Compressive Properties of Tropical Natural Fibers Reinforced Epoxy Polymer Composites

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Abstract

Fiber reinforced plastics composites are particularly valued for their high tensile strength. Other mechanical properties, especially compressive strength is often overlooked during the characterization process. In fact, the comparatively low compression strength of some composite reduces their promising application. This paper presents the experimental investigation on the compressive strength of epoxy polymer composites reinforced by natural fibers of sisal, jute, hemp and bamboo grown in tropical area. The natural fiber composites were prepared using vacuum bagging method and the fibers were treated with alkali treatment prior to further processing. The results showed that the average values of compressive strength obtained in this work ranged from 31.69 MPa to 86.64 MPa. Those results indicate that the obtained compressive strength of natural fibers composites investigated in this research were comparable to the results of previous work, which ranged from from 16.75 MPa to 108.07 MPa.

Keywords: compressive strength, epoxy, natural fiber composites, vacuum bagging

Abstrak

Komposit polimer yang diperkuat dengan serat biasanya dihargai secara khusus berdasarkan kekuatan tarik yang dimilikinya. Sifat mekanik yang lain, khususnya kuat tekan seringkali diabaikan dalam proses karakterisasi. Padahal, kuat tekan yang rendah akan mengurangi peluang aplikasi dari produk komposit meskipun mempunyai kuat tarik yang tinggi. Artikel ini mempresentasikan hasil penelitian eksperimen yang dilakukan dengan menguji kuat tekan komposit resin epoxy polimer yang diperkuat dengan beberapa serat alam yang biasa tumbuh di daerah tropis; sisal, jute, hemp dan bambu. Komposit dibuat dengan metode vacuum bagging dan serat alam yang digunakan sebagai penguat terlebih dahulu diawetkan dengan perlakuan alkali. Hasil pengujian menunjukan bahwa kuat tekan komposit yang dihasilkan berkisar antara 31 MPa sampai 86 MPa. Hasil tersebut mengindikasikan bahwa kuat tekan komposit yang dihasilkan hampir sama dengan hasil-hasil penelitian yang sudah dilakukan sebelumnya, yakni berkisar antara 16 MPa sampai 108 MPa.

Kata kunci: epoksi, komposit serat alam, kuat tekan, metode vacuum bagging

Introduction

Most of research works in the field of natural fiber composites have been focused only on the tensile and flexural properties of natural fiber composites. Only few works have been related to the compressive and shear properties analysis. Rajulu *et al.* (2005) reported that the compressive strength of *Hildegardia populifolie* fiber reinforced polyester resin is about 114.73 MPa (untreated) and 123.36 MPa (treated with alkali solution). Naidu *et al.* (2011) investigated the compressive and impact properties of hybrid composite made of sisal and glass fiber with polyester matrices. They found that the prepared composite has the compressive strength of 113 MPa. Also, Samuel *et al.* (2012) studied the mechanical properties of several natural fibers reinforced polyester resin.

Table 1 Compressive strength and compressive modulus of different natural fiber composites from several literatures

No	Fiber	Matrix	Compressive strength, MPa	Compressive modulus, MPa	References
1	Gomuti	Epoxy	82.08	1930	Ticoalu *et al*. (2011)
2	Gomuti	Vinylester	108.07	2010	Ticoalu *et al*. (2011)
3	Gomuti	Polyester	104.07	2140	Ticoalu *et al*. (2011)
4	Sisal	Polyester	113	-	Naidu *et al*. (2011)
6	Banana	Resin	16.75	-	Samuel *et al*. (2012)
7	Sisal	Resin	42	-	Samuel *et al*. (2012)
8	coconut	Resin	30.35	-	Samuel *et al*. (2012)
9	*Hidegardia populifolia*	Polyester	114.73	-	Rajulu *et al*. (2005)

It was found that the compressive strength of polyester composite reinforced with banana, sisal and coconut fibers was 16.75 MPa, 42 MPa, and 30.35 MPa, respectively. In addition, Ticoalu *et al.* (2012) assessed the effect of using different thermoset resins as the matrices of gomuti fiber composite. It was found that the compressive strength of gomuti/epoxy composite was 82.98 MPa, gomuti/vynilester reached 108 MPa, and 104 MPa for gomuti/polyester composite. The above mentioned compressive strength of natural fiber composites are summarized in Table 1.

In reality, fiber reinforced polymer composites are particularly valued for their high tensile strength. However, the comparatively low compressive strength of some composite reduces their potential application. Therefore, measuring the compressive strength of natural fiber composites is of particular interest as well as their tensile strength. This research was aimed at investigating the compressive strength of epoxy resin composite reinforced with natural tropical fibers of sisal, hemp, jute and bamboo.

Materials and Methods

Sample preparations

Four tropical natural fibers were used in this research, i.e. sisal, jute hemp and bamboo. Jute and sisal fibers used in this research were chemically treated using alkali treatment. The alkaline treatment was carried out by soaking natural fibers in 2% NaOH. For the post treatment, the treated fibers were washed several times with warm tap water, neutralized with acetic acid and washed with demineralized water. The fibers were then allowed to dry for 3 days at room temperature. The percentage of NaOH used in this research was 2% by weight (2% wt). A modified low viscosity epoxy resin (R180) was used with a hardener (H180) for the matrix of the composite. The natural fiber laminates were prepared using vacuum bagging method, which is a process that combines a manual method using hand-lay-up or spray-up on the open mold to produce a laminated component with a vacuum process after covering the laminates using polymeric sheet (Kaynak & Akgul 2001, Akovali 2001). The process of sample preparation using vacuum bagging process is shown in Figure 1.

Testing set-up

Compressive or compression properties are a fundamental type of test used to characterize materials. Static compressive tests apply an escalating compressive load until failure or apply a specific load and hold it for a certain

period. The compressive test of NFCs in this research was carried out as per ASTM D 695M standard. This standard is suitable for measuring compressive strength of NFCs as the natural fiber based composites are not very strong. This standard is not suitable for high strength composites due to the low transverse and interlaminar strength of these materials that may lead the specimens to fail by crushing or longitudinally splitting (Mathews 2000, Hodgkinson 2000). The test was carried out using a MTS machine with a maximum load capacity of 100 kN.

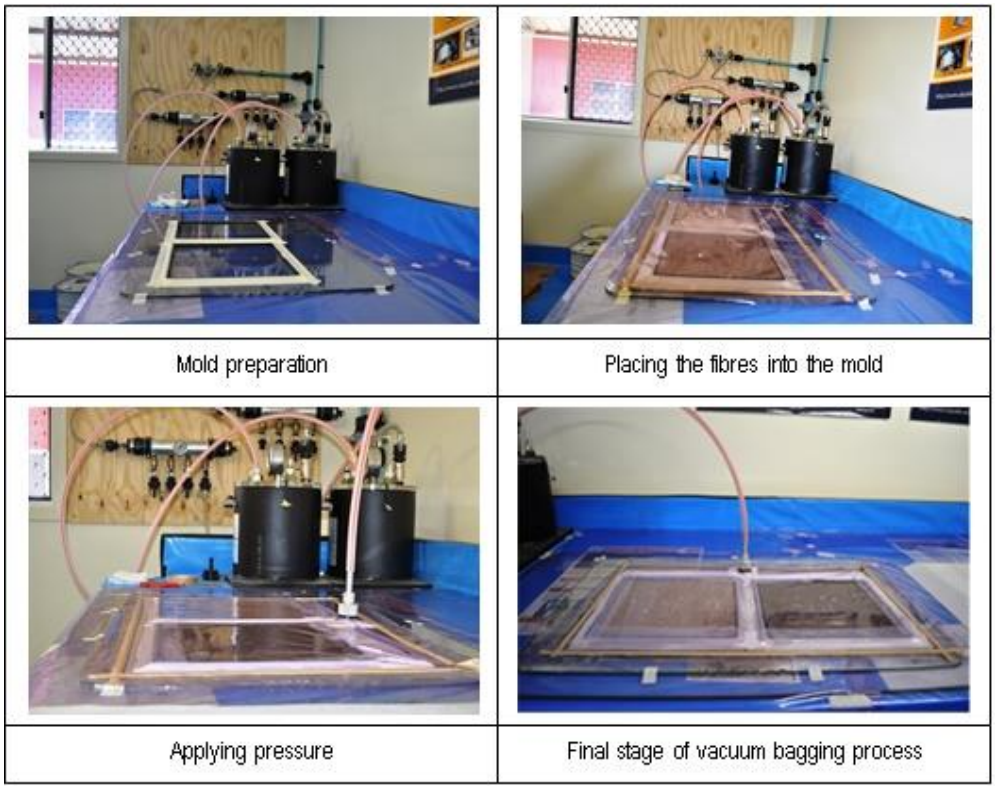

Figure 1 Process of fabricating natural fiber composite laminates with vacuum bagging method in this research.

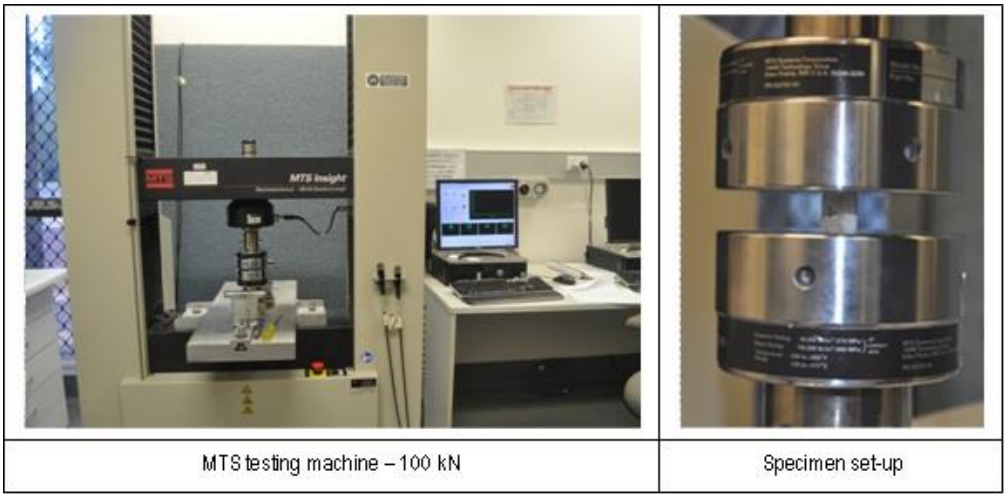

Figure 2 Setting-up for compressive test of NFCs.

Five specimens with recommended dimensions were prepared for each panel. The testing speed was 1.3 mm min^{-1}, as recommended by the referred standard. The testing set up for the compressive test is shown in Figure 2.

Results and Discussions

Compressive strength

The results of compressive testing are presented in Tables 2-4. Table 2 presents the result of the compressive testing of jute natural fiber composite, while the compressive properties of sisal natural fibers are shown in Table 3. Table 4 shows the compressive properties of bamboo based composite and hemp natural fiber composite. The data presented in the above tables has been reorganized in the form of dot-plot diagram in order to obtain more comprehensible and immediate information. The dot-plot diagram of compressive strength of NFCs investigated in this research is presented in Figure 3.

When a glance observation is given to the concentration of data in Figure 3, it seems that only two groups of specimens, SRNC-CMP and HNC-CMP, have a consistent compressive strength distribution. The average values of these two specimens group were 50.32 MPa and 31.69 MPa, respectively. The values of remaining four groups need to be normalized in order to obtain more reliable average values. The analysis was focused only on one single parameter, i.e. compressive strength. Sample JNC0-CMP has an average compressive strength value of 51.70 MPa which ranges from 29.47 MPa to 71.01 MPa. The data of specimen 3 (29.47 MPa) was considered as a peculiar data. Hence, when this data is neglected the average value of JNC0-CMP has now turned to 57.26 MPa. A similar process was applied to the JNC1-CMP samples which have a definite average value of 45.30 MPa. Excluding the data of specimen 2 and specimen 4, results in new average value of 56.85 MPa

Table 2 Compressive properties of jute natural fiber composite

Jute natural fiber composite-flexure, thickness (3-4 mm) – (JNC0-CMP)					
Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	4.1	8	32.80	2052	62.56
2	3.9	8.1	31.59	1778	56.28
3	3.8	8	30.40	896	29.47
4	4.2	8	33.60	2386	71.01
5	3.8	8.1	30.78	1206	39.18
Mean	3.96	8.04	31.83	1664	51.70
Std Dev	0.18	0.05	1.35	609	17.05
CV	4.55	0.62	4.24	36.60	32.98
Jute natural fiber composite-flexure, thickness (5 mm) – (JNC1-CMP)					
Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	6.6	13.2	87.12	5330	61.18
2	6.6	13.2	87.12	2583	29.65
3	6.4	12.7	81.28	3640	44.78
4	6.7	13.4	89.78	2362	26.31
5	6.5	12.9	83.85	5417	64.60
Mean	6.5	13	85.83	5145	45.30
Std Dev	0.55	13.07	3.30	4080	17.54
CV	8.46	100.54	3.84	79.30	38.72

Table 3 Compressive properties of sisal natural fiber composite

Sisal *(randomly oriented)* natural fiber composite-compressive – (SRNC-CMP)

Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	6.4	12.9	82.56	3689	44.68
2	6.5	13	84.50	4658	55.12
3	6.5	13	84.50	3869	45.79
4	6.5	12.8	83.20	4932	59.28
5	6.6	13.1	86.46	4041	46.74
Mean	6.5	12.96	84.24	4238	50.32
Std Dev	0.07	0.11	1.50	533	6.49
CV	1.08	0.85	1.78	12.58	12.90

Sisal *(unidirectional)* natural fiber composite-compressive – (SUNC-CMP)

Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	3.9	7.2	28.08	2193	78.10
2	3.5	7.1	24.85	1272	51.19
3	3.6	7.2	25.92	1300	50.15
4	3.6	7.2	25.92	993	38.31
5	3.8	7.7	29.26	2535	86.64
Mean	3.68	7.28	26.81	1659	60.88
Std Dev	0.16	0.24	1.81	666	20.48
CV	4.35	3.30	6.75	40.14	33.64

Table 4 Compressive properties of bamboo based and hemp natural fiber composite

Bamboo *(randomly oriented)* based composite-compressive – (BRNC-CMP)

Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	5.7	11.4	64.98	3499	53.85
2	5.7	11.4	64.98	2646	40.72
3	5.7	11.3	64.41	1095	17.00
4	5.7	11.4	64.98	1354	20.84
5	5.7	11.4	64.98	3023	46.52
Mean	5.7	11.38	64.87	2323	35.79
Std Dev	0	0.04	0.25	1052	16.14
CV	0.00	0.35	0.39	45.29	45.10

Hemp natural fiber composite-compressive – (HNC-CMP)

Specimen	Thickness, mm	Width, mm	Area, mm^2	Peak load, N	Peak stress, MPa
1	7.6	15	114.00	4408	38.67
2	7.7	14.8	113.96	4503	39.51
3	7.9	15.1	119.29	3479	29.16
4	7.5	15	112.50	2185	19.42
Mean	7.5	15	114.94	2109	31.69
Std Dev	0.62	14.98	2.98	2781	9.43
CV	8.27	99.87	2.59	131.86	29.76

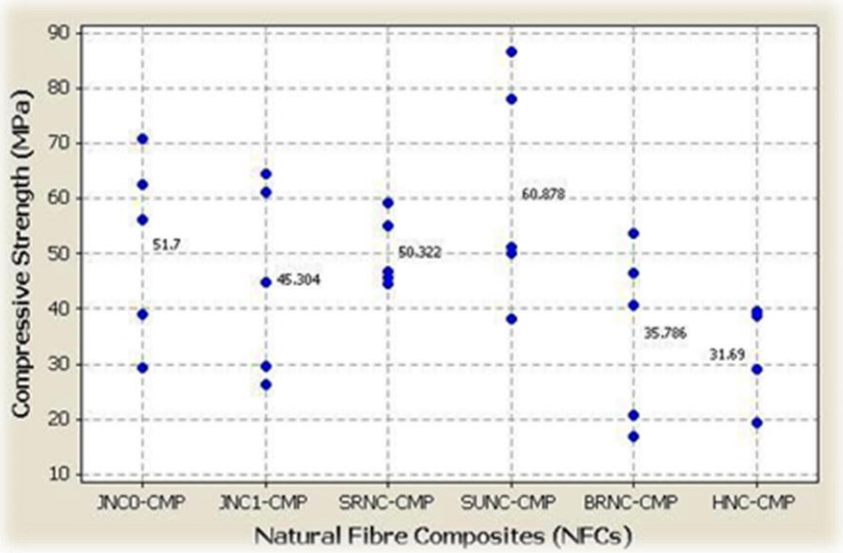

Figure 3 The dot-plot diagram of the compressive strength of NFCs.

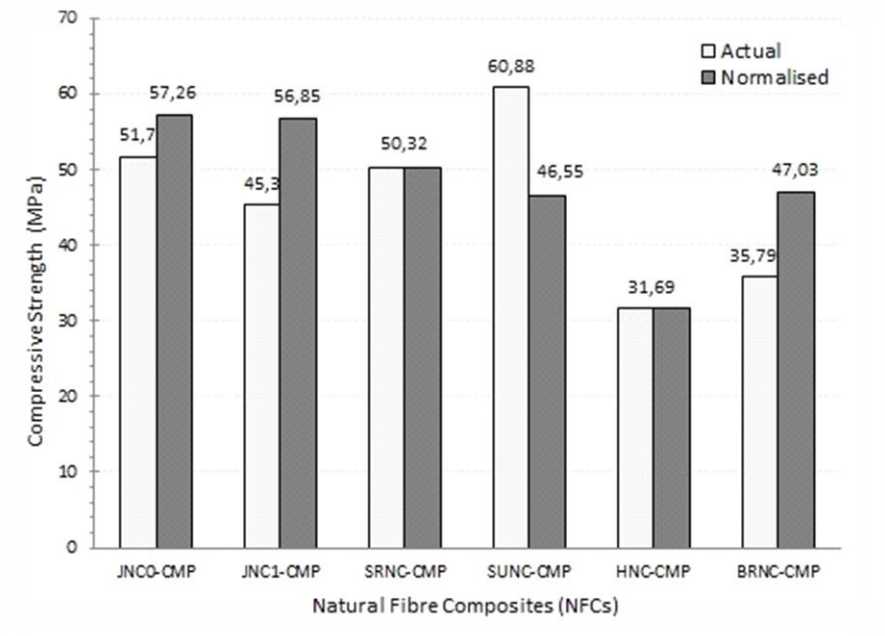

Figure 4 The average compressive strength values of different NFCs.

new average value of 56.85 MPa. It can be noted here that by doing this normalization process, the difference between the two groups can be significantly reduced, from 11.17% when comparing actual average values to 0.71% after normalization.

The SRNC-CMP specimen group shows less variation in their compressive strength data distribution. The data of this sample group ranges from 44.68 MPa to 59.28 MPa with the average value of 50.32 MPa and a standard deviation of 6.49 MPa. On the other hand, SUNC-CMP sample group has the tendency to distribute into two sets of average value. If the two highest values are considered, the compressive strength of specimen 1 and specimen 5, it gives a new average value of 82.37 MPa. An average value of 46.55 MPa can be obtained when the three lower values of compressive strength are considered.

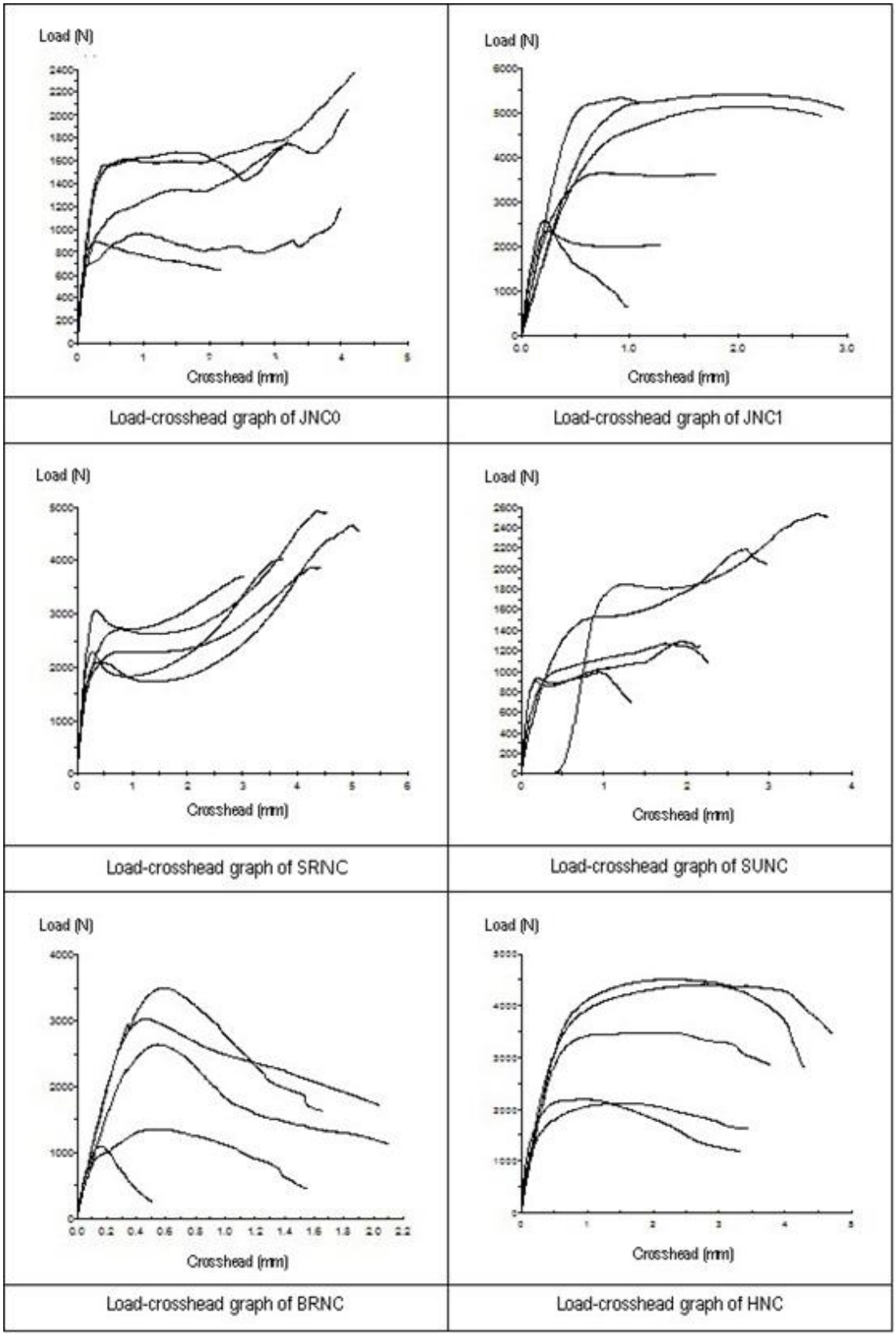

Figure 5 Typical load-deformation graphs of different NFCs in compressive.

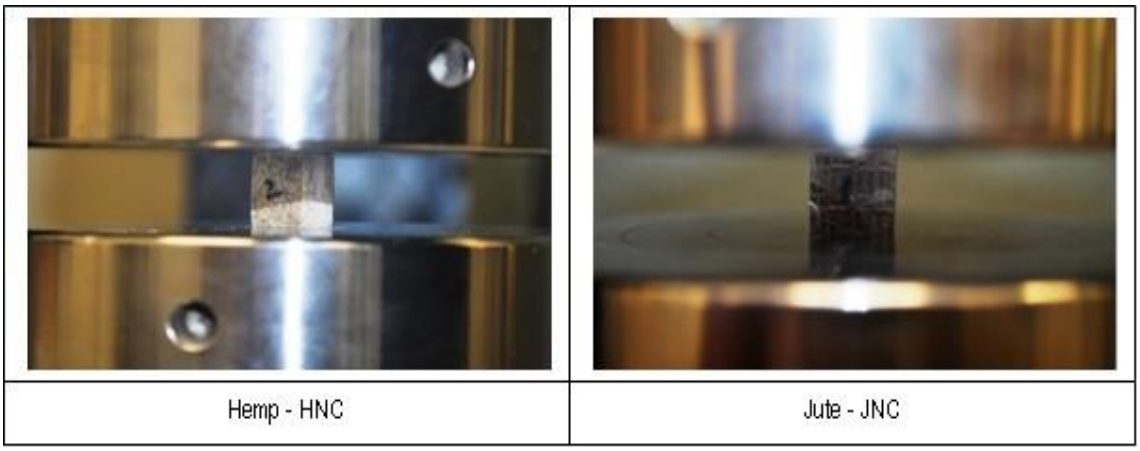

Figure 6 Typical compressive failure patterns of different NFCs.

A quick observation into the compressive strength data of BRNC-CMP gives the thought that the data was not uniformly distributed. The actual average value of this specimens group was 35.79 MPa with the standard deviation of 16.14 MPa. However, the compressive strength of BRNC-CMP has the tendency to separate into two levels. When three higher values of the data are considered, the average value increases to 47.03 MPa and only 18.92 MPa when only two lowest data are considered.

Lastly, the average compressive strength value of different natural fiber composites is presented in Figure 4. The average compressive strength of sample groups represented jute fiber composites, JNC0-CMP and JNC1-CMP, were only slightly different of 57.26 MPa and 56.85 MPa. Their values are ranked as the highest among the other NFCs and these values are followed by sisal fiber composites, both SRNC-CMP and SUNC-CMP. The value of these two specimen groups was 50.32 MPa and 46.55 MPa. Nested in the last place is the hemp fiber composite (HNC-CMP) with average value of 31.69 MPa. Bamboo based composite (BRNC-CMP) has an average value higher than HNC-CMP and comparable to the average value of SUNC-CMP, which is 47.03 MPa.

Load-deformation relationship and failure modes

The typical load-deformation curves of different NFCs tested under compressive load in this work are presented in Figure 5. As it can be observed from the presented graphs, the load-deformation curves showed a linear elastic behavior at the initial stage. After reaching the ultimate load, the curve bends sharply, some becoming flat at the top, indicates a significant reduction in stiffness, and finally descends until the specimens fractured. In other word, the material behaves plastically after the peak load. All specimens tested under compressive failed due to fracture at the gauge length. The failure pattern of NFCs under compressive load can be observed in Figure 6. Unfortunately, only two groups of tested samples are pictured as the specimens were quite small.

Conclusions

The average values of compressive strength obtained in this work range from 31.69 MPa to 86.64 MPa. The average compressive strength of jute fiber composites in this study is approximately 56 - 57 MPa. The composite made of sisal fiber has the compressive strength of 50.32 MPa (randomly oriented) and 46.55 MPa

(unidirectional). Hemp fiber composite has the average compressive strength value of 31.69 MPa, while bamboo based composite has the average value of compressive strength of 47.03 MPa. Those results indicate that the compressive strength of natural fiber composites obtained in this work were acceptable and comparable to the result of previous studies.

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