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TENSILE PROPERTIES OF LIGNOCELLULOSIC COMPOSITES: A COMPARISON ANALYSIS BETWEEN NATURAL FIBER COMPOSITES (NFCs) AND MEDIUM DENSITY FIBER (MDF)

Jauhar Fajrin[1] and Nasmi Herlina Sari[2]

[1]*Department of Civil Engineering, Faculty of Engineering, Mataram University*
[2]*Department of Mechanical Engineering, Faculty of Engineering, Mataram University*
Email:jauhar.fajrin@unram.ac.id

ABSTRACT

This paper presents an experimental investigation on the tensile properties of lignocellulosic composites; which is specifically compare the tensile properties of composites derived from natural fibers (jute, sisal and hemp) to a medium density fiber (MDF). The study was conducted experimentally by performing tensile tests according to BS EN ISO 527-2 using a MTS machine. Five specimens were prepared for each composite laminate. The results show that the tensile properties of lignocellulosic composites derived from natural fibers are superior to medium density fiber. The tensile strength of medium density fiber is 17.1 MPa; while sisal, jute and hemp fiber composite has the value of 40.25 MPa, 37.25 MPa and 31.37 MPa, respectively. Further, medium density fiber has the elastic modulus of 2603 MPa; while jute, sisal and hemp fiber composite has the values of 4592 MPa, 3643 MPa and 3048 MPa, respectively. Natural fiber composites also possess higher Poisson's ratio which is greater than 0.36, while medium density fiber has the value of 0.25.

Keywords: *Lignocellulosic composite, tensile properties, Poisson ratio, elastic modulus*

SIFAT TARIK KOMPOSIT LIGNOSELULOSA: ANALISA PERBANDINGAN ANTARA KOMPOSIT SERAT ALAM DENGAN MEDIUM DENSITY FIBER (MDF)

ABSTRAK

Paper ini membahas hasil kajian yang dilakukan secara eksperimental mengenai sifat tarik dari komposit lignoselulosa yang terbuat dari dua bahan berbeda; serat alam (jute, sisal dan hemp) dan medium desnity fiber (MDF). Studi ini dilakukan secara eksperimen dengan melakukan uji tarik berdasarkan BS EN ISO 527-2 menggunakan alat testing MTS. Lima buah sampel diuji dari masing-masing lamina. Hasil pengujian menunjukan bahwa komposit yang terbuat dari serat alam mempunyai sifat tarik yang lebih baik daripada MDF. Kuat tarik komposit yang terbuat dari serat Sisal, Jute dan Hemp masing-masing sebesar 40,25 MPa, 37,25 MPa dan 31,37 MPa; sedangkan nila rata-rata kuat tarik MDF hanya sebesar 17, 1 MPa. Selanjutnya, MDF mempunyai modulus elastisitas sebesar 2603 MPa; sementara komposit yang diperkuat dengan jute, sisal dan hemp mempunyai nilai modulus elastisitas masing-masing sebesar 4592 MPa, 3643 MPa dan 3048 MPa. Komposite serat alam juga mempunyai nilai Poisson's ratio yang lebih tinggi (≥ 0,36) sementara nilai Poisson ratio MDF hanya sebesar 0,25.

Kata Kunci: *Komposit lignoselulosa, sifat tarik, serat alam, rasio Poisson, modulus elastisitas*

1 INTRODUCTION

Any substance containing cellulose and lignin which includes wood and agriculture crops is considered as a lignocellulosic composite (English et al., 1994). Agricultural crops and residues also included in this material category. Based on their particle size, traditional lignocellulosic composites can be categorized into three main groups; veneer, particle and fibre based materials. Includes in particle board class are also waver board, oriented strand board (OSB), chipboard and particleboard, while other wood-based products such as hardboard and medium density fiberboard (MDF) are categorized as fibre-based panel materials (English et al., 1994; Gilbert, 1994). All those products have been intensively used in civil engineering applications. Natural fibers are also classified as lignocellulosic fibers (Monteiro et al., 2011), hence all the composite products produced from natural fibers also can be categorized as lignocellulosic composites (Fajrin et al., 2011). Fiberboards produced in dry process are widely known as medium density fibre (MDF) and high density fibre (HDF). MDF has a density ranges from 450 to 800 kg/m^3 and its strength depends on the embedded fiber. Formaldehyde is a typical resin employed for the production of MDF (Halvarsson, 2008). However, the use of lignocellulosic composites derived from natural fibers is still find a way to be extensively employed in civil engineering field, particularly for structural member. A newly effort to use natural fiber composites in structural application is by developing hybrid sandwich panels with intermediate layer (Fajrin et al. (2016); Fajrin et al., 2017). The theoretical concept of the newly developed sandwich panel was reported by Fajrin (2015).

Over the past 20 years, extensive researches have been conducted to investigate the use of natural fibers as reinforcement in polymeric matrices. A number of researchers have investigated the tensile properties as they consider that natural fiber composite (NFCs) is particularly valued for their high tensile strength. Interestingly, there are large discrepancies among the values reported in the literature (Fidelis and Filho, 2013). One of the main problem that has been pointed by several researchers is the incompatibility of the two primary constituents; fiber and matrix. Also, the inherent high moisture absorption of fibre that may lead to the micro cracking and degradation of the composite laminates (Li et al., 2007). Among the current available choices of chemical treatment method, alkali treatment is the most frequently used for natural fibres modification (English et al., 1994) by using certain amount of sodium hydroxide (NaOH).

As mentioned previously, there are large differences among the values reported in the literature. The tensile properties of various natural fiber composites are presented in Table 1. It can be quickly assessed from the obtained data that the tensile properties of natural fibre composites differ quite significantly for each previous reported study. The reason for this inconsistently results is most probably due to each investigator was using different types of fibres and material composition, treatment process or may arise from using different testing standards.

Table 1. Tensile properties of natural fibre composites reported in previous studies

No	Fibre	Matrix	Tensile properties		References
			Tensile Strength (MPa)	**Tensile Modulus (MPa)**	
1	Jute	Polyurethane	59.3	1300	Khan, 2016
2	Jute	Polyester	45.82	3700	Ticoalu et al., 2010
3	Sisal	Polyester	47.10	12900	Mwaikambo, 2006
4	Coir	Polyester	20.40	-	Singh and Gupta, 2005
5	Hemp	Polyester	32.90	1421	Rouison et al., 2006
6	Flax	Polyester	61	6300	Rodriguez et al., 2005
7	Sugar palm	Epoxy	30.49	1060	Sastra et al., 2006
8	Banana	Polyester	57	-	Pothan et al., 2002
9	Sisal	Polyester	65.5	1900	Prassad and Rao, 2011

Although research on natural fiber composites has been conducted quite extensively, until now there has lack of natural fiber composite products that readily and commercially available in the market. The current work presents the experimental investigation on the tensile properties of lignocellulosic composites; which is specifically compare the tensile properties of composites derived from natural fibers (jute, sisal and hemp) to a medium density fiber which is a commercially available lignocellulosic composites in the current market.

2 MATERIAL AND EXPERIMENTAL PROCEDURE

2.1 Material

Lignocellulosic fibers derived from natural fibers; jute, sisal and hemp were collected from different sources. Jute fiber was obtained in the form of woven fabric with a commercial name of Hessian jute. Sisal fiber was a unidirectional fiber extracted from Agave Sisalana leaves, while hemp fiber was in the form of hemp mat. An epoxy resin with a commercial name of R180 was used as the matrix. The resin was mixed with a hardener with the name of H180 to a ratio of 100:20 by weight. All fibres were washed with warm water as a pretreatment and then dried at room temperature for 12 hours. The fibers were also chemically treated using 2% NaOH by soaking them at ambient temperature. The treated fibres were washed several times with warm tap water, neutralized with acetic acid and washed with demineralized water as a post treatment. The fibres were then dried up for 3 days at room temperature. The composite laminates were prepared using a vacuum bagging process, which is generally a combination of a hand lay-up process and applying pressure on the natural fibre composite laminate (Fajrin et al., 2011).

2.2 Experimental procedure

Tensile tests were performed as per British Standard (BS EN ISO 527-2, 1996). Five specimens were prepared for each composite laminate and tested using MTS machine with a maximum load capacity of 100 kN. The longitudinal and transverse deformation were measured using extensometer for the determination of Poisson's ratio. The extensometer was removed from the specimen once the longitudinal strain reached 3000 microstrains in order to prevent any damage to the testing equipment. The testing speed applied was 2 mm/min as required by the standard. The tensile testing set up is shown in Figure 1.

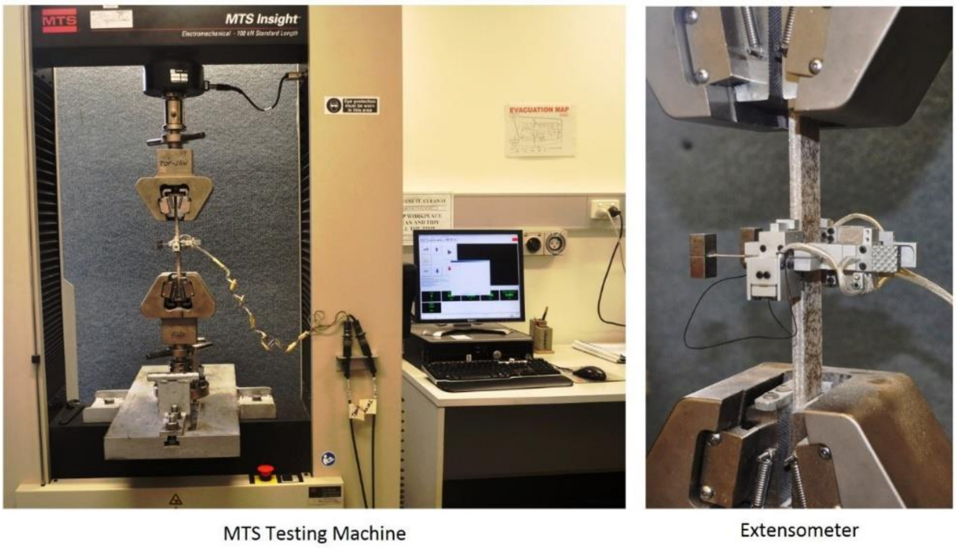

Figure 1. Setting-up testing machine for the tensile test

3 RESULTS AND DISCUSSIONS

According to BS EN ISO 527-2 (British Standard, 1996), tensile stress is "the tensile force per unit area of the original cross-section within the gauge length, carried by the test specimen at any given moment". The results of tensile testing are tabulated in Table 2. The table provided some important parameters such as tensile strength, modulus of elasticity and Poisson's ratio. In order to see the quality of specimens, the coefficient of variation (CV) of each specimen group was also obtained. As clearly shown in Table 2, within each sample set individual test results differ as represented by the coefficient of variations. The CV values ranges from around 3 to 20 percent. This noise is usually called as experimental error. Montgomery (2009) termed this as a statistical error, meaning that it arises from variation that is uncontrolled and generally unavoidable. It is also noticeable that the CV values of lignocellulosic composites prepared in this work were higher than CV values of MDF which is commercially available that can be purchased elsewhere. The CV values for MDF range from 3.1 to 5.53 percent, while for NFCs range from 4.07 to a maximum value of 20.6 percent.

Variations in the properties of natural fibre composites have been a tremendous concern of many investigators in this field of research. Those variations on the properties can be affected by many factors such as type of fibre and matrix uses, composition of constituent materials, and also manufacturing process. The lower CV values of MDF specimens indicates the consistency of its properties. MDF has been developed for few decades and some concerns related to the manufacturing process have been solved in many ways. One thing that also clearly observed is that the CV values of jute fiber composite are higher than 10 percent which is considered as high meaning that the quality of JFC laminate is lower than the others.

Table 2. Tensile properties of lignocellulosic composites

Lignocellulosic Composite	**Tensile Strength**		**Modulus of Elasticity**		**Poisson's Ratio**	
	Average (MPa)	**CV (%)**	**Average (MPa)**	**CV (%)**	**Average (MPa)**	**CV (%)**
Jute Fiber Composite (JFC)	37.28	20.6	4592	15.77	0.36	14.27
Sisal Fiber Composite (SFC)	40.25	8.7	3643	6.64	0.44	4.07
Hemp Fiber Composite (HFC)	31.37	7.9	3048	6.50	0.39	4.09
Medium Density Fiber (MDF)	17.10	3.5	2605	3.11	0.25	5.53

3.1 Tensile strength

The comparison of tensile strength among different NFCs and MDF is presented in Figure 2 (A). It is clearly depicted in the figure that the tensile strength of NFCs is superior to MDF. The average tensile strength of MDF is only 17.1 MPa, which is approximately half of the NFCs. Sisal fiber composite has the highest value of tensile strength which is 40.25 MPa, followed by JFC and HFC with their values of 37.25 MPa and 31.37 MPa, respectively. The reason behind the superiority strength of NFCs is the use epoxy as the matrix, which is stronger than the urea formaldehyde resin than commonly used in MDF production.

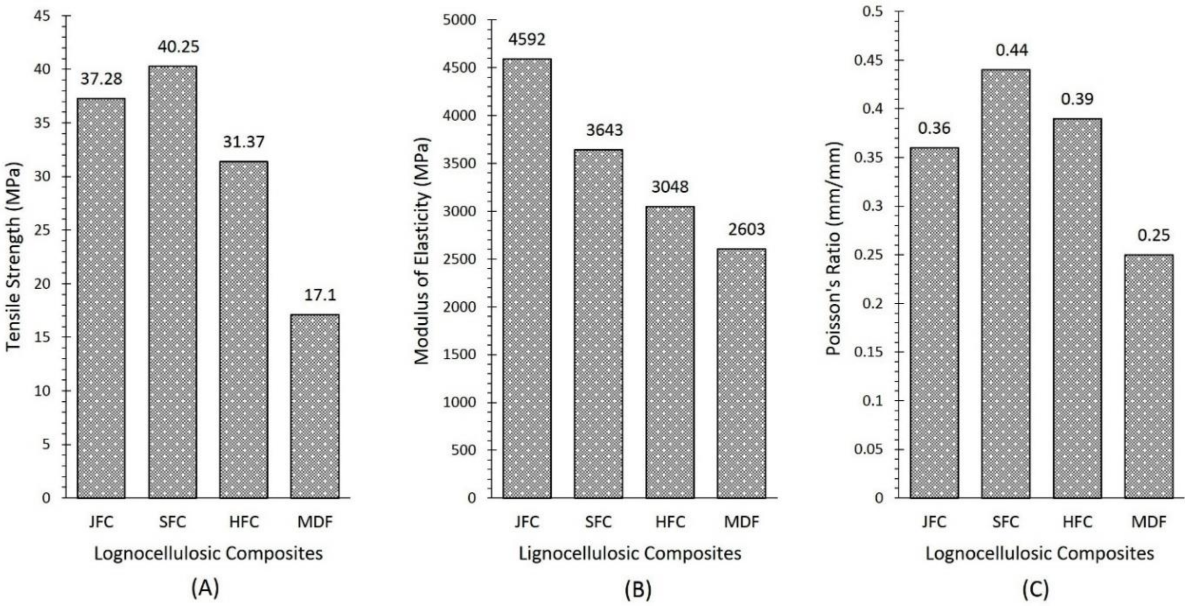

Figure 2. Tensile properties of lignocellulosic composites; (A) Tensile strength, (B) Modulus of elasticity, and (C) Poisson's ratio

Further, as mentioned previously, there are large differences of tensile strength reported among the previous works, even when using the same material such as presented in Table 1. Prassad and Rao (2011) reported that the tensile strength of sisal/polyester composite was 65.5 MPa, while Mwaikambo (2006) with similar material obtained a tensile strength of 47.1 MPa. The tensile strength provided in this research when sisal was used for the reinforcement of epoxy resin is only 40.25 MPa. Similarly, the tensile strength of JFC obtained in this research (37.28 MPa) is also lower than values reported in literature. Khan (2006) reported that the tensile strength of jute/polyurethane composite was 59.3 MPa, while jute/polyester composite reached a tensile strength of 45.82 MPa as reported by Ticoalu et al. (2010). Unlike the JFC and SFC, the tensile strength of HFC (31.37 MPa) almost comparable to a previous reported work of Rouison et al. (2006), where the tensile strength of hemp/polyester composite was approximately 32.90 MPa.

3.2 Tensile modulus

Figure 2 (B) shows the elastic modulus or modulus of elasticity of the lignocellulosic composites. Jute fiber composite has the highest elastic modulus (4592 MPa), which is approximately 76 percent higher than those of medium density fiber (2603 MPa). It is also 26 and 50 percent higher than those of SFC (3643 MPa) and HFC (3048 MPa), respectively. Likewise the tensile strength, the elastic modulus of NFCs is also greater than MDF. Further, it was also observed that there has a considerable variability on the elastic modulus of NFCs provided from previous literature. As it can be seen in Table 1, the lowest elastic modulus value was possessed by polyurethane composite reinforced with jute fiber (1300 MPa), while the highest value belonged to polyester composite reinforced with sisal fiber (12900 MPa). Meanwhile, the elastic modulus of NFCs obtained in this work ranges from 3048 MPa for HFC to 3643 for SFC and 4592 for JFC. It is important to note that the elastic modulus of JFC provided in this work is higher than those reported by Ticoalu et al. (2011) which is 3700 MPa. In the work reported by Ticoalu et al. (2010), polyester resin was employed for the matrix and jute fiber as the reinforcement. Further, the elastic modulus of sisal fiber composite obtained in this work also higher than that reported by Prassad and Rao (2011), which is 1900 MPa. Most probably, the reason is that using epoxy resin as the matrix may provide composite laminate with superior tensile properties than using polyester resin.

3.3 Poisson's ratio

Another parameter which is also important for any material includes natural fibre composites is Poisson's ratio. This parameter deals with the way of a material is stretching or compressing which causes it to compress or stretch in the opposite direction. The Poisson's ratio measures the extent of this effect in a particular material which may be different from one material to another. The ratio's value can even be negative, which usually observed in man-made substances. It is also clearly shown in Figure 2 (C) that the Poisson's ratio of NFCs is superior to those of MDF. Sisal fiber composite possessed the highest value (0.44), followed by HFC (0.39) and JFC (0.36). While MDF only has the average Poisson's ratio of 0.25, which is 76 percent less than the highest Poisson's ratio provided in this work. It is important to note that the Poisson's ratio of most materials ranges between 0.0 and 0.5. A perfectly incompressible material, which deformed elastically at small strains, would have a Poisson's ratio of exactly 0.5.

3.4 Failure Modes

All the specimens failed due to tensile failure within the gauge length, as shown in Figure 3, with no observed failure caused by slippage at the anchorage zone. The tensile failure along the longitudinal was in a brittle manner in which all the specimens suddenly collapsed or cut-off into two pieces.

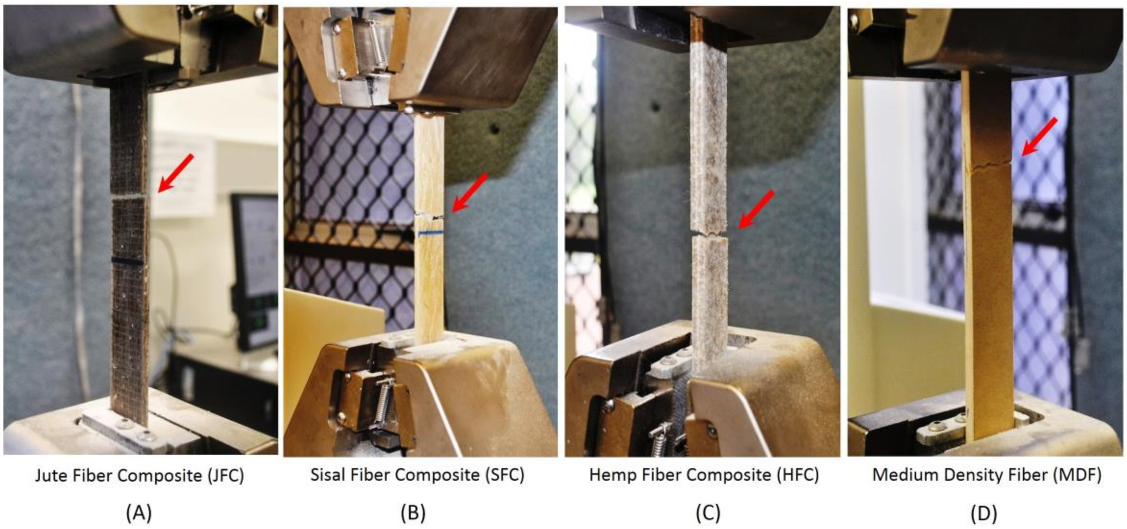

Figure 3. Failure mode of lignocellulosic composites under tensile load; (A) Jute fiber composite, (B) Sisal fiber composite, (C) Hemp fiber composite, and (D) Medium density fiber

During the progress of testing, it was clearly observed that all the lignocellulosic composites exhibit a linear elastic behaviour in tension. The load increases linearly with the extension with a slightly noise due to the removing process of extensometer during the testing progress. Also, there has actually a slightly decrease in stiffnesses at some point prior to failure mechanism begins. It is most likely due to the formation tensile crack within the matrix. It was also noticed that MDF specimens show a slightly non-linear behaviour before reaching the ultimate load and then collapsed in abrupt mode of failure.

4 CONCLUSSIONS

A comparison study on the tensile properties of lignocellulosic composites derived from natural fibers (NFCs) and wood fibers (MDF) has been investigated comprehensively. The results of this experimental investigation show that the tensile properties of lignocellulosic composites derived from natural fibers are superior to medium density fiber. More specific finding are as follows:

1. The tensile strength of medium density fiber is approximately only half of the natural fiber composites. The tensile strength of medium density fiber is only 17.1 MPa, while sisal, jute and hemp fiber composite

has the value of 40.25 MPa, 37.25 MPa and 31.37 MPa, respectively. Similarly, the elastic modulus of natural fiber composites is also significantly greater than medium density fiber. Jute, sisal and hemp fiber composite has the elastic modulus of 4592 MPa, 3643 MPa and 3048 MPa, respectively. In contrast, medium density fiber only has the elastic modulus of 2603 MPa. Natural fiber composites also possess higher Poisson's ratio which is greater than 0.36, while medium density fiber has the value of 0.25.

2. Although natural fiber composites have superior tensile properties, the quality of laminate is still less consistent compared to medium density fiber shown by the CV values. The CV values of medium density fiber ranges from 3 to 6 percent, while those of natural fiber composites ranges from 4 up to 20 percent. There is a strongly need to improve the fabrication process.

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