* at 1.45g/cc and *Areca catechu* at 1.37g/cc. The densities of the three samples are in order UNAAB>CHAAB>ENAAB. Hence, it could be concluded that among the set II samples, sample CHAAB showed the best performance at six frequency points. where the average SAC value for sample ENAAB was the highest 0.3348 and could be used as sound absorption material.

4.3.12.3 Sound Absorption Coefficient (α) for SET III Samples

The results obtained for samples of set III are presented in Table XXXVII and Figure 41c.

Table XXXVII
Sound Absorbency Coefficient (α) of UNABS Vs CHABS Vs ENABS

S.No	Frequency (Hz)	Sound Absorbency Coefficient (α)		
		UNABS	CHABS	ENABS
1	200	0.063414	**0.2598**	0.1774
2	400	0.13715	**0.19629**	0.04942
3	600	**0.067462**	0.033712	0.045993
4	800	0.096463	0.113293	**0.118579**
5	1000	0.060733	**0.105535**	0.078799
6	1200	0.185334	0.22937	**0.26229**
7	1400	0.120383	0.122097	**0.152583**
8	1600	0.221809	0.244457	**0.284061**
9	1800	0.21552	0.237292	**0.256035**
10	2000	0.167519	0.209762	**0.213747**
11	2200	0.04201	0.07053	**0.07438**
12	2400	0.534066	**0.597112**	0.16996
13	2600	0.440338	**0.678955**	0.678715
14	2800	**0.14763**	0.06455	0.078593
15	3000	0.265731	**0.392644**	0.391208
16	3200	0.15461	0.345585	**0.371514**
17	3400	0.332001	**0.701575**	0.664019
18	3600	0.188252	0.218174	**0.323693**
19	3800	0.518543	**0.781464**	0.750953
20	4000	0.22569	0.57973	**0.475712**
Average		**0.2092329**	**0.309096**	**0.280883**

Table XXXVII reveals that the sample UNABS showed the highest SAC value at 600 and 2800 Hz frequency points with 0.067462 and 0.14763 dB, respectively, The sample CHABS shows the highest SAC values at eight frequency points, namely 200, 400, 1000, 2400, 2600, 3000, 3400 and 3800 Hz, with 0.2598, 0.19629, 0.105535, 0.597112, 0.678955, 0.392644, 0.701575, and 0.781464, respectively. The highest SAC values were observed in the sample CHABS among the three samples, whereas the treated fibre blended nonwoven structures show better SAC results, which were higher in sample ENABS at ten frequency points at 800, 1200, 1400, 1600, 1800, 2000, 2200, 3200, 3600 and 4000Hz with 0.118579, 0.26229, 0.152583, 0.284061, 0.256035, 0.213747, 0.07438, 0.371514, 0.323693, and 0.475712. The densities of these three samples are in order UNABS> CHABS> ENABS. Among the treated fiber-blend nonwoven structures, the denser sample CHABS performed better in SAC at six frequency points. The sample ENABS, which showed the highest thickness value, exhibited the highest SAC at nine different frequency points. It is the highest among these samples, and sample ENABS exhibits the highest SAC at nine points of frequency. The average SAC value was the maximum in sample CHABS (0.3091), which was followed by sample ENABS (0.2808). This is in par with previous studies showing that sound absorption drops with an increase in density (Nandanwar *et al.,* 2017). The material CHABS can be used as Sound Absorption Material.

4.3.12.4 Sound Absorption Coefficient (α) for SET IV Samples

The SAC results obtained for nonwoven samples in set IV are presented in Table XXXVIII and Figure 41d.

Table XXXVIII

Sound Absorbency Coefficient (α) of UNAABS Vs CHAABS Vs ENAABS

S.No	Frequency (Hz)	Sound Absorbency Coefficient (α)		
		UNAABS	CHAABS	ENAABS
1	200	0.219702	0.277836	**0.5201**
2	400	0.01843	**0.16283**	0.15727
3	600	**0.058025**	0.033092	0.028128
4	800	0.060544	**0.12523**	0.06035
5	1000	0.063732	0.066197	**0.081145**
6	1200	0.200757	**0.206941**	0.198205
7	1400	**0.099286**	0.089877	0.058887
8	1600	**0.269257**	0.242366	0.211137
9	1800	0.181937	**0.194196**	0.173415
10	2000	**0.231728**	0.214093	0.14102
11	2200	**0.09359**	0.08571	0.08519
12	2400	**1.19784**	0.20492	0.229391
13	2600	0.41175	0.443547	**0.471178**
14	2800	**0.110488**	0.091072	0.06778
15	3000	0.279996	**0.32002**	0.244615
16	3200	**0.269232**	0.247248	0.153158
17	3400	0.458771	**0.518951**	0.442186
18	3600	0.223059	**0.264974**	0.064525
19	3800	**0.721027**	0.704503	0.600947
20	4000	0.426114	**0.839826**	0.130798
Average		**0.279763**	**0.266671**	**0.205971**

Table XXXVIII reveals that the sample UNAABS showed the highest SAC at ten frequency points, namely 600, 1400, 1600, 2000, 2200, 2400, 2800, 3200 and 3800Hz with 0.058025, 0.099286, 0.269257, 0.231728, 0.09359, 1.19784, 0.110488, 0.269232, and 0.721027. The sample CHAABS is thicker than the sample ENAABS among the treated fibre blended nonwovens and also exhibits better SAC values at seven different frequency points. At low frequencies, a lesser sound absorption coefficient was observed irrespective of the weight, thickness, or density of the nonwoven samples. A major increase in SAC was observed beyond 2400Hz Hz in all sets of comparisons. The sample ENAABS showed the highest SAC at 200, 1000, and 2600 Hz frequencies with 0.5201, 0.081145, and 0.471178, respectively. The highest average SAC values were noted in sample UNAABS (0.27976), followed by sample CHAABS (0.26667). The density of these three samples is noted to be in the order CHAABS > UNAABS> ENAABS, and so the denser nonwoven samples are ENAABS.

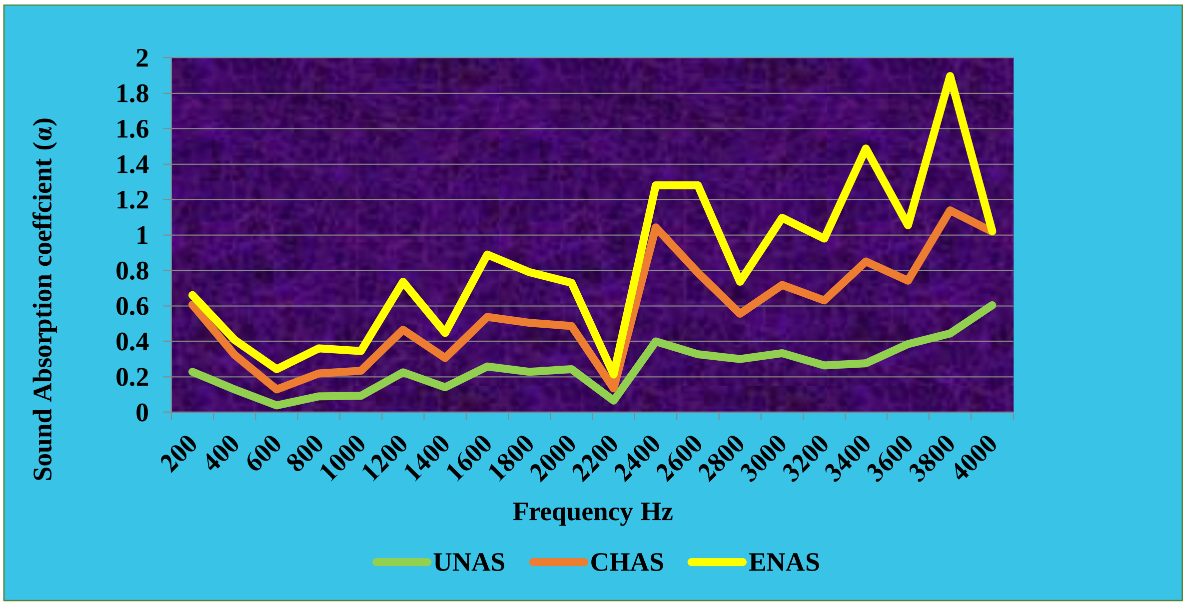


Figure 41a Sound Absorption Coefficient for Set I Nonwoven Fabric Samples

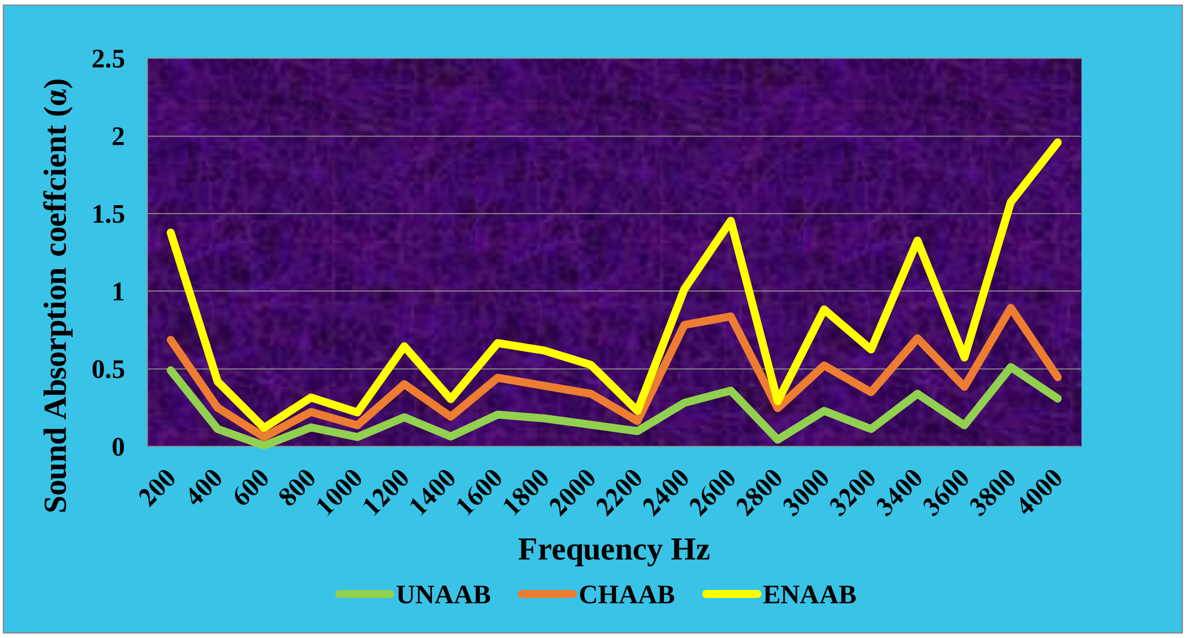


Figure 41b Sound Absorption Coefficient for Set II Nonwoven Fabric Samples

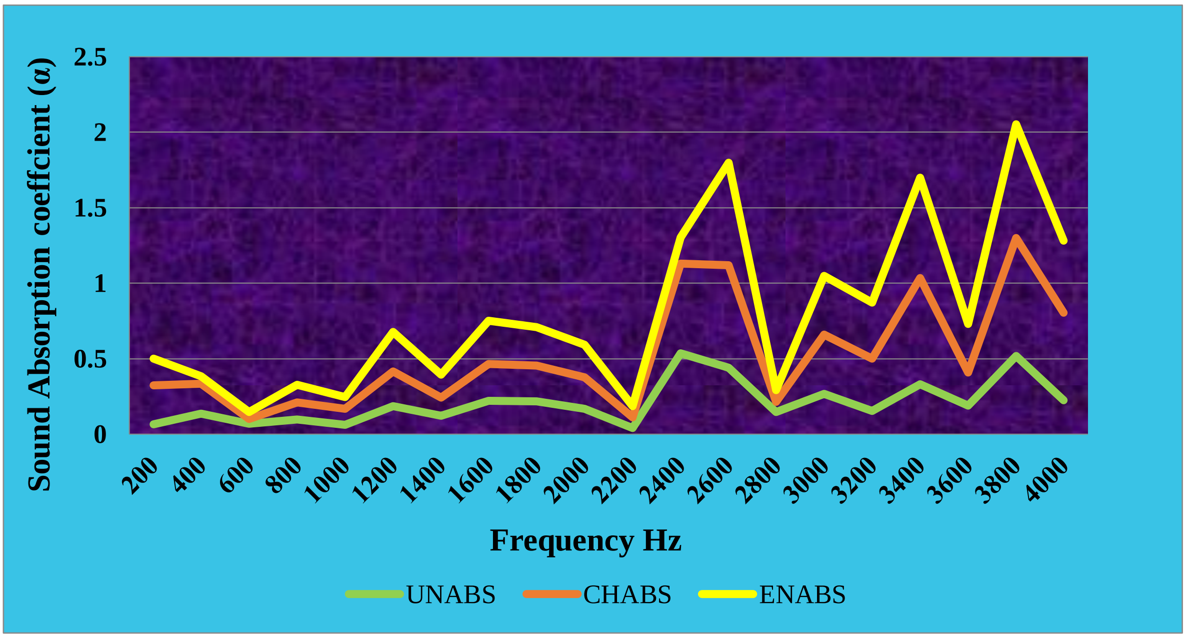


Figure 41c Sound Absorption Coefficient for Set III Nonwoven Fabric Samples

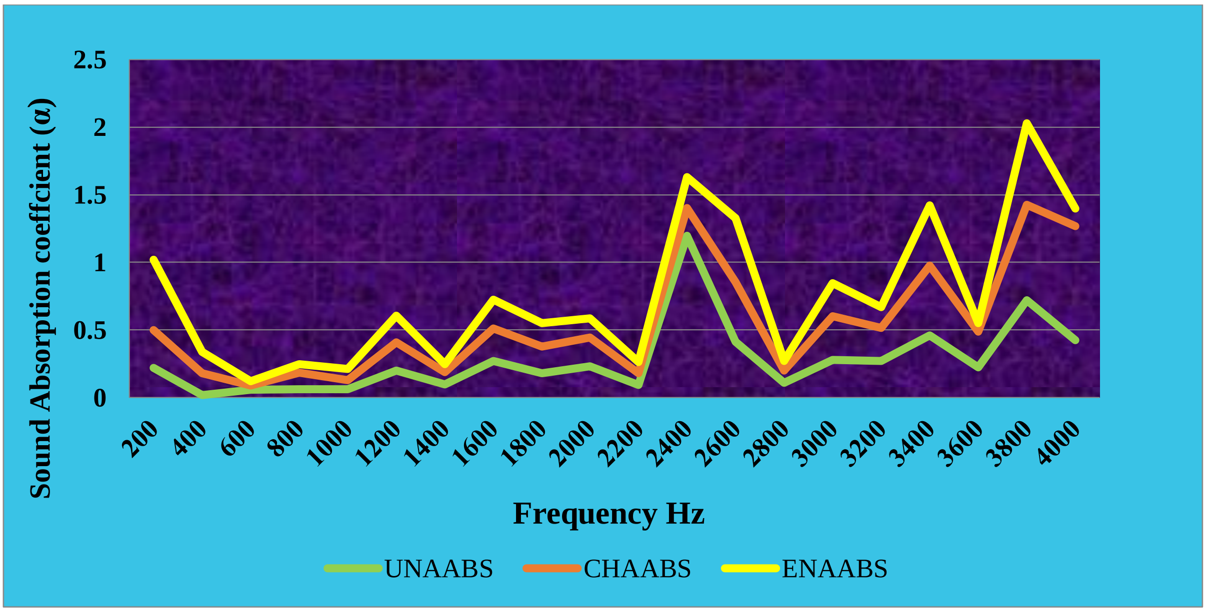


Figure 41d Sound Absorption Coefficient for Set IV Nonwoven Fabric Samples

Figure 41 Sound Absorption Coefficient and Nonwoven Fabric Samples

4.3.13 Correlation Between Thickness and Acoustic Property

The correlation made between the thickness and acoustic property of nonwoven material is presented in Table XXXIX.

Table XXXIX

Correlation between Thickness and Acoustic Property of Nonwoven Fabric Samples

Variables	Thickness		Frequency		Correlation coefficient	Significance
	Mean	Standard Deviation	Mean	Std. Deviation		
200	6.1483	1.2881194	0.29654	0.1915757	0.016	0.96
400			0.129239	0.055261	0.013	0.968
600			0.052578	0.0294622	0.464	0.129
800			0.104145	0.0258481	0.555	0.061
1000			0.085035	0.0243299	0.599**	0.039
1200			0.222219	0.0283007	0.884*	0.000
1400			0.116408	0.0331997	0.55	0.064
1600			0.252579	0.0407631	0.673**	0.017
1800			0.222167	0.0371303	0.739*	0.006
2000			0.202777	0.0371662	0.646**	0.023
2200			0.074492	0.0157081	0.105	0.746
2400			0.435761	0.291581	-0.123	0.703
2600			0.488162	0.1138734	0.531	0.076
2800			0.13213	0.0856958	0.013	0.967
3000			0.322783	0.0594157	0.883*	0.000
3200			0.262405	0.0876996	0.851*	0.000
3400			0.494525	0.147102	0.816*	0.001
3600			0.242478	0.0930447	0.54	0.07
3800			0.629084	0.1341357	0.699**	0.011
4000			0.47167	0.4028526	0.387	0.214

*= 1 %level significance, ** = 5 %level significance

The Table XXXIX reveals Correlation coefficient results between the thickness and acoustic properties at different frequencies, namely 1000, 1600, 2000, and 3800 Hz, with a significant difference at 5% level. At frequencies 1200, 1800, 3000, 3200, and 3400 Hz, the correlation between thickness and acoustic property was noted to have significance at the 1% level. Hence, the thickness influences the acoustic properties of the nonwoven structures at frequencies of 1200, 1800, 3000, 3200, and 3400 Hz.

4.4 Evaluation of Prepared Composites

The prepared composites were analyzed for various properties, namely mechanical, thermal, and physical, and the results obtained with discussion are presented under the following headings

4.4.1 Tensile Strength and Elongation

The results obtained for the Tensile Strength and Elongation of the composites are presented in Table XL and Figure 42a.

Table XL

Tensile Strength of Composites

S.No	Samples	Tensile Strength		Statistical analysis		Elongation	
		Value (Mpa)	Gain (%)	F-value	Significance	Value (%)	Loss (%)
1	EP	18.25	-	8.240	.000*	3.38	-
2	CAABE	30.25	65.75			1.53	54.73
3	CABSE	**36.21**	98.41			1.80	46.74
4	CASE	33.52	83.67			2.74	18.93
5	EAABSE	25.39	39.12			2.76	18.34

***=Significant at 1% level**

From the Table XL it is clear that the tensile strength of the sample EP was 18.25 MPa. This was observed to have gain in all the fabric reinforced composites, with the highest gain in sample CABSE with 98.41 per cent followed by the samples CASE, CAABE and EAABSE with 83.67 per cent, 65.75 per cent and 39.12 per cent respectively. In the statistical analyses of the interaction made between the samples EAABSE, CASE, CAABE and CABSE with sample EP by one-way ANOVA, a significant difference of one per cent level was observed. As for the elongation of the samples, the sample EP showed 3.38 per cent elongation. This decreased in all the nonwoven fabric reinforced composite samples and was the highest in sample CAABE (54.73 per cent). This was followed by the samples CABSE (46.74 per cent), CASE (18.93 per cent) and EAABSE (18.34 per cent). The tensile strength of the composite specimen with the combination of coarse areca husk fibre and glass fibre was 24.80 Mpa in earlier study (Muralidhar *et.,al* 2019). But in the present research, the combination of *Areca catechu* with other natural fibres namely *Abutilon indicum* and *Agave americana* has given better results in the hybrid composites. Hence it could be concluded that the natural fibre fabricated nonwoven structure reinforced samples exhibited better strength compared to neat epoxy composite and also that among the reinforced structures the sample CABSE showed the best result. But the elongation of all the reinforced samples decreased over the neat epoxy sample.

4.4.2 Flexural Strength

The results obtained for the flexural strength of the neat epoxy and reinforced composites are presented in Table XLI and Figure 42b.

Table XLI

Flexural Strength of Composites

S.No	Samples	Flexural Strength		Statistical Analysis	
		Value (Mpa)	Gain (%)	F-value	Significance
1	EP	25.88	-	34.179	.000*
2	CAABE	59.24	128.90		
3	CABSE	76.92	197.22		
4	CASE	**86.61**	234.66		
5	EAABSE	72.58	180.45		

***= Significant at 1% level**

It is clear from the Table XLI that the flexural strength of the epoxy polymer sample EP was 25.88 MPa which showed an increase in all the fabric reinforced composites, of which it was the highest in flexural strength with 86.61 MPa in sample CASE followed by sample CABSE with 76.92 MPa, sample EAABSE with 72.58 MPa and sample CAABE with 59.24 MPa. In the statistical analysis carried out between sample EP and fabric reinforced samples by One-Way ANOVA, it is clear that there was a significant difference at 1 % level.

Hence, the flexural strength of all the fabric reinforced samples increased, which was the highest in sample CASE. The flexural strength of an arecanut fiber reinforced epoxy composite in an earlier study (Praveena *et.al.*,2022) showed 64.8 MPa. The highest flexural strength of 86.61 MPa was achieved in the sample CASE which is the combination of *Areca catechu* and *Agave americana* fibres blended nonwoven structure proving the advantages of hybridization.

4.4.3 Compressive Strength

The results of compressive strength of the neat epoxy and reinforced composites are presented in Table XLII and Figure 42c.

Table XLII

Compressive Strength of Composites

S.No	Samples	Compressive Strength		Statistical Analysis	
		Value (Mpa)	Gain (%)	F-value	Significance
1	EP	7.78	-	28.929	.000*
2	CAABE	**26.44**	239.84		
3	CABSE	22.21	185.47		
4	CASE	24.73	217.87		
5	EAABSE	21.06	170.69		

***= Significant - 1% level**

From the Table XLII, it is clear that the sample EP showed a compressive strength of 7.78 Mpa. There was an increase in compressive strength noted in all the composite slabs reinforced with fabric, of which the maximum was in sample CAABE (26.44 Mpa) followed by samples CASE (24.73 Mpa) CABSE (22.21 Mpa) and EAABSE (21.06 Mpa). As for the statistical analysis made between the sample EP and fabric reinforced composites for compressive strength, a significant difference was noted at 1 % level.

4.4.4 Shore D Hardness

Table XLIII presents the Shore D Hardness of the neat epoxy and reinforced composites Figure 42d.

Table XLIII

Shore D Hardness of Composites

S.No	Samples	Hardness	
		Value (SHN)	Gain %
1	EP	89.9	-
2	CAABE	94	4.56
3	CABSE	94.2	4.78
4	CASE	90	0.11
5	EAABSE	**96.1**	6.89

The Table XLIII reveals that the hardness of the sample EP was 89.9 Shore D. This showed a gain in all the fabric reinforced samples, of which the highest was in sample EAABSE with 6.89 per cent followed by the samples CABSE (4.78 percent), CAABE (4.56 per cent) and CASE (0.11per cent) over the neat epoxy sample.

Hence, it could be concluded that there was a gain in hardness in all the fabric reinforced samples, of which the highest was in sample EAABSE over the neat epoxy samples.

4.4.5 Impact Strength

The results obtained for the impact strength of the neat epoxy and reinforced composite samples are expressed in Table XLIV and Figure 42e.

Table XLIV

Impact Strength of Composites

S.No	Samples	Impact Strength		Statistical Analysis	
		Value (Joules)	Gain %	F-value	Significance
1	EP	0.17	-	3.438	.027**
2	CAABE	0.24	41.18		
3	CABSE	0.30	76.47		
4	CASE	0.30	76.47		
5	EAABSE	**0.38**	123.53		

****= Significant at 5% level**

The Table XLIV reveals that the sample EP exhibited an impact strength of 0.17 J.The impact strength improved in all the fabric reinforced samples over the unreinforced sample, with the maximum increase in sample EAABSE (0.38 Joules) followed by both samples CASE and CABSE with 0.30 Joules and sample CAABE with 0.24 Joules. The statistical analysis between the sample EP and the fabric reinforced samples EAABSE, CASE, CAABE, and CABSE for the impact strength by one-way ANOVA showed 5% significance only. Hence, the sample EAABSE showed the best impact values, among all the fabric reinforced samples, and all the fabric reinforced samples gained impact strength over the sample EP.

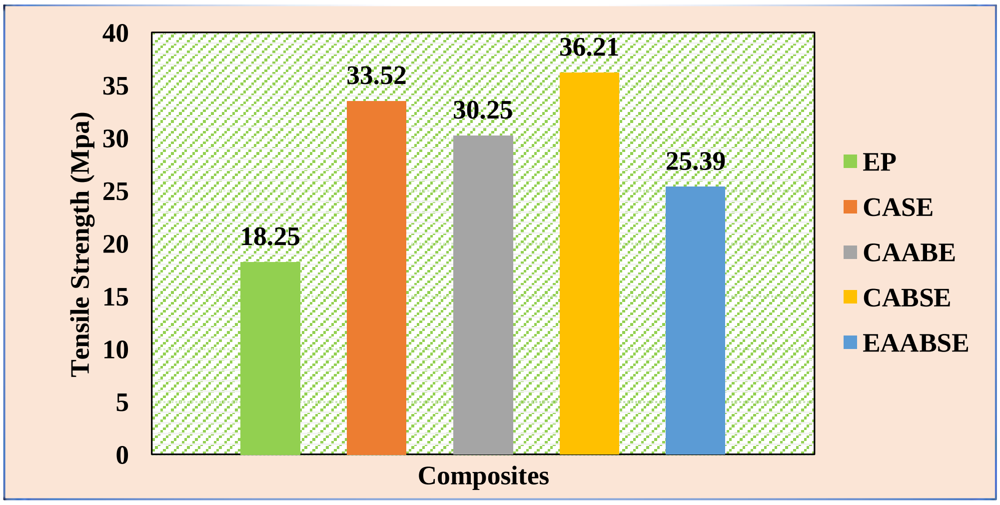


Figure 42a Tensile strength

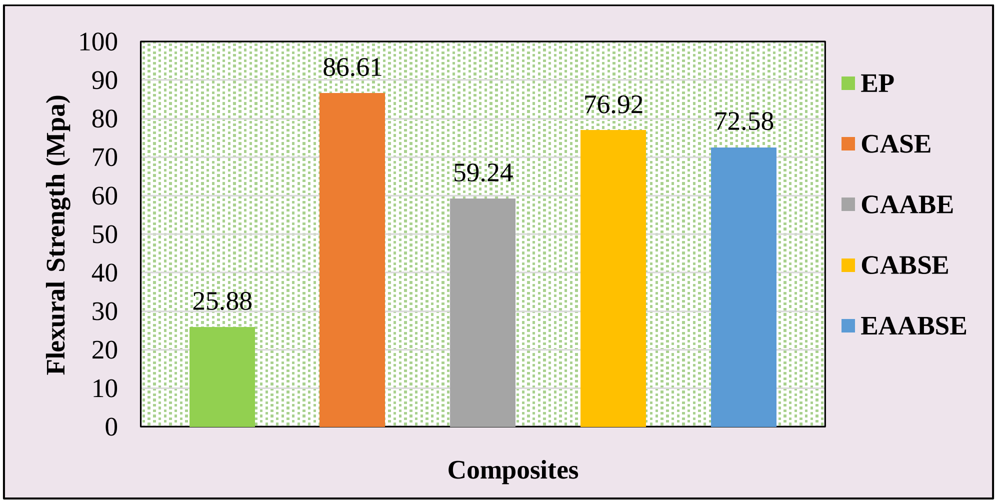


Figure 42b Flexural Strength

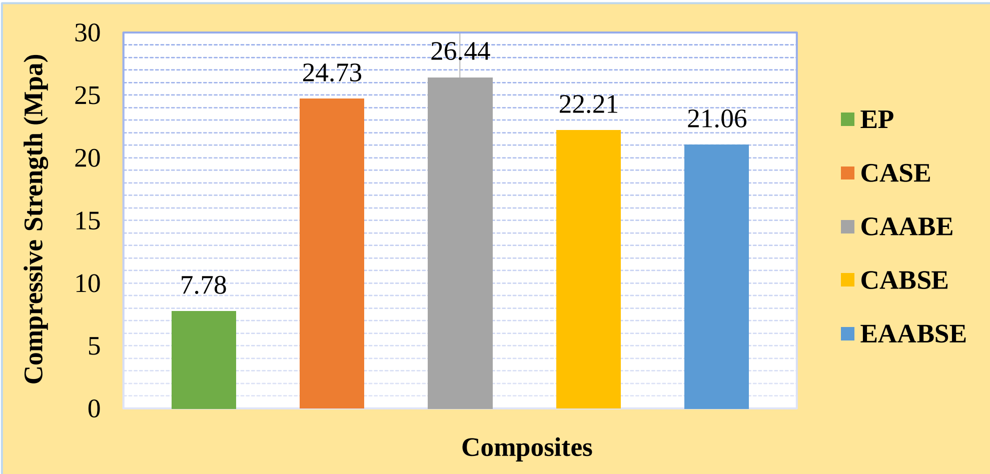


Figure 42c Compressive Strength

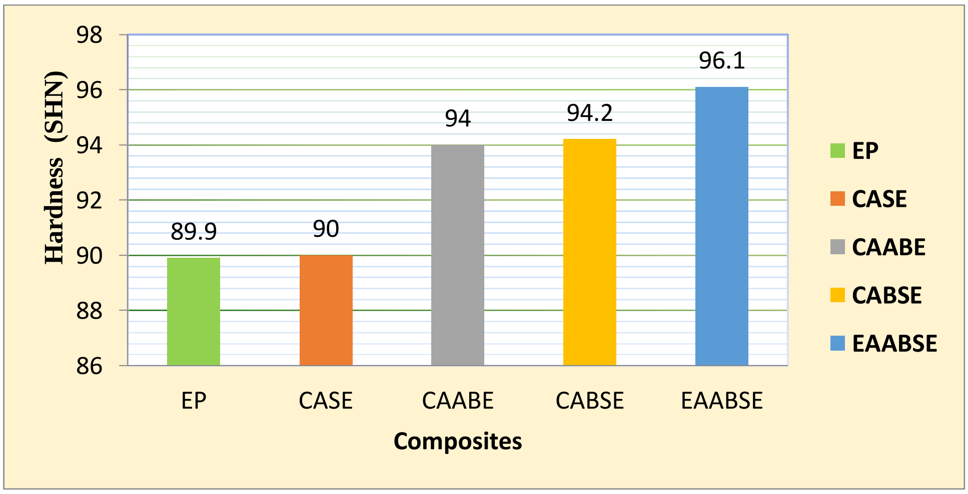


Figure 42d Shore D Hardness

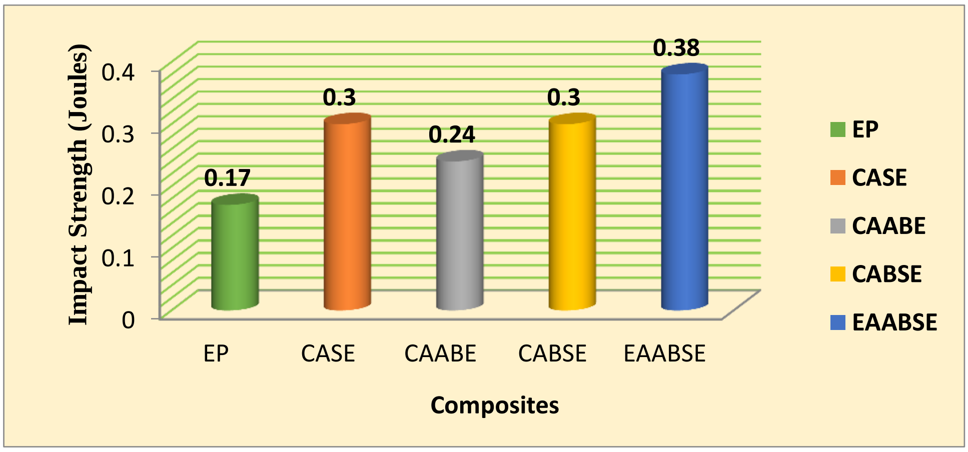


Figure 42e Impact Strength

Figure 42 Evaluation of Composites

4.4.6 Spectro Photometric Analysis

The colour is a very important aspect in determining the aesthetic properties of the prepared composites. The neat epoxy sample was noted to be a transparent slab. So, for the fabric reinforced slabs, color has been analyzed, and the results of the spectrophotometric analysis of the samples are presented in Table XLV.

Table XLV

Spectro Photometric Analysis of Composites

`	Sample name	Brightness Index	Whiteness Index	Yellowness Index
1	CAABE	5.891	1.081	34.226
2	CABSE	**8.068**	**1.989**	33.486
3	CASE	6.465	0.553	36.451
4	EAABSE	5.893	-0.962	**42.312**

The Table XLV and Figure 43 reveal that among the fabric reinforced samples, the brightness index of the sample CABSE was the highest with 8.068, followed by the samples CASE (6.465), EAABSE (5.893), and CAABE (5.891). The whiteness index was also the highest in the CABSE sample (1.989). The yellowness index was lowest in the sample CABSE (33.486) and highest in the sample EAABSE (42.312). Hence, it could be concluded that the sample CABSE exhibited the highest whiteness and brightness indices, whereas the sample CAABE showed the least brightness index and the sample EAABSE showed the least whiteness index.

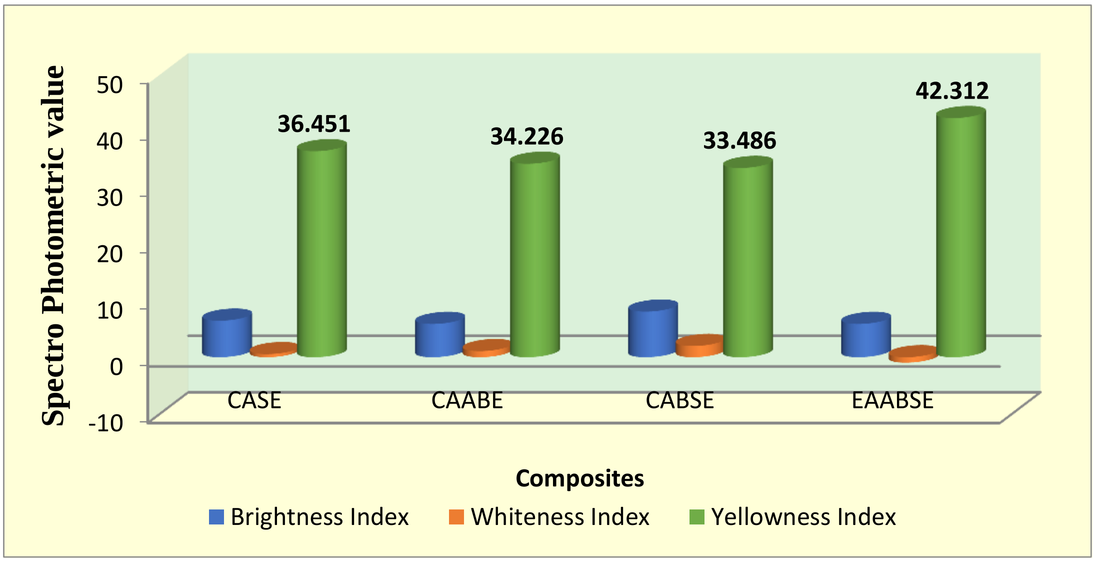


Figure 43 Spectro Photometric Analysis

4.4.7 Thermogravimetric Analysis (TGA)

The results of Thermogravimetric Analysis of composite structures are presented in the Table XLVI and Figures 44a - 44e.

Table XLVI

Thermogravimetric Analysis of Composites

S.No	Samples	Stage 1		Stage 2		Final Stage	
		Temp. (^{O}C)*	Wt. (%)*	Temp. (^{O}C)*	Wt. (%)*	Temp.(^{O}C)*	Wt. (%)*
1	EP	360	18.8	420	50.5	470	83.3
2	CAABE	310	15.0	450	71.1	580	96.1
3	CABSE	360	21.4	510	57.3	580	**87.9**
4	CASE	350	21.2	480	73.2	580	104.4
5	EAABSE	230	17.8	450	65.4	580	96.4

*temp.- Temperature, wt. – weight

From Table XLVI and Figure 42, it is obvious that all the samples showed three stages of degradation. The sample EP exhibited 83.3 % weight loss at 470°C temperature. Among the fabric reinforced composite structures the highest degradation was noted in sample CABSE (21.4 per cent) initially followed by sample CASE (21.2 per cent), EAABSE (17.8 per cent) and sample CAABE (15 per cent) between the temperature ranges 230°C to 360°C. Between the temperature ranges of 420°C and 510°C, the degradation of the fabric reinforced composites samples was noted to be higher than the sample EP (50.5 per cent) of which it was the highest in the sample CASE (73.2 per cent) followed by the samples CAABE (71.1per cent), EAABSE (65.4 per cent) and CABSE (57.3 per cent). The final degradation of the sample EP was 83.3 per cent at 470°C and at 580°C, the sample CASE showed the highest degradation (104.4 per cent) followed by the samples EAABSE (96.4per cent), CAABE (96.1per cent) and CABSE (87.9 per cent).

Hence all the nonwoven fabric reinforced composite structures exhibited higher degradation than the neat epoxy sample EP, but among the fabric reinforced structures, the least degradation was observed in sample CABSE indicating higher thermal stability in the sample.

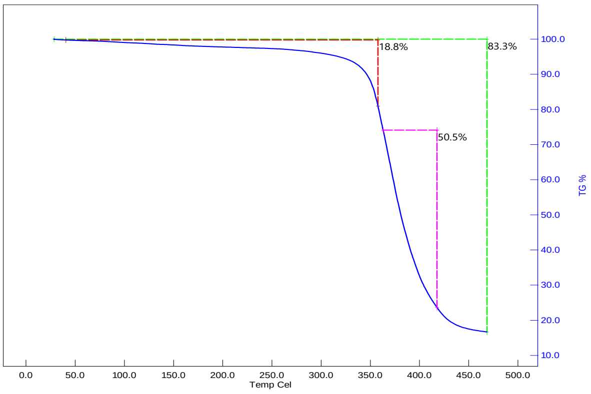


Figure 44a EP

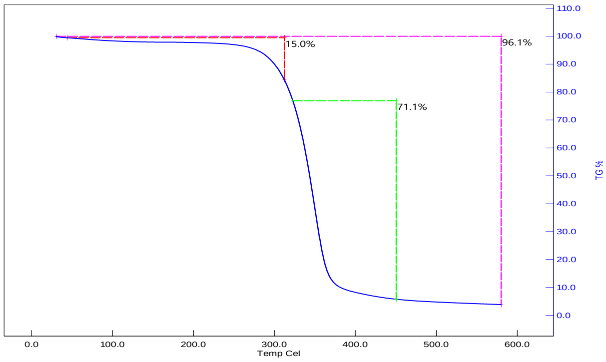


Figure 44b CAABE

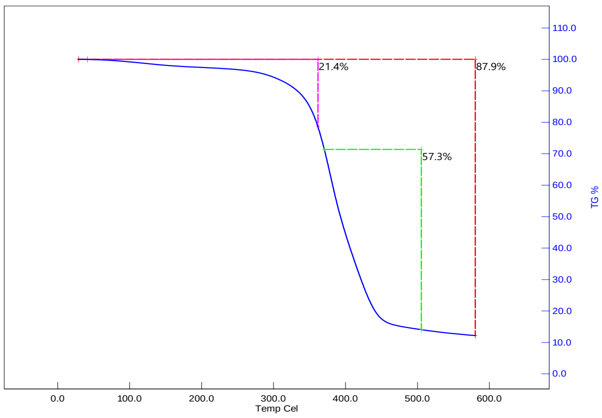


Figure 44c CABSE

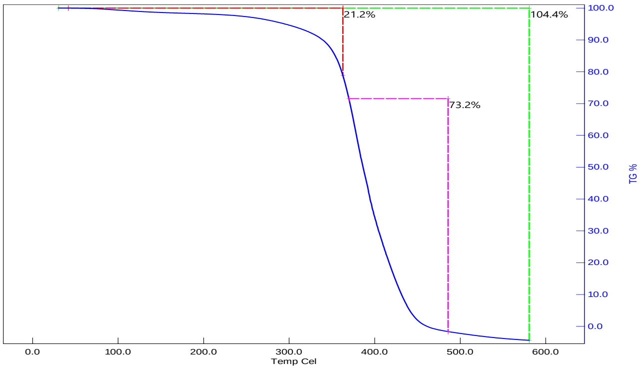


Figure 44d CASE

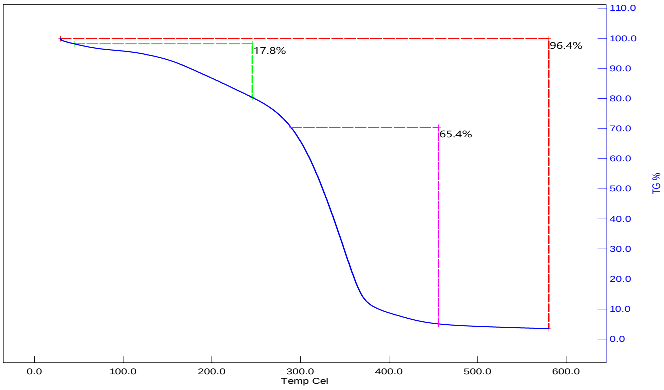


Figure 44e EAABSE

Figure 44 TGA of composites

4.4.8 Density and Void Fraction of Composites

The results obtained for Density and Void Fraction of Composites are presented under the following headings.

4.4.8.1 Density of Composites

Findings of the density for neat epoxy and reinforced composite samples are expressed in the Table XLVII

Table XLVII

Density of Composites

S.No	Samples	Mass (g)	Volume (cc)	Density (g/cc)
1	**EP**	1.95	2.68	0.72
2	CAABE	2.56	2.49	1.02
3	CABSE	3.51	3.41	1.02
4	CASE	0.90	0.86	**1.04**
5	EAABSE	1.04	1.06	0.98

From the Table XLVII it is obvious that the density of the sample EP was 0.72 g/cc. All the fabric reinforced samples showed greater density values, of which the highest was in sample CASE (1.04 g/cc) followed by both the composite samples CAABE and CABSE with 1.02 g/cc and sample EAABSE with 0.98 g/cc. Hence, it could be concluded that the density increased with fabric reinforcement and was the highest in the sample CASE among all the samples.

4.4.8.2 Void Fraction of Composites

The void fraction of composite structures is presented in Table XLVIII

Table XLVIII

Void Fraction of Composites

S.No	Sample	Theoretical Density (ρc) (g/cc)	Experimental Density (ρ) (g/cc)	Fibre volume fraction (V_f)	Volume Fraction of Voids V_v (%)
1	CAABE	2.22	1.02	0.19	0.54
2	CABSE	2.28	1.02	0.18	0.55
3	CASE	2.31	1.04	0.20	0.54
4	EAABSE	1.49	0.98	0.12	**0.34**

From the Table XLVIII it is clear that the theoretical density values do not match with the experimentally measured density values due to the presence of voids or air bubbles in composite structures which would affect the mechanical properties and performance of the structures. The volume fraction of voids were noted to be lesser in all the samples and was the least in sample EAABSE (0.34 per cent) followed by both the samples CASE and CAABE (0.54 per cent). Hence it could be concluded that all the composites exhibit the volume fraction of voids which are found to be reasonably small < 1.5 per cent and in par with earlier studies (Mohanta and Acharya 2015).

4.4.9 Liquid Absorbency Test

The Figure show the Liquid absorption rate of Neat Epoxy and Reinforced composite samples.

4.4.9.1 Between Samples in Deionised Water (DW)

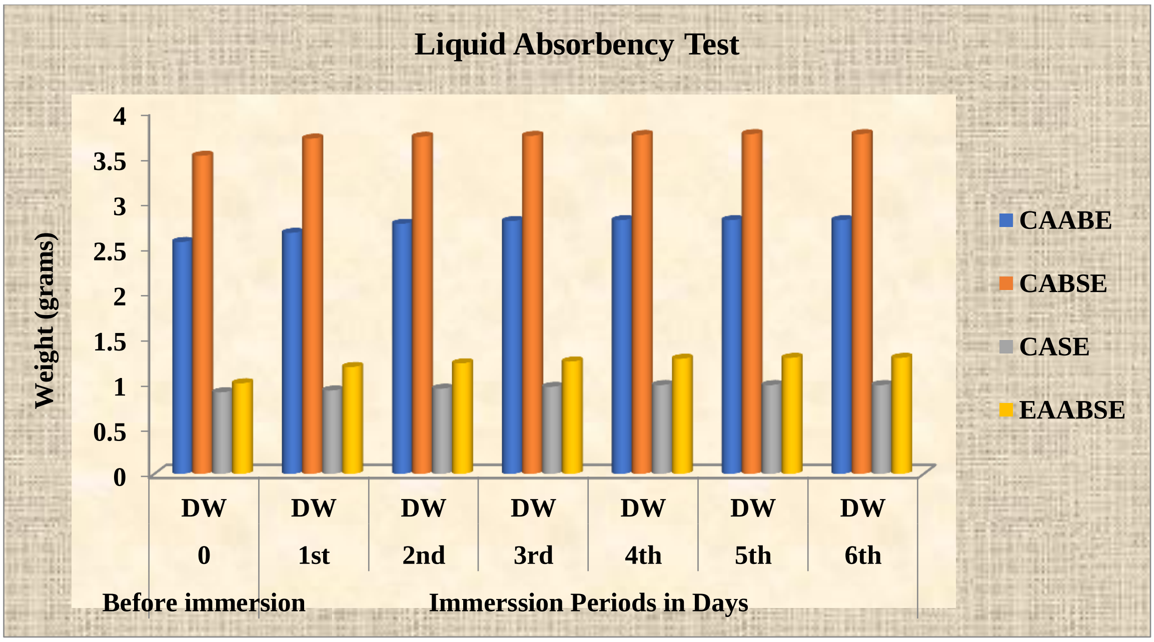


Figure 45a Liquid Absorbency in Deionized Water (DW)

From the Figure 45a, it is clear that the neat Epoxy sample EP did not show any absorbency in DW water and Ionised water (IW) water environments even after six days of immersion, but the kerosene immersed sample showed a very slight increase in weight with a gain of 5.64 per cent. After the first day of immersion, this attained saturation in weight. The maximum gain in absorbency rate after the first day of immersion was noted in sample EAABSE at 13.46 percent. On the second day, the sample EAABSE showed the maximum gain in weight due to absorption in DW of 17.30 percent. On the third day, the same trend was observed in samples CASE, EAABSE, and CAABE with 19.23 per cent and 18.98 per cent followed by samples CASE (6.66 per cent) and CABSE (6.26 per cent). After four days of immersion, it was observed that the maximum gain was in sample EAABSE (22.11 per cent). On the fifth day, the maximum gain was observed in sample EAABSE with 23.07 per cent followed by samples CAABE (9.37 per cent), CASE (8.88 per cent) and CABSE (6.55 per cent). After five days of immersion, the maximum gain was observed in sample EAABSE at 23.07 per cent. This same trend was observed in the sample after immersion for six days, with a saturation in weight gain. A saturation in weight gain was noted after four days of immersion in the samples CAABE and CASE, whereas the samples CABSE and EAABSE showed a saturation in weight gain in DW water after the fifth day of immersion.

4.4.9.2 Between Samples in Ionised Water (IW)

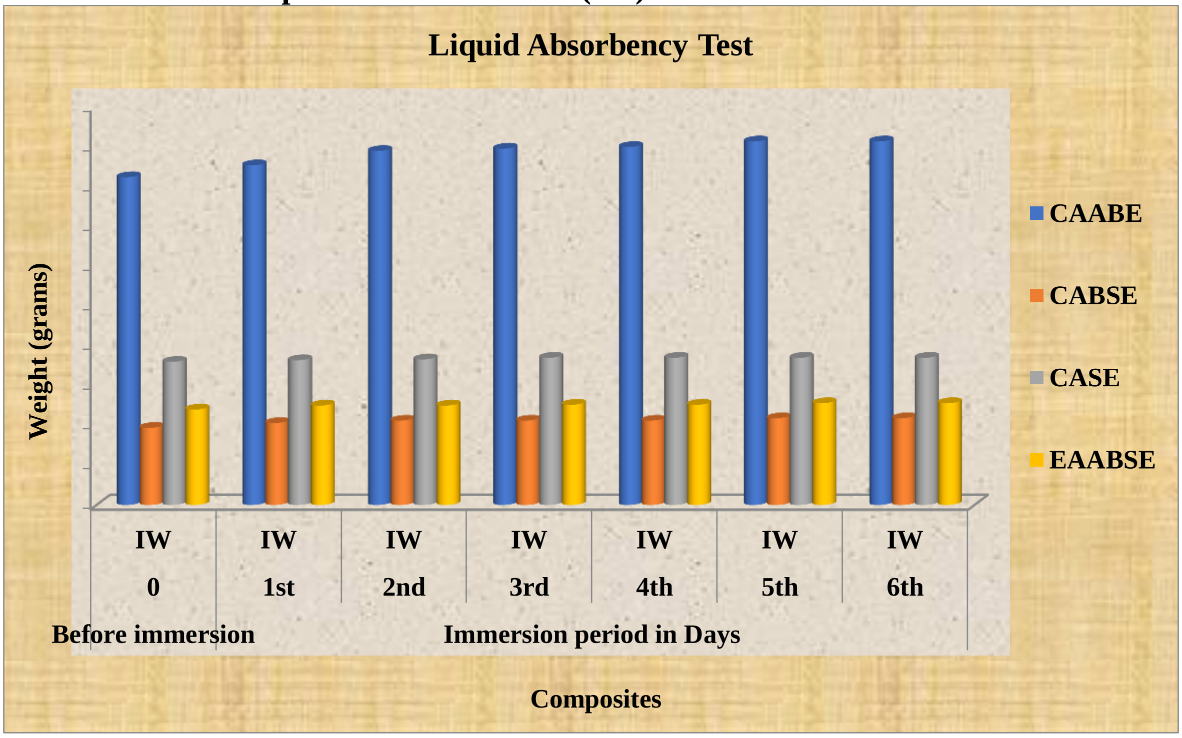


Figure 45b Liquid Absorbency in Ionized Water (IW)

From Figure 45b after the first day of immersion, the maximum weight gain was noted in sample CABSE with 6.18 per cent followed by samples EAABSE, CAABE and CASE with 4.16, 3.64, 1.11 percentages respectively. After the second day of immersion, it was observed that the maximum gain in weight due to absorbency was in the sample CABSE at 19.29 per cent. On the third day, this same trend was observed in the samples of CABSE with 9.27 per cent with a maximum gain per cent. On the fourth day, the sample CABSE showed the maximum gain per cent due to an absorbency of 9.27 per cent. After the fifth and sixth days of immersion, the maximum absorbency was also noted in sample CABSE at 12.37 per cent with a saturation in the gained values after the fifth and sixth days of immersion in the samples. The saturation of the weight gain was observed in the samples CAABE, CABSE, and EAABSE after the fifth day of immersion, whereas the samples CASE showed saturation in weight gain after three days of immersion in IW Figure 43b. Hence it could be concluded that the minimum absorbency of iodized water was observed in the sample CABSE and a quick saturation was noticeable in the sample CASE.

4.4.9.3 Between Samples in Kerosene (K)

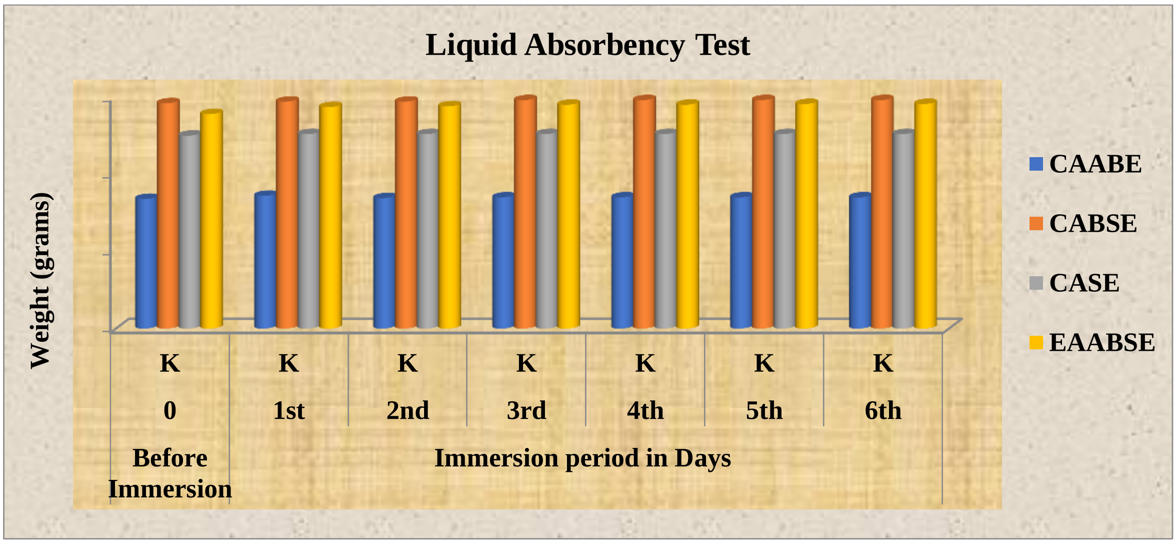


Figure 45c Liquid Absorbency in Kerosene (K)

From Figure 45c the sample EAABSE showed the maximum gain in weight of 3.23 per cent in Kerosene after the first day of immersion, followed by samples CAABE with 2.38 per cent, CASE with 0.80 per cent and CABSE with 0.68 per cent. On the second day of immersion, it was noted that the sample EAABSE showed a maximum weight gain of 3.59 per cent. On the third day of immersion, the sample EAABSE also exhibited a maximum weight gain of 4.31 per cent. This same trend was also observed after the fourth day of immersion of the samples in kerosene, with the highest gain per cent of weight in sample EAABSE 4.31 percent. After the fifth day of immersion, the sample EAABSE showed the highest gain (4.67 per cent) followed by samples CABSE (1.36 per cent) CAABE (1.19 per cent) and CASE (0.80 per cent). After the sixth day, the same gain values were observed as there was a saturation in weight gain. After the third day of immersion, saturation in weight gain was noted in the samples CAABE, CABSE and CASE whereas the sample EAABSE showed saturation only after five days.

Hence, it could be concluded that among all the four samples, the sample CASE showed quick saturation in weight gain in the liquids, namely dionized water (after four days of immersion), ionized water (after three days of immersion), and kerosene (after three days of immersion) depicting the minimum absorbency rate on exposure in various liquid environments. The samples attained saturation quickly, and absorption of liquid was also minimal, which may be due to the minimum presence of voids. Figure 43c. The practical implication of the findings may be with Ionized water as almost all water found in nature are of this type. The practical implication of the findings may be with ionized water as almost all water environments found in nature are of this type.

4.4.10 Scanning Electron Microscopic Appearance (FESEM)

The surface morphology of different combinations of nonwoven fabric reinforced samples is revealed through FESEM which is presented in Plate 17.

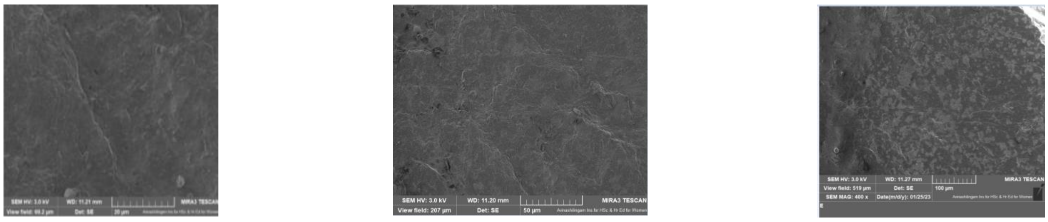


Plate 17a EP

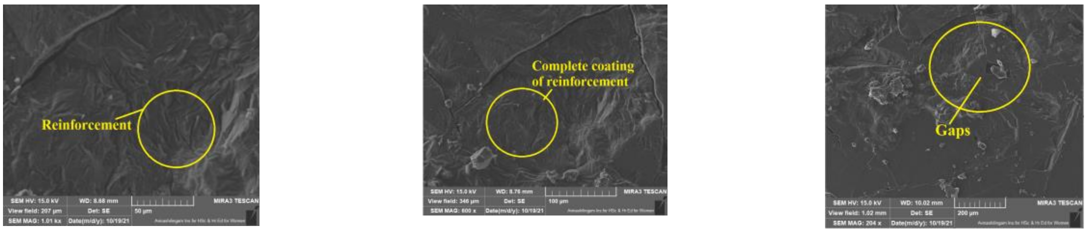


Plate 17d CAABE

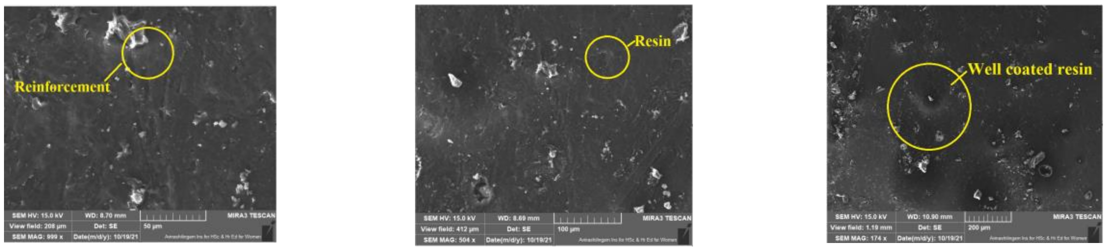


Plate 17c CABSE

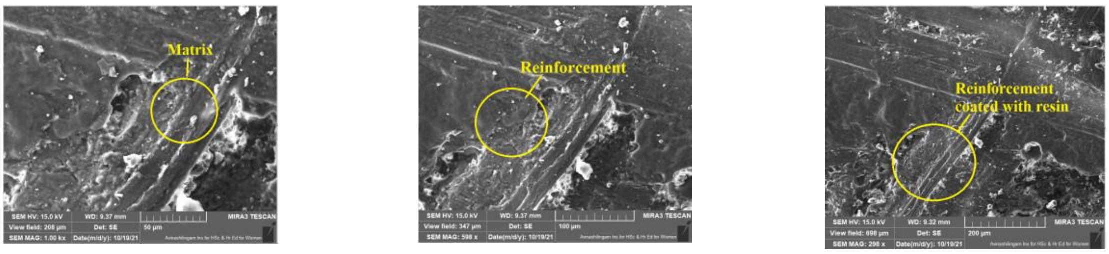


Plate 17b CASE

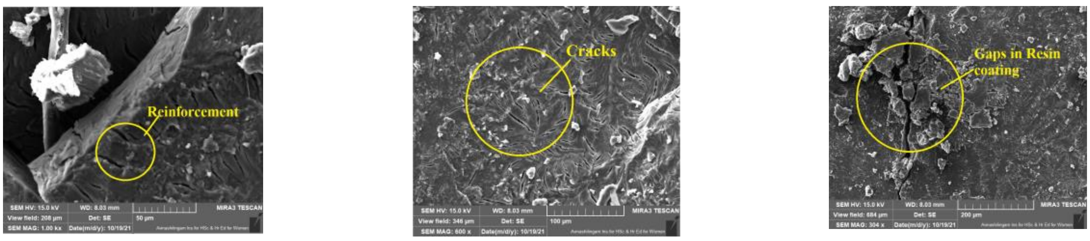


Plate 17e EAABSE

Plate 17 SEM Appearance of Composites at Different Magnifications

From Plate 17a-17e, it is clear that the samples have a scanning electron microscopic appearance, the micrographs of the samples are vividly observed at different magnifications, namely 50µm, 100µm and 200µm. In the sample EP it is clear that the epoxy resin has no fibre reinforcement as it is neat epoxy and the bonding of the slab is well defined. From Plate 17b, the sample CASE, it is clear that the resin is well coated over the reinforced material. This shows the perfect compatibility between the matrix and reinforcement. In sample CABSE the matrix has coated the reinforcement perfectly (Plate 17c). The Plate 17d for samples of CAABE showed the complete coating of reinforcement by the resin. The sample EAABSE showed the matrix and reinforcement vividly with the presence of small gaps in it. There are also some cracks noted in sample EAABSE (Plate 17e) in the matrix, which may be due to the improper compatibility of the reinforcement and matrix.

4.4.11 Fourier Transform Infrared Spectroscopic Analysis (FTIR)

For finding the presence of different functional groups in the samples, FTIR was the technique was used (Caban, 2022). It was done for all the prepared composite samples and the results are presented in Figures 46a – 46e and in Appendix XI

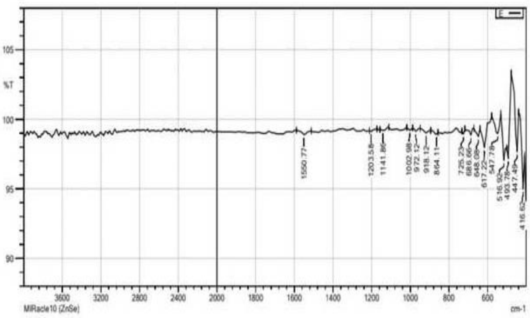


Figure 46a EP

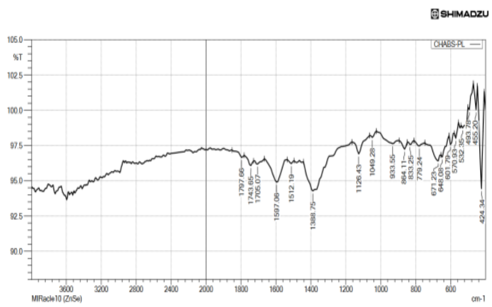


Figure 46b CAABE

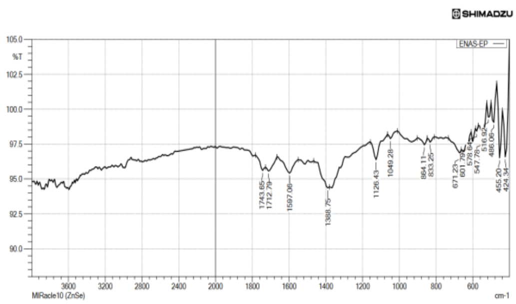


Figure 46d CASE

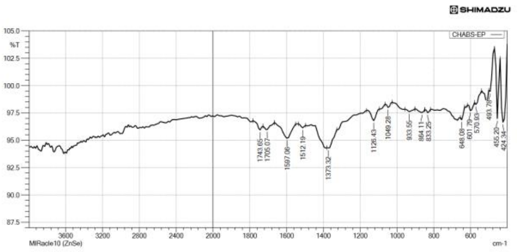


Figure 46c CABSE

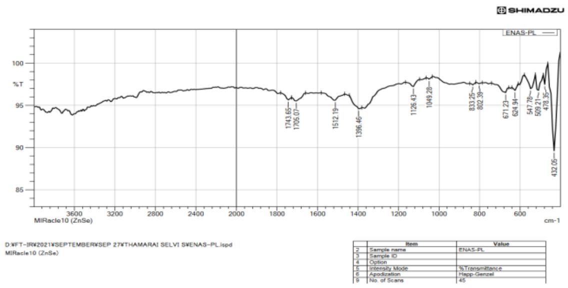


Figure 46e EAABSE

Figure 46 FTIR of Composites

From the Figure 46a-46e, the FTIR peak values of the sample CABSE are exhibited at 1743.65, 1705.07, 1597.06, 1512.19, and 1126.43 cm^{-1}, which are attributed to the presence of ester (C=O) carboxylic acid, aromatic compound (C-C) and fluoride (C-X) respectively. In the sample CASE, the peak values are noted at 1743.65, 1712.79, 1597.06, 1388.75, and 1126.43, which are attributed to the presence of ester (C=O**),** carboxylic acid (C=0) Aromatic compound (C-C), Alcohol (C-O) and fluoride (C-C), Achelous (C-O) and (C-X) fluoride. In the sample EAABSE, it was noted that the peak values were exhibited at 1743.65, 1705.07, 1512.19, and 1126.43 cm^{-1} depicted the presence of ester (C=O), carboxylic (C=O), Aromatic compound (C-C) and fluoride (C-X), functional groups. Hence, it could be concluded that there was the presence of carboxylic acid, alcoholic, and fluoride functional groups was found in the fabric reinforced composite samples, which were not present in the neat epoxy sample.

4.4.12 Soil Burial Test

The weight loss, degradation and visual evaluation of the soil buried samples for the established time are presented in following Tables and Plates.

4.4.12.1 Weight Loss of Composites

The loss in weight occurred in the samples before and after soil burial is expressed in the Table XLIX

Table XLIX

Weight Loss of Composites

S.No	Samples	Soil Burial Test (Days)						
		0	20		40		60	
		Weight (g)	Weight (g)	Loss (%)	Weight (g)	Loss (%)	Weight (g)	Loss (%)
1	EP	2.02	2.02	-	2.02	-	2.02	
2	CAABE	2.20	**2.20**	0	**2.09**	5.00	**2.07**	5.91
3	CABSE	1.80	1.80	0	1.76	2.22	1.70	5.56
4	CASE	2.08	2.05	1.44	2.01	3.36	1.98	4.80
5	EAABSE	2.02	2.01	0.50	2.00	0.99	1.98	1.98

From the Table XLIX, it is obvious that the sample EP exhibited a mass of 2.2g and did not show any loss or gain in weight even after sixty days of soil burial. The sample CASE showed a weight loss of 1.44 per cent and other samples did not lose weight on soil burial after twenty days. Among the fabric reinforced samples, the sample CAABE exhibited the highest weight loss after forty days with five per cent followed by the samples CASE, CABSE, and EAABSE with 3.36, 2.22, and 0.99 percentages respectively. After sixty days of burial, the sample CAABE showed the highest weight loss of 5.91 per cent which was followed by the samples CABSE, CASE, and EAABSE with 5.56, 4.80, and 1.98 percentages respectively.The fabric reinforced samples exhibited weight loss, and it was the highest in sample CAABE, which may be due to the attack of microbes on the sample.

4.4.12.2 Degradation of Composites

The degradation occurred in the soil buried sample after established time is presented in the Table L

Table L

Degradation of Composites

S.No	Samples	Soil Burial Test Days		
		20	40	60
		Degradation (% day)	Degradation (% per day)	Degradation (% per day)
1	CAABE	-	**0.125**	0.099
2	CABSE	-	0.055	0.093
3	CASE	0.072	0.084	0.080
4	EAABSE	0.025	0.024	0.033

From the Table L, it is clear that the degradation of the composite sample CASE was noted to be 0.072 per cent per day after 20 days of burial, but it was less in sample EAABSE with 0.025 per cent per day and no degradation was observed in both the samples CAABE and CABSE. After 40 days of burial, the degradation was noted to be the highest in sample CAABE with 0.125 per cent per day, followed by samples CASE, CABSE, and EAABSE with 0.84, 0.055, and 0.024 percent per day, respectively. After 60 days of burial, it was observed that the degradation was the highest in sample CAABE (0.099), which was followed by the samples CABSE, CASE, and EAABSE with 0.093, 0.080, and 0.033 per cent per day, respectively.

Hence the degradation was the highest in sample CAABE. This may be due to the fact that *Areca catechu* fibre is more favorable to microbes, which is in par with earlier study (Mahyudin *et al.*, 2020).

4.4.12.3 Visual Evaluation

The Table LI showed the results of visual evaluation for neat epoxy and fibre reinforced composites (Plate 18)

Table LI

Visual Evaluation of Soil Buried Composites

S.No	Samples	No. of Days	Colour				Texture				General Appearance		
			VB	B	D	VD	VR	R	S	VS	VG	G	F
1	EP	0	10	90	-	-	-	-	-	100	95	5	-
		20	-	10	80	10	-	-	-	100	90	10	-
		40	-	10	65	25	-	-	98	2	-	85	15
		60	-	-	68	32	-	-	95	5	-	80	20
2	CAABE	0	100	-	-	-	-	-	-	100	85	15	-
		20	5	80	15	-	-	7	80	13	65	35	-
		40	-	20	30	50	75	10	15	-	-	90	10
		60	-	-	40	60	55	45	-	-	-	75	25
3	CABSE	0	100	-	-	-	-	2	6	92	100	-	-
		20	10	30	60	-	-	5	80	15	78	22	-
		40	-	-	30	70	-	33	67	-	65	23	2
		60	-	-	15	85	10	75	15	-	-	68	22
4	CASE	0	3	97	-	-	-	-	3	97	-	100	-
		20	-	90	8	2	-	-	77	23	-	97	3
		40	-	-	88	12	-	25	75	-	-	88	12
		60	-	-	70	30	2	90	8	-	-	76	24
5	EAABSE	0	0	88	12	-	-	-	-	100	100	-	-
		20	-	75	25	-	-	10	80	10	98	2	-
		40	-	20	80	-	-	90	8	2	-	96	4
		60	-	10	90	-	-	95	5	-	-	95	5

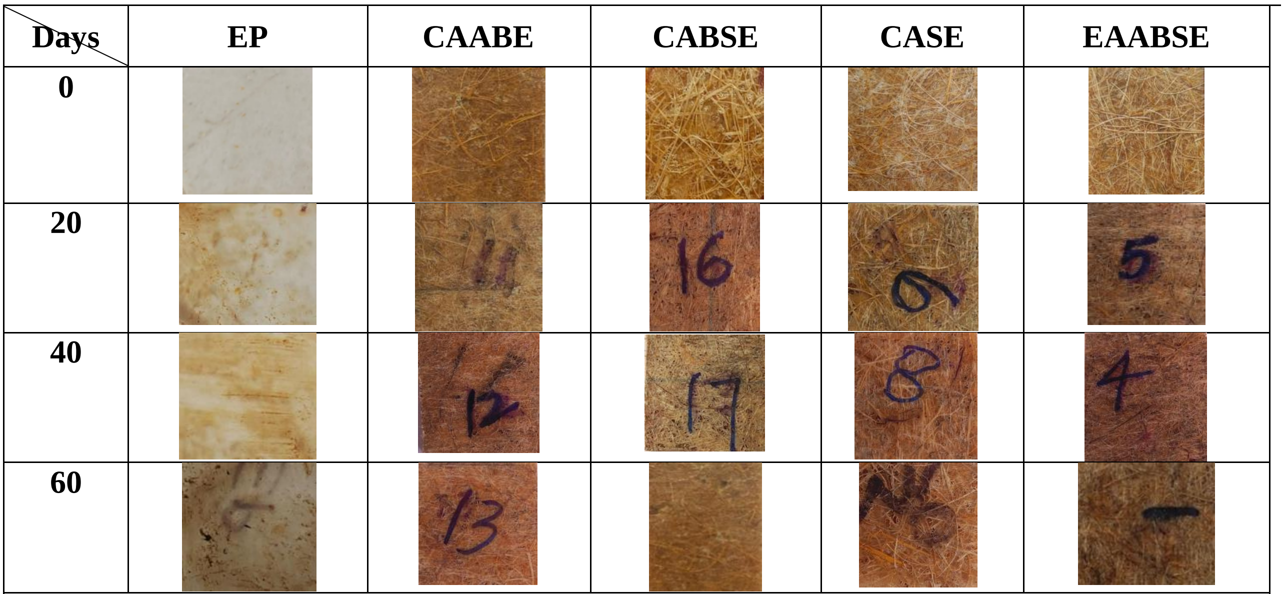


Plate 18 Soil Buried Composite and Neat Epoxy Samples

The Table LI and Plates 18 reveal that it is clear that the colour of the sample EP was expressed to be bright by 90 per cent of the judges for the unburied sample. This diminished gradually as after twenty, forty, and sixty days of burial, the samples were rated dull by 80, 65, and 68 percentages of judges, respectively. From the Plates, it was noted that there was adherence of soil and a slight stain on the surface of the composite samples EP.

Colour

The sample EAABSE was judged bright in colour by the maximum of 88 per cent of judges for the unburied sample, whereas after 20 days of burial, the sample was judged bright only by 75 per cent of the judges. After 40 and 60 days of soil burial, the samples became dull, as judged by 80 per cent and 90 per cent of them, respectively. The sample CASE was judged to be bright by 97 per cent of the judges for the unburied sample, followed by the sample buried for 20 days, which was judged by 90 per cent of them as bright. After 40 and 60 days of soil burial, the samples were noted to be dull, as per the expressions of 88 per cent and 70 per cent of the judges, respectively. The sample CAABE was judged to be very bright by cent percent of judges in the case of unburied sample. After 20 days of burial, it showed lesser brightness, as per the expression of 80 per cent of the judges. The samples turned very dull after 40 and 60 days of soil burial, as expressed by 50 per cent and 60 per cent of the judges respectively. The sample CABSE was judged to be very bright by cent percent of judges. The sample became dull after 20 days of burial, as expressed by 60 per cent of judges. After forty and sixty days of soil burial the samples turned very dull, as expressed by 70 per cent and 85 per cent of the judges respectively. Hence, it could be concluded that a longer duration of soil burial had made the samples duller and it was the highest after the longest period of soil burial.

Texture

The sample EP showed a very smooth texture before and after 20 days of burial, as expressed by cent percent of judges. After forty and sixty days of burial, this reduced from very smooth to smooth as judged by 98 and 95 per cent of judges respectively. The samples in EAABSE showed a very smooth surface, as judged by cent per cent of judges. 80 percent of judges expressed satisfaction that the sample had a smooth surface after 20 days of burial. The roughness increased, as expressed by 90 and 95 percentages of judges respectively after forty and sixty days of soil burial. The unburied sample of CASE was judged to have a very smooth surface by 97 per cent judges. This reduced from very smooth to smooth, as expressed by 77 and 75 percentages of judges for twenty-day and forty-day buried samples respectively. The sample showed roughness as expressed by 90 per cent of them after 60 days of burial. The sample CAABE was rated by cent per cent of judges as very smooth. This reduced slightly to smooth from very smooth, as expressed by 80 per cent of judges, after 20 days of soil burial. The sample turned rough and very rough, as expressed by 75 and 55 per cent of judges respectively after forty and sixty days of soil burial. The sample CABSE was rated very smooth by 92 per cent of them. This was reduced to smooth from very smooth, as expressed by 80 and 67 percentages of judges after twenty and forty days of burial respectively. After 60 days of soil burial, the sample turned rough, as per the expression of 75 per cent of judges. Hence, it could be concluded that all the fabric reinforced samples gradually turned rough with an increase in the period of soil burial, and of these, the sample CAABE turned very rough.

General Appearance

The sample EP was expressed as very good by 95 per cent of judges for the unburied sample, which slightly reduced to 90 per cent after 20 days of burial. After 40 and 60 days of burial, the appearance was rated as good by 85 and 80 percentages of judges respectively. The sample EAABSE was rated to have a very good appearance, as expressed by cent per cent of judges for the unburied sample, which slightly decreased to 98 per cent after 20 days of burial. The sample, which was buried for 40 and 60 days, was judged to have a good appearance, as expressed by 96 per cent and 95 per cent of judges respectively. The sample CASE was rated to have a good appearance by cent per cent of them for an unburied sample, which reduced gradually on established periods of soil burial for 20 days, 40 days, and 60 days, as expressed by 97 per cent, 88 per cent and 76 per cent of judges respectively. The sample CAABE was judged to have a very good appearance by 85 per cent of judges in the unburied sample, which gradually reduced to 65 per cent after twenty days of burial. After forty and sixty days of soil burial the samples were judged to have a good general appearance as expressed by 90 and 75 per cent of judges respectively. Sample CABSE was judged to have very good appearance by cent per cent of judges in the unburied sample, which reduced to 78 per cent and 65 per cent of judges for twenty and forty days of burial respectively. This showed a decrease in rating for general appearance as expressed by 68 per cent judges for good general appearance. Hence, the general appearance was reduced in all the samples after soil burial, and the effect was maximum in the sample CAABE after a longer period of soil burial.

4.4.14 Comparison of Mechanical Properties of Composites

The standard deviation of the observed values for the properties Tensile Strength, Elongation, Flexural Strength, Impact Strength, Compressive strength, and Hardness already presented in Tables LI for the composite structures is expressed in Figure 47. The Table with the standard deviation values for the mechanical properties is presented in the Appendix XII.

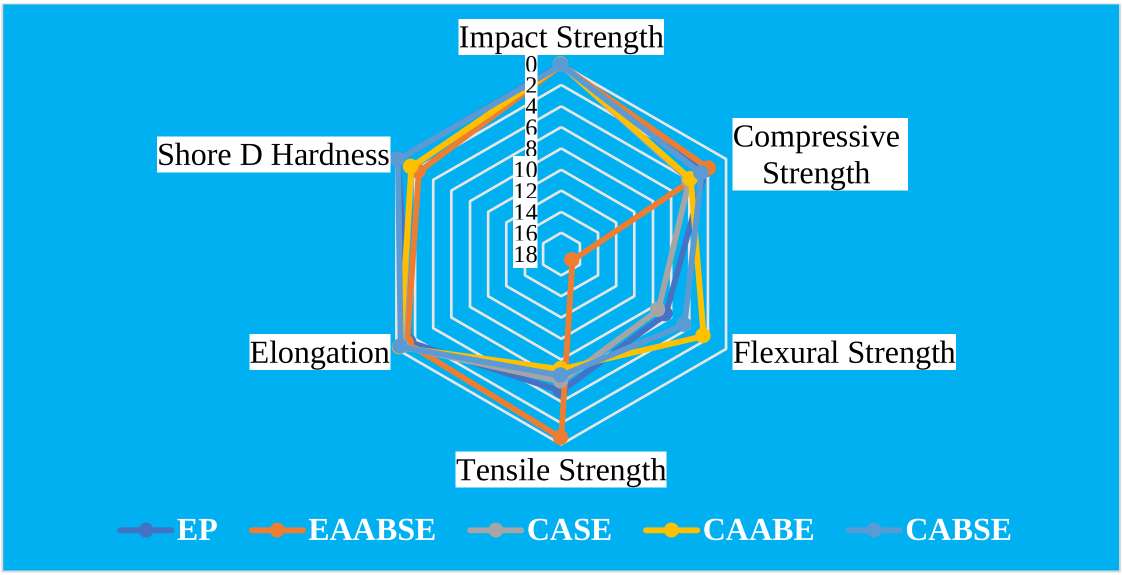


Figure 47 Comparison of Mechanical Properties of Composites

From the Table LII and Figure 47 from the Radar chart, it is obvious that the sample EAABSE exhibited the highest flexural strength, followed by CASE, whereas tensile strength was noted to be the highest in the sample CAABE. This was followed by sample CASE but was the least in sample EAABSE. Hardness was noted to be the highest in sample EAABSE and the least in sample CABSE. The compression was highest in sample CAABE and least in sample EAABSE. All the considered (mechanical) properties of the sample with nonwoven reinforcement improved when compared with the non-reinforced samples, and all the properties were noted to be average in both the samples CASE and CABSE. Hence, this two-hybrid sample was considered for further analysis.

4.5 Evaluation of Selected Composites

The results obtained for the special tests which were carried out for the selected composites are presented in the following headings

4.5.1 Roughness of Selected Composites

The results obtained from roughness test for selected composites along with neat epoxy are presented in the Table LII (Figure 48)

Table LII

Roughness of Composites (µm)

S.No	Samples	Rp (µm)	Rv (µm)	Rz (µm)
1	EP	**4.052**	3.035	5.461
2	CASE	**4.573**	7.048	7.498
3	CABSE	**8.913**	11.50	10.96

***Rp -** Peak height, **Rv** - Valley depth, **Rz -** Average of (Rp-Rv) from five sections

From the Table LII, it is obvious that the sample EP showed an RP value of 4.052 µm. The peak value (RP) was the highest among all three samples in sample CABSE with 8.913 µm followed by sample CASE with 4.573 µm and sample EP. The valley (Rv) was the highest in sample CABSE (11.50 µm) followed by samples EP and CASE with 7.048 µm and sample 3.035 µm respectively. The Rz value, which is the average of (Rp-Rv) from five sections, showed the highest value in sample CABSE with 10.96 µm followed by samples CASE with 7.498 µm and sample EP with 5.461 µm. Hence, it could be concluded that both the fabric reinforced samples showed better roughness results than the unreinforced neat epoxy sample, whose roughness was greater in sample CABSE. This roughness may aid in good acoustic properties.

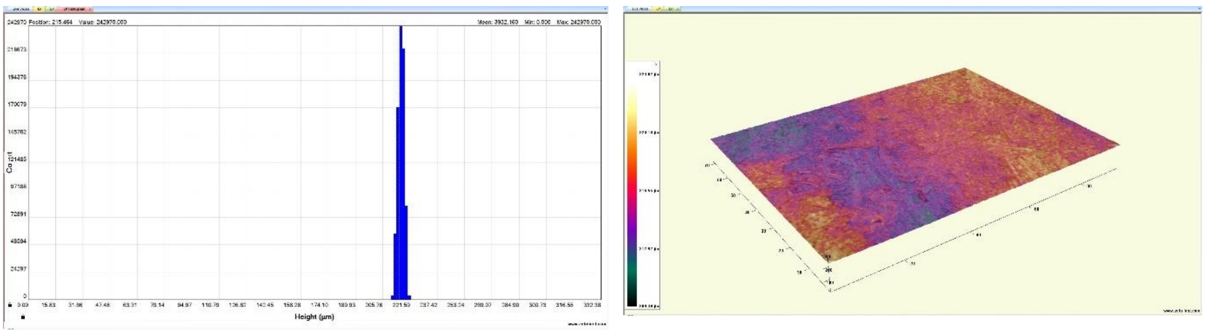


Figure 48a EP

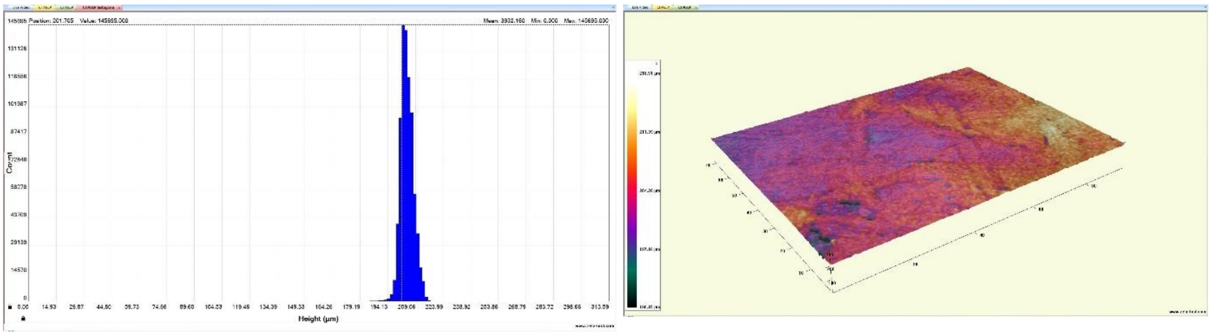


Figure 48b CASE

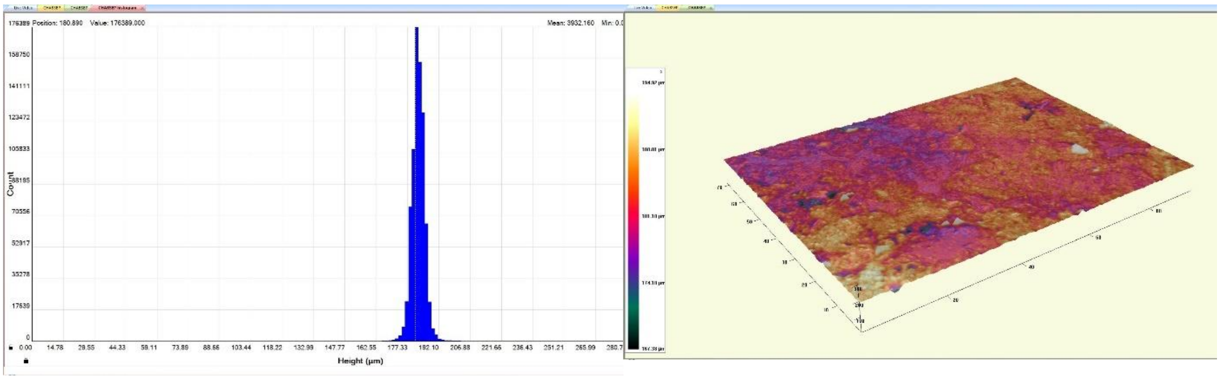


Figure 48c CABSE

Figure 48 Roughness of Neat Epoxy and Composites

4.5.2 Drill Behavior of Selected Composites

The results obtained from the drill test for the neat epoxy and composites are presented under the following headings.

4.5.2.1 Penetration Time

The time taken for penetration of each drill bit into the composite structure is presented in Table LIII

Table LIII

Drill test of the Composite Structures

S.No	Samples	Penetration time with various Drill Bits (sec)		
		2HSS	3HSS	4HSS
1	EP	2.10	2.19	2.43
2	CASE	2.09	**2.38**	2.68
3	CABSE	**2.28**	2.35	2.62

From the Table LIII, it is clear that the penetration time taken was the highest at 2.28 seconds in sample CABSE followed by the samples EP (2.10 seconds) and CASE (2.09 seconds) using a 2mm drill bit (2Hss). When a 4mm drill bit was used, the sample CASE took the longest time of 2.38 seconds, which was followed by the samples CABSE with 2.35 seconds and EP with 2.19 seconds. This same trend was observed when the drill bit 4HSS was used, with the highest time of 2.68 seconds for sample CASE. As the size of the drill bit increased, the time taken for penetration into the fibre reinforced composite structures also increased. The sample CASE had a higher penetration time than the sample EP in all three sizes of drill bits. This may be due to the higher hardness of the sample. Hence, the time taken was the highest in the sample CASE using a 4 mm drill bit, and the least was also observed in the sample CASE with a 2 mm drill bit.

4.5.2.2 Damage and Cut Fibres

The damage of cut fibres occurred on drilling are expressed in the Table LIV and Plate 19.

Table LIV
Observation of Damage using various Drill Bits

S.No	**Samples**	**Observation of Damage using various Drill Bit Diameter**					
		2mm		**3mm**		**4mm**	
		Damage	Cut fibres	Damage	Cut fibres	Damage	Cut fibres
1	EP	H	No	VH	Md	H	M
2	CASE	L	H	No	L	Md	H
3	CABSE	Md	H	No	No	VL	L
VL- Very Low, VH – Very High, H – High, L – Low, VL – Very Low, Nil – No, Md – Medium, Mo – More							

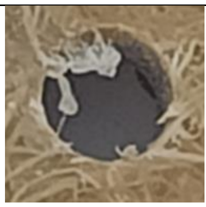
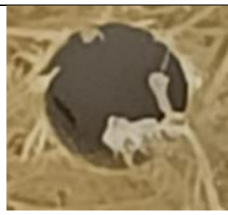
Samples	Drill Bit Biameters		
	2 mm	3 mm	4 mm
EP			
CASE			
CABSE			

Plate 19 Sample Damage by Drilling

From the Table LIV and Plate 19, it is clear that the damage level was low in sample CASE, medium in sample CABSE, and high in sample EP, when a 2 mm drill bit was used. The damage level was very high in sample EP, no damage was found in both the samples CASE and CABSE using a 3 mm drill bit and when a 4 mm drill bit was used, the damage was at a very low level in sample CABSE, medium in sample CASE, and high in sample EP. As the observation for the presence of cut fibres in the drilled portion of the samples showed no cut fibres due to the absence of reinforcement, there was a high level of cut fibres observed in samples CASE and CABSE at the 2 mm drill bit. Using a 3 mm drill bit, the observation of cut fibres was low and not found in samples CASE and CABSE respectively. In the case of a 4 mm drill bit, the sample CABSE showed a low level of cut fibres and the sample CASE exhibited a high level of cut fibres. This may be due to the insertion of drill bit with a larger diameter. In all three cases, though the damage was minimum on the exit side of drill bit in the slab, it showed protruding effects, which were also absent in the sample CABSE. The perfect drilling without delamination was noted in the sample CABSE even while using a 4 mm drill bit. This enables an easy riveting process and may be useful for panels.

4.5.3 Flammability of Selected Composites

The observation from the flammability test of the neat epoxy and composites are presented in the Table LV (Plate 20).

Table LV

Flammability of Composite Structures

S.No	Sample Name	Flame time (Seconds)	Burning after flame time (Seconds)	Glowing after burning (Seconds)	Dripping particle while ignition
1	EP	53	17	Nil	Very high
2	CABSE	47	75	Nil	Nil
3	CASE	38	70	Nil	Nil

Plate EP

Plate CASE

Plate CABSE

Plate 20 Burnt Composite Slabs

From the Table LV and Plate 20, it is obvious that the neat Epoxy sample EP took 53 seconds for ignition after the standard flame inducing time of 12 seconds. The composite slabs CAABE and EAABSE took 7 seconds and 13 seconds respectively, after the standard flame induction time (12 seconds). The burning after flame was the highest in the sample CABSE (75 seconds). The glow after burning was observed in the samples CAABE and ENAABSE for 70 seconds and 25 seconds respectively which was not seen in the samples, EP, CABSE, or CASE. There was very high dripping of particles during ignition in the neat epoxy sample, which was not noted in the reinforced samples. Hence, it could be concluded that there was delayed ignition in the sample CABSE though flame was noticed for the longest duration which may be due to the fibre reinforcement and also the chemical treatments the fibres underwent namely alkalization and benzoylation.

4.5.4 Acoustics

The acoustic tests of the materials which were determined in terms of sound transmission loss and sound absorption coefficient are expressed under the following heads

4.5.4.1 Transmission Loss

The Table LVI revealed the results of transmission loss of neat epoxy and fibre reinforced composites.

Table LVI

Transmission Loss of Composite Structures

S.NO	Frequency (Hz)	Transmission Loss (dB)		
		EP	CASE	CABSE
1	100	7.70747	7.61694	7.38256
2	200	6.27215	6.89924	2.79106
3	300	3.5576	4.0076	2.96994
4	400	0.6321	1.48134	**2.82138**
5	500	4.14544	0.48952	1.9025
6	600	6.1532	6.0875	8.6449
7	700	12.128	8.7179	6.3649
8	800	6.6074	7.5908	6.2612
9	900	6.91011	9.56963	**11.0078**
10	1000	3.766	2.5511	3.1118
11	1100	12.986	13.53	14.235
12	1200	9.19	12.094	5.8115
13	1300	10.523	10.027	11.048
14	1400	1.69644	3.03745	1.12072
15	1500	5.6091	6.00249	**8.17596**
16	1600	15.556	17.33	11.848
17	1700	4.5199	11.295	7.8841
18	1900	0.6477	1.0294	0.17992
19	2000	14.8085	14.2385	**16.4495**
	Average	**7.021901**	**7.557653**	**6.842671**

The Table LVI and Figure 49 reveal that, the sample EP exhibited the highest transmission loss of 7.70747 dB at 100 Hz, followed by the samples CASE and CABSE with 7.61694 dB and 7.38256 dB respectively. Also, at 500 Hz, the sample EP exhibited the highest sound transmission loss of 4.14544 dB, followed by the sample CASE with 0.48952 dB. Among the fabric-reinforced polymer composite samples, the sample CABSE exhibited better transmission loss values at four frequency points, namely 400 Hz, 900 Hz, 1500 Hz and 2000 Hz, with 2.82138 dB, 11.0078 dB, 8.17390 dB, and 16.4495 dB, respectively, than the sample CASE. The sample CASE showed the highest transmission loss values only at two points, namely 200 Hz and 1400 Hz, with **6.89924 dB** and **3.03745 dB** respectively. The average transmission loss values of all the frequencies showed that it was the maximum in sample CASE (7.557653), which was followed by the samples CABSE and EP. Hence, it could be concluded that the sample CABSE showed the best results even at the highest frequencies, though the average value was slightly lower than the sample CASE.

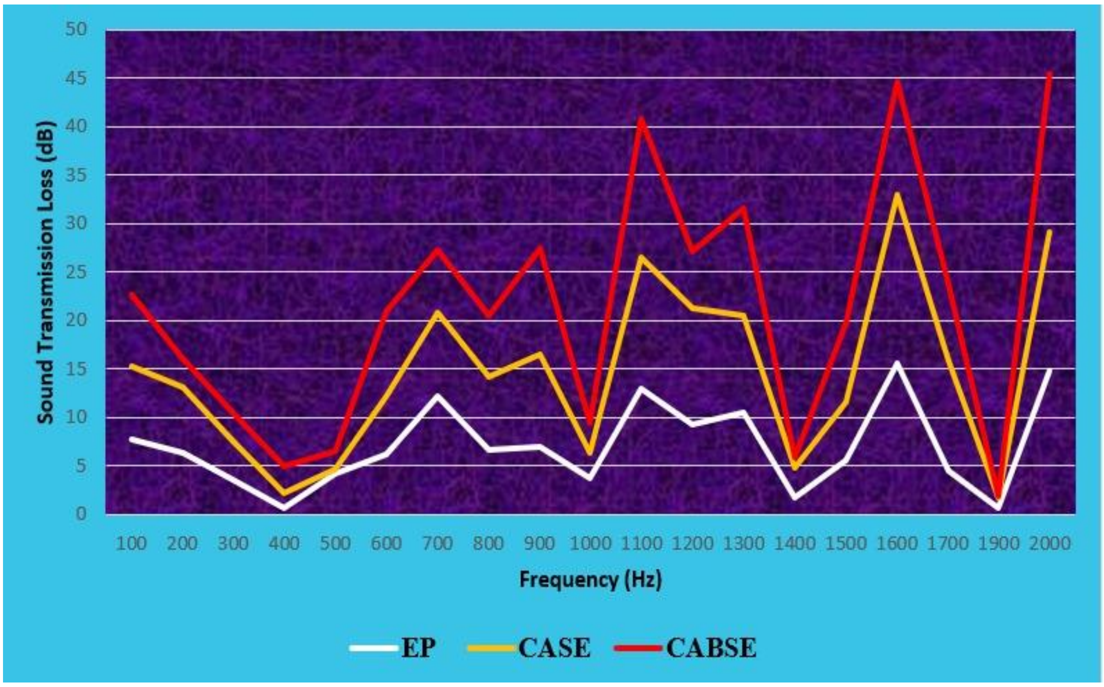


Figure 49 Transmission Loss of Composite Structures

4.5.4.2 Sound Absorption Coefficient (SAC)

The findings obtained for the SAC (α) for neat epoxy and composites are presented in Table LVII and Figure 50

Table LVII

Sound Absorption Coefficient of Composites

S.No	Frequency (Hz)	Sound Absorption Coefficient (α)		
		EP	CASE	CABSE
1	200	0.035636	**0.239425**	0.084583
2	400	0.037636	0.022723	**0.04538**
3	600	0.034276	0.030768	**0.042558**
4	800	**0.044719**	0.03177	0.033574
5	1000	0.051649	0.081913	**0.106817**
6	1200	0.081219	0.103247	**0.140296**
7	1400	0.106679	0.079096	**0.202947**
8	1600	0.080987	0.098669	**0.272391**
9	1800	0.066124	0.057009	**0.418574**
10	2000	0.034805	0.047894	**0.64669**
11	2200	0.126176	0.08722	**0.982114**
12	2400	0.242287	0.252266	**0.85229**
13	2600	0.319991	0.263958	**0.759543**
14	2800	0.176811	0.256948	**0.733727**
15	3000	0.200119	0.220459	**0.499032**
16	3200	0.260981	0.21583	**0.344504**
17	3400	**0.373317**	0.237504	0.285204
18	3600	0.364554	**0.400925**	0.204541
19	3800	0.306663	**0.69975**	0.285678
20	4000	0.253876	1.14385	**0.35322**
	Average (α)	**0.15993**	**0.22856**	**0.36468**

From Table LVII and Figure 50, it is clear that the sample EP showed maximum α coefficient values of 0.044719 and 0.373317 at 800 and 3400 Hz frequencies respectively. The sample CABSE showed the highest α coefficient values at 200, 3600, and 3800, with α coefficient values of 0.239425, 0.400925, and 0.69975 respectively. But the sample CABSE showed the highest SAC values at 15 frequency points. The highest SAC among the 15 points was at 2200 Hz, with α coefficient values of 0.982114. The average α coefficient values also showed the highest value in sample CABSE with 0.36468, followed by sample CASE (0.22856) and sample EP (0.15993).

Hence, the sample CABSE showed the best α coefficient result among all the three samples. This may be due to the increased roughness exhibited by the sample and the reinforcement that has been done.

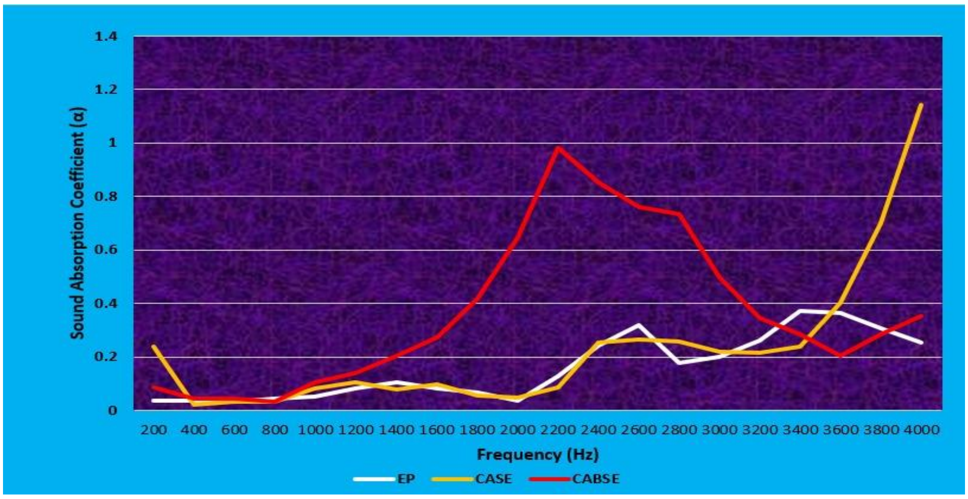


Figure 50 Sound Absorption Coefficient of Composites

4.5.4.3 Comparison Between Nonwoven Fabrics and Composite Structures

The Table LVIII and Figure 51 reveals the results of the comparison of sound absorbance coefficients between Nonwoven fabric and selected composite structures, along with a neat epoxy sample. The data in the table are from the previous Tables XXXV, XXXVII and LXVII for comparison, they have been presented again.

Table LVIII
Comparison between Nonwoven fabrics and Composite Structures

S. No	Frequency (Hz)	Samples			*	
		EP	CHAS	CHABS	CASE	CABSE
1	200	0.03564	0.379473	0.2598	0.081541	0.01522
2	400	0.03764	0.19638	0.19629	0.114365	0.267646
3	600	0.03428	0.08991	0.033712	0.237833	**0.82667**
4	800	0.04472	0.130049	0.113293	**0.810151**	0.645777
5	1000	0.05165	0.142565	0.105535	0.531508	0.309948
6	1200	0.08122	0.240168	0.22937	0.249926	0.194555
7	1400	0.10668	0.163213	0.122097	0.195857	0.171603
8	1600	0.08099	0.280658	0.244457	0.13748	0.112267
9	1800	0.06612	0.277618	0.237292	0.115562	0.100154
10	2000	0.03481	0.242312	0.209762	0.076447	0.080764
11	2200	0.12618	0.06866	0.07053	0.069471	0.014102
12	2400	0.24229	0.641331	0.597112	**0.997313**	**0.905211**
13	2600	0.31999	0.458273	0.678955	0.50527	0.136308
14	2800	0.17681	0.257343	0.06455	0.251359	0.289382
15	3000	0.20012	0.383772	0.392644	0.248961	0.076575
16	3200	0.26098	0.365486	0.345585	0.726006	0.34546
17	3400	**0.37332**	0.57295	0.701575	0.51813	0.384403
18	3600	0.36455	0.359089	0.218174	**1.87648**	0.021738
19	3800	0.30666	**0.694028**	**0.781464**	0.048877	0.479715
20	4000	0.25388	0.415341	0.57973	0.23994	**0.838832**
	Average (α)	0.159927	0.317931	0.309096	0.401624	0.310817

*Values repeated for the comparison from previous Tables

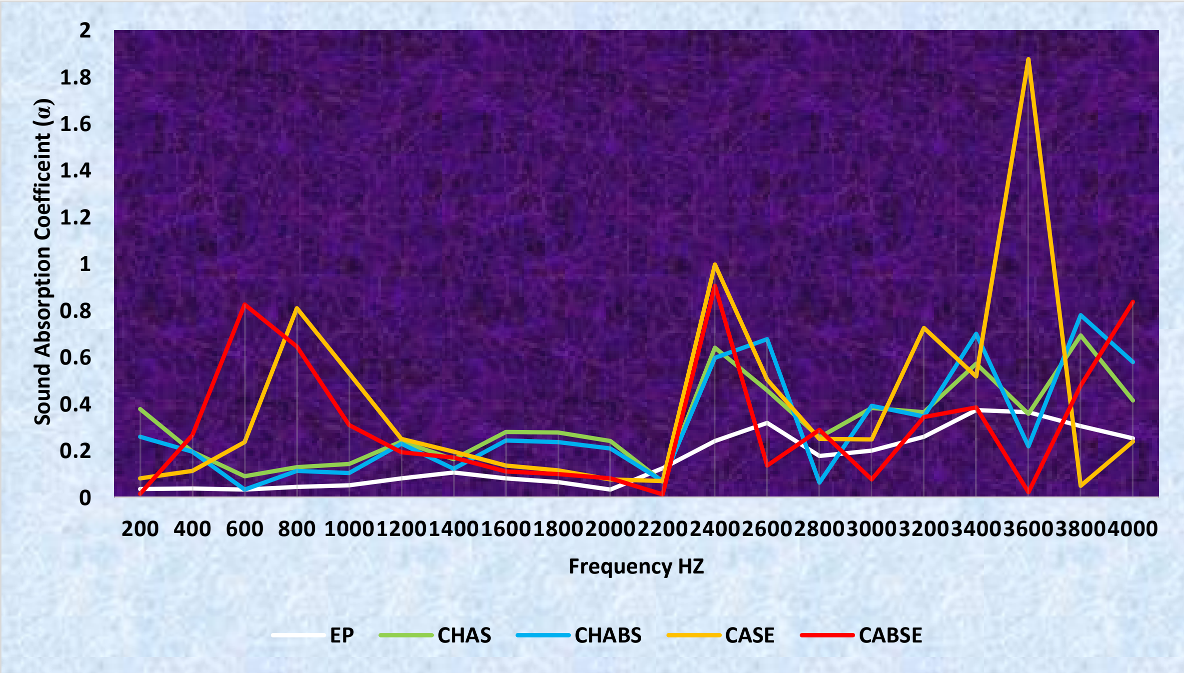


Figure 51 Comparison Between Nonwoven Fabric and Composite Structures for Acoustic Property

Nonwoven material also showed better SAC values than neat epoxy sample (EP), as at very high frequency (3800 Hz), both the nonwoven samples CHAS and CHABS exhibited the highest SAC values with 0.694028 dB and 0.781464 dB, respectively, which was greater in sample CHABS. Natural fibre reinforced composites, namely CASE and CABSE exhibited the maximum sound absorption coefficient values of 0.810151 and 0.82667 respectively, at lower frequencies of 800 Hz and 600 Hz. These two composite slabs, CASE and CABSE, showed the best results with 0.997313 dB and 0.905211 dB, respectively, at high frequency of 2400 Hz. At the maximum frequency (4000 Hz), the sample CABSE showed the best results (0.838832 dB), which is in par with earlier studies, and as suggested, this may find its use in aeronautical applications (Yang and Li 2012).

Hence, it could be concluded that the fabric reinforced hybrid composite structures may also serve as good acoustic panels at higher frequencies.

4.5.4.4 Noise Reduction Coefficient (NRC)

The results obtained for **NRC** for the neat epoxy, composites and the respective nonwoven structures utilized for composite making are presented in Table LIX.

Table LIX

Noise Reduction Coefficient (NRC)

S.No	Frequency (Hz)	EP	CHAS	CHABS	CASE	CABSE
1	500	0.04141	0.0784	0.072851	0.142153	0.758101
2	1000	0.05165	0.142565	0.105535	0.531508	0.309948
3	2000	0.03481	0.242312	0.209762	0.076447	0.080764
4	4000	0.25388	0.415341	0.57973	0.23994	0.838832
	Mean	0.0954375	0.219655	0.24197	0.247512	**0.496911**

The Table LIX reveals that the NRC value was noted to be 0.0954375 in sample EP, whereas the reinforced samples, namely CASE and CABSE, exhibited better NRC values of 0.247512 and 0.496911 respectively. The nonwoven fabric samples, namely CHAS and CHABS, showed NRC values of 0.219655 and 0.24197 respectively, which were improved by the conversion into composites. The material with a noise reduction coefficient value greater than 0.20 is absorption material (Su *et al.*, 2009). All the four samples, namely CHAS, CHABS, CASE, and CABSE, can be used as sound absorption materials for the results exhibited. The best NRC value was exhibited by the sample CABSE with 49.6 per cent (**0.496911**) which could be well utilized as a sound absorbent panel. Hence, it could be concluded that the sample nonwoven fabric reinforced composite specimen CABSE showed the greatest noise reduction coefficient, depicting 49 per cent of sound absorbency rate.

4.5.5 Cost Estimation of Composite Slab

The estimated cost for one square foot composite slab is presented in Table LX (Appendix XIII)

Table LX
Cost Estimation for Composite Preparation (one Sq./ft)

S.No	Cost Particulars	Product Rate (Rs) Unit price
1	Fibre	45
2	Fibre Treatment	50
3	Nonwoven Fabrication	45
4	Resin	110
5	Cutting and Shaping	20
6	Labour involved and others	100
	Total	**370**

The Table LX reveals that the manufacturing cost for one square foot of composite slab includes the costs for fibre – Rs 45/-, Treatment of fibres – Rs 50/-, Nonwoven Fabrication Rs 45/-, Resin – Rs 110/-, Cutting and Shaping Rs 20/-, labour involved, and other hidden expenses Rs 100/-. The total cost of one square foot of slab prepared from natural fibre reinforced (in nonwoven fabric form) composite slab is equal to Rs 370/-. This may be comparatively lesser than the selected commercially available acoustic panels. But when this is produced in large scale, it would definitely be cost effective competing with other commercially available products.

4.5.6 Feedback for Selected Composite Materials

Feedback obtained about the prepared reinforced composite slab for the general appearance was judged to be 'very good' by a maximum of 40 percent of judges. This was followed by their expression as 'good' (32 percent) for texture and 24 per cent who expressed 'very good' texture. The strength was expressed to be good by the maximum of 44 per cent of judges, followed by excellent and very good by 32 per cent and 24 percent of them, respectively. The respondents expressed that there would be good potentiality for the prepared composite materials.

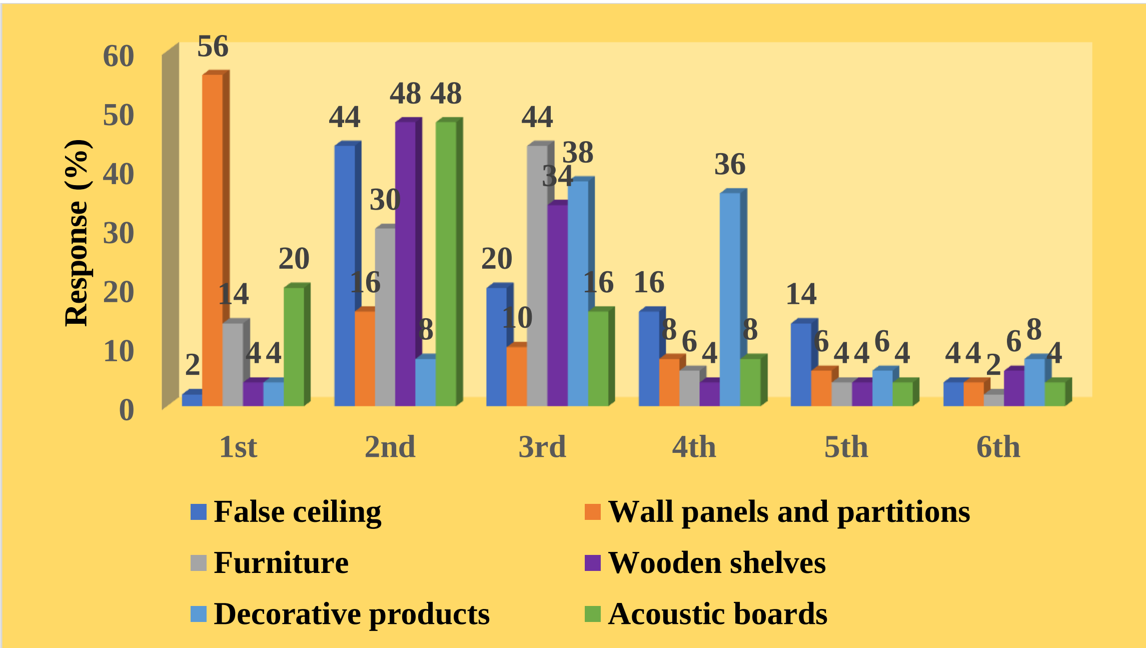


Figure 52 Application of Composite Materials

The maximum number of respondents (95.8 per cent) expressed that the prepared composite slab would be suitable for building materials. As for the application of the prepared composite material as a building material, the order and ranking were given as first by the maximum number of judges for wall panels and partitions (56 per cent), as second for acoustic boards (48 per cent), as third for wooden shelves (48 per cent), as fourth for false ceilings (44 per cent), as fifth for furniture (44 per cent), and sixth for decorative products (38 per cent) Figure 52. A maximum of 96 per cent of judges expressed that the cost fixed for the prepared slabs was cost effective. About market potentiality cent per cent of judges expressed that the composite slabs would have market potentiality in future. The preference for prepared, eco friendly material was by cent per cent of the respondents and the reason given by them was environmental protection (75 per cent) followed by social responsibility. About 96 per cent of the respondents expressed that they would recommend the prepared composite slabs for buildings. Hence, it could be concluded that this eco-friendly hybrid composite slab with novelty and functionality would find its application as panel boards, decorative products, and furniture in the future.