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MECHANICAL PROPERTIES OF NATURAL FIBER COMPOSITE MADE OF INDONESIAN GROWN SISAL

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ABSTRAK

Serat sisal merupakan salah satu serat alam yang paling banyak digunakan dan mudah dibudidayakan. Sisal dipercaya berasal dari Amerika tengah dan selatan. Menurut FAO, hampir 4,5 juta ton serat sisal diproduksi setiap tahun di seluruh dunia. Brazil dan Tanzania adalah dua negara produsen utama. Indonesia dan Thailand adalah dua negara Asia Tenggara yang juga memproduksi sisal. Artikel ini menyajikan hasil eksperimen mengenai sifat mekanik komposit epoxy yang diperkuat dengan serat sisal yang asli tumbuh di Indonesia. Secara khusus, serat sisal yang digunakan adalah serat sisal yang tumbuh dan berkembang di Lombok, Indonesia. Komposit serat alam tersebut dibuat dengan proses vakum-kantong. Proses karakterisasi dilakukan dengan mengevaluasi sifat mekanik dari komposit yang dihasilkan yang meliputi kuat tarik, kuat lentur, kuat geser dan kuat tekan. Hasil penelitian menunjukkan bahwa sifat mekanik komposit sisal-epoxy yang dihasilkan memiliki kesamaan dengan beberapa hasil penelitian yang telah dipublikasikan sebelumnya. Komposit epoksi yang diperkuat dengan serat sisal berorientasi sejajar (UOS) memiliki kuat tarik, kuat lentur, kuat geser dan kuat tekan berturut-turut sebesar 40,25 MPa, 62,16 MPa, 23,26 MPa dan 60,88 MPa. Sementara komposit epoksi yang diperkuat dengan serat sisal berorientasi acak (ROS) memiliki kuat tarik, kuat lentur, kuat geser dan kuat tekan berturut-turut sebesar 22,52 MPa, 51,5 MPa, 22,34 MPa dan 49,12 MPa. Hasil ekseperimen tersebut menunjukkan dengan jelas bahwa komposit epoksi yang diperkuat dengan serat sisal berorientasi sejajar mempunyai sifat mekanik yang lebih baik dibandingkan dengan komposit yang diperkuat dengan serat sisal berorientasi acak.

Kata Kunci: Sifat mekanik, karakterisasi, komposit serat alam, serat sisal

ABSTRACT

Sisal fiber is one of the most widely used natural fibers and is very easily to be cultivated. Sisal is considered to be indigenous to central and south America. According to FAO, nearly 4.5 million tons of sisal fiber is produced every year throughout the world. Brazil and Tanzania are the two main producing countries. Indonesia and Thailand are two of the South East Asian countries that also produces sisal. This paper presents a comprehensive experimental work on the fabrication and characterization of epoxy composite reinforced with Indonesian grown sisal. The sisal fiber was specifically grown in Lombok, Indonesia. The composite laminate was fabricated using vacuum bagging process. The characterization processes were conducted to evaluate the the mechanical properties which includes tensile, flexure, shear and compressive properties of such composites. The results showed that the mechanical properties of the examined sisal-epoxy composite in this study has a comparable properties with some of the previous reported studies. The epoxy composite reinforced with unidirectional oriented sisal (UOS) fiber has the tensile, flexural, shear and compressive stress of 40.25 MPa, 62.16 MPa, 23.26 MPa and 60.88 MPa, respectively. While the epoxy composite reinforced with randomly oriented sisal (ROS) fiber has the tensile, flexural, shear and compressive stress of 22.52 MPa, 51.5 MPa, 22.34 MPa and 49.12 MPa, respectively. The results have clearly shown that epoxy composite reinforced with unidirectional oriented sisal fiberhas a better mechanical properties than epoxy composite reinforced with randomly oriented sisal fiber.

Keywords: Mechanical properties, characterization, natural fiber composite, sisal fiber

1. Introduction

In relation to the principles of sustainability, natural fibres are a major renewable resource material throughout the world and specifically in the tropics. According to a Food and Agriculture Organization (FAO) survey, natural fibres like jute, sisal, coir, and banana are abundantly available in developing countries such as India, Srilanka, Thailand, Indonesia, Bangladesh, Philippine, Brazil, and South Africa. Recent reports indicate that plant fibres can be used as reinforcement in polymer composite to replace more expensive and non-renewable synthetic fibres such as glass especially in low pressure laminating (Mathur, 2006).

Currently, natural fibre reinforced composites (NFC) have drawn more attention as alternative building materials, especially as wood substitutes in the developing countries. The concept of using natural fibre as a building component is actually not a new idea since it has been used centuries ago for different applications.As the name implies, the NFCs composite is a class of composite that contains natural fibres mixed with synthetic or bio resins that are inherently environmentally beneficial. Other advantages of NFC are well explained in many published papers dealing with this topic, Suddel and Rosemaund (2008) highlighted the advantages of using NFC: low density, low cost, high toughness, acceptable specific strength properties, good thermal properties, low embodied energy, reduced tool wear in the moulding process and better acoustic properties thereby reducing the noise, reduced irritation to the skin and respiratory system, and they also have low energy requirement for processing.

Sisal (Agave Sisalana) is a leaf fibre derived from a plant that most commonly referred to species of agave family. It is mainly cultivated for its fibre, which is extracted from the leaves. Sisal is considered to be indigenous to central and south America. Owing to its potential to grow under diverse ecological and climatic conditions, it has now widespread to Asian and African countries. The primarily uses of sisal are in ropes and twines industries. Sisal is also converted to yarn, string, bags, floor mats, wall coverings and handicrafts. The paper industry also uses the plant as a source of cellulose pulp. Currently, the applications have extended to automotive, furniture and building industry in the form of sisal-reinforced composites. In building industry, sisal is also seen as a potential candidate to replace asbestos in roofing material (Anandjiwala and John, 2010; Mussig, 2010).

The potential for using sisal as reinforcement in composites has been studied by many researchers. Rong et al (2002) studied the role of interaction in sisal-epoxy composites and its influence on the impact performance of the composites. In this work, the sisal fibres were modified using different methods; alkali, acetylation, cyanoethylation, silane coupling agent and heat treatment prior to incorporate into epoxy resin matrix. Surface tensiometer and dynamic mechanics analysis were employed to investigate the interfacial interactions of the composites. The effect of such interactions to the impact properties was then obtained. Mechanical properties and morphology of sisal-epoxy composites was investigated by Oksman et al (2000). Unidirectional sisal fibres were used to reinforce epoxy resin through resin transfer moulding method. The results showed that the stiffness of composite was about 20 GPa compared to the stiffness of pure epoxy resin of 3.2 GPa. The tensile strength was also higher, 210 MPa compared to the value obtained by testing pure epoxy resin, 80 MPa.

In addition to these studies, Fonseca et al (2004) evaluated mechanical properties of sisal-polyester composites. The work focused on the polyester matrix formulation. Three different polyester formulations were introduced; polyester modified with silane coupling agent, flame retardant system and the blend of the two materials. The obtained composites were then compared to the unmodified sisal-polyester composite. It was demonstrated that the flame retardant acted as a particulate reinforcement to the polyester matrix while the silane coupling agent acted as a plasticizer, and that the addition of the two materials tended to decrease the composites performance. In addition, silane and alkali treatments improved the wettability of the fibres resulting in better mechanical properties and good water resistance of sisal-epoxy composites (Bisanda et al, 2000; Bledzki et al, 2002). Using other thermosets composites, Singh et al (1996) evaluated the effect of chemical treatment to the sisal-polyester composites. Sisal fibre was chemically treated using organotitanate, zirconate, silane and N-substituted methacrylamide. The overall conclusion drawn was that the mechanical properties of resulted composites were improved significantly. It was also observed that the tensile decreased by 30 to 44% when exposed to humid conditions, and by 50 to 70% for flexural strength. The composites made of N-substitute treated-sisal fibre exhibited better properties when exposed under dry and wet conditions.

As mentioned previously, sisal is not a native of Indonesian fibres. It is considered to be indigenous to central and south America (Anandjiwala and John, 2010; Mussig, 2010). This paper presents the results of experimental work dealing with the use of Indonesian grown sisal to reinforce epoxy resin polymer. The fabrication and characterization processes are discussed thoroughly. The comparison of the results with previous reported studies is also provided.

2. Fabrication Process

2.1. Materials

Sisal fibre was provided from local trader in Lombok, Indonesia. The fibre was traditionally processed by the local farmer from *Agave Sisalana* leaves.In Lombok, sisal is mostly growing wildly in less productive land. Sisal is quite resilient to disease and requires less cost to growth compared to other crops. Traditionally the local people use sisal fibre for rope and twine. The fibres are obtained by removing or scraping the pulpy material using hand stripping. As the economic value of this commodity has now increased, the local people have paid their attention to cultivate this crop regularly. Currently, sisal has been developed extensively in a large area in Sumbawa Island, which is located at the eastern part of West Nusa Tenggara Province of Indonesia.

Figure1. Sisal grown wildly in Lombok (left); Sisal plantation in Sumbawa (right)

The matrix for the composite was a modified low viscosity epoxy resin (R180) with a hardener (H180). The ratio of resin and hardener was 100:20 by weight. Low viscosity combined with a fast cure makes this material combination ideal for marine and civil engineering application.The specifications of the resin system used for preparing the sisallaminates are presented in Table 1.

Table 1. Properties of resin system

Resin R180		
Specification	Viscosity (at 20^0C)	110-1500 Cps
	Specific gravity	1.10 -1.10 kg/lt
Application	Elastic modulus	2630 MPa
	Flexural stress	30.6 MPa
Hardener H180		
Specification	Viscosity (at 20^0C)	100-300 Cps
	Specific gravity	0.96 kg/lt
Typical properties (100:20 by wt)	*Flexural properties (ASTM D790-90), 80 mm span at the rate of 2 mm/min*	
	Tangent elastic modulus	3000 MPa
	Modulus of rupture	93 MPa
	Compression properties (ASTM D695-91)	
	Elastic modulus	1340 MPa
	Compressive stress	86 MPa

2.2. Fiber Treatment

The fibres were treated using sodium hydroxide (NaOH) with the composition of 2% by weight (2% wt). As a pre-treatment, fibres were washed with warm tap water and then dried at room temperature for 12 hours. The alkaline treatment was carried out by soaking natural fibres with 2% NaOH at ambient temperature for 4 hours. For the post treatment, the treated fibres were washed several times with warm tap water, neutralized with acetic acid and washed with demineralized water. The fibres were then allowed to dry for 3 days at room temperature. The sodium hydroxide was purchased with a commercial name of Formosoda-P. This chemical is classified as a caustic soda with a purity of 99%.

2.3. Composite Fabrication

A vacuum bagging process was used for preparing natural fibre laminates. Vacuum bagging uses atmospheric pressure as a clamp to hold fibre and matrix together within an airtight envelope. A more simple description of vacuum bag moulding is the process that combines a manual method using hand-layup or spray-up on the open mould to produce a laminated component with a vacuum process after covering the laminated using polymeric sheet (Kaynak and Akgul, 2001; Akovali, 2001). Once the laminate was cured, it was cut into the required size for mechanical properties characterization. The equipment for the vacuum bagging process used in this research is shown in Figure 2.

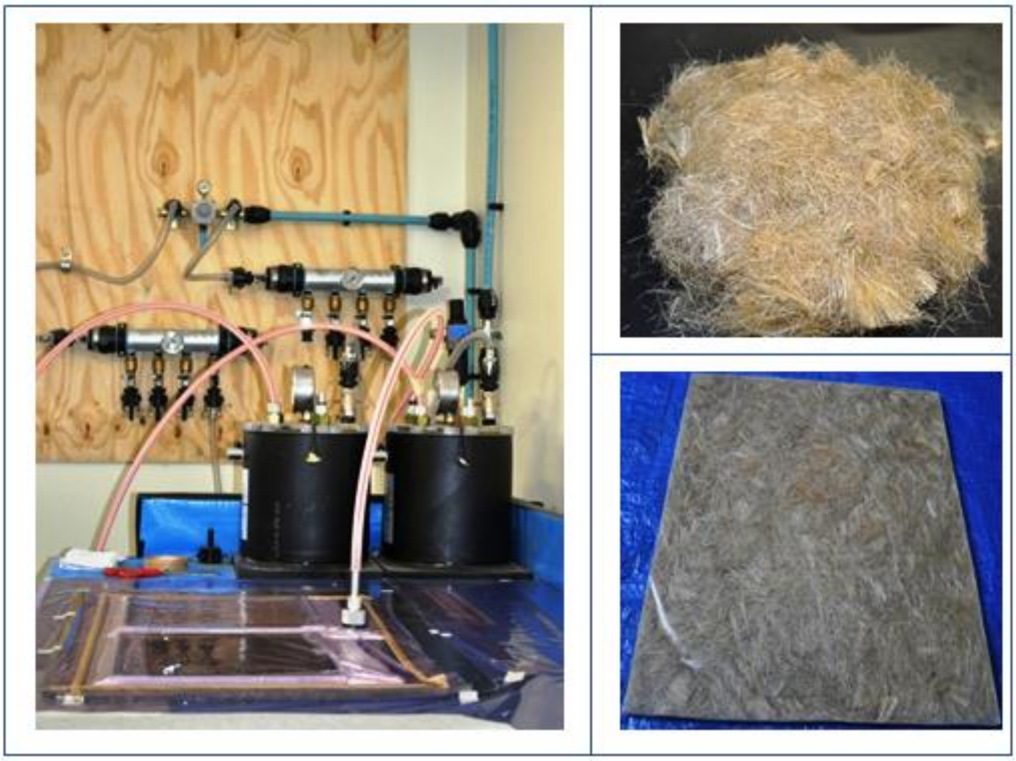

Figure 2. Sisal fibre composite preparation using vacuum bagging process

3. Characterizaton Process

Sisal natural fibre composites were prepared using randomly oriented fibre and unidirectional oriented fibre and were labelled as ROS and UOS, respectively. The experimental characterizations of sisal fibre composite were performed using tensile, compressive, flexural and shear tests. The tests were carried out as per the relevant ISO and ASTM standards for composite laminates. Five to sixspecimens for each type of mechanical test had been prepared from the sisal laminates. The testing standards for each type of mechanical test are listed in Table 2. While the testing set-up of each mechanical properties test is presented in Figure 3.

Table 2. Testing standards used for mechanical characterization of Sisal fibre composites

Type of test	**Testing Standard**	
	Code	**Title**
Tensile	BS EN ISO 527-2:1996	Plastics-determination of tensile properties
Compressive	ASTM D695-10	Standard test method for compressive properties of rigid plastics
Flexure	EN ISO 14125:1998	Fibre-reinforced plastic composites-Determination of flexural properties
Shear	ASTM D 5379/D5379 M-05	Standard test method for Shear properties of composite by the V-Notched beam method

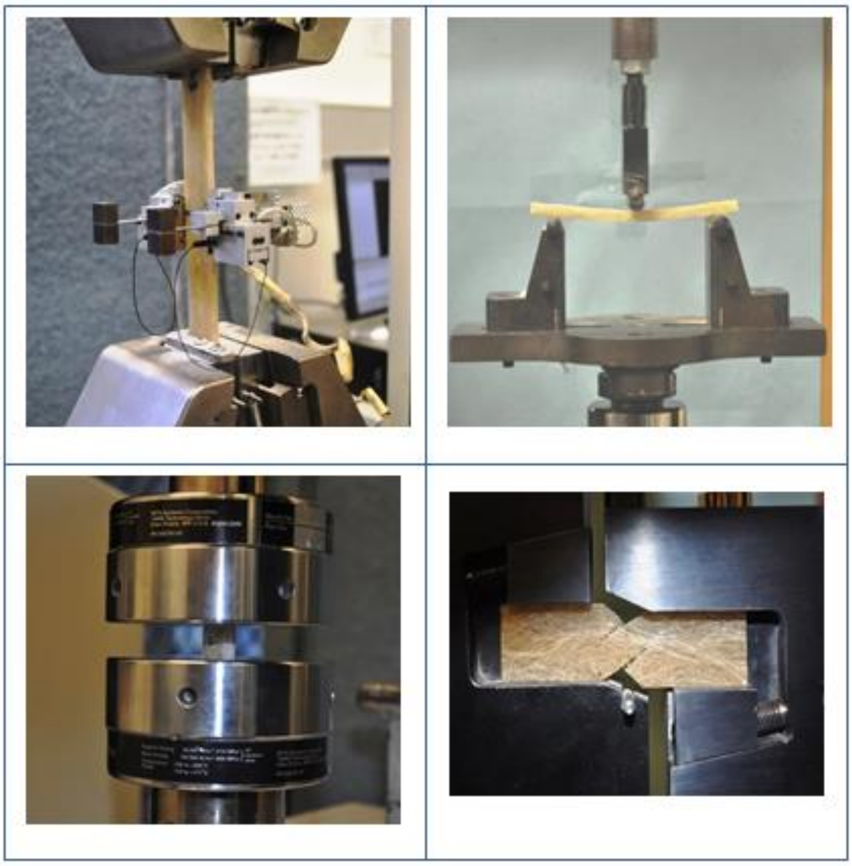

Figure 3.Testing set up for mechanical properties characterization

4. Results And Discussions

4.1. Tensile properties

Tensile test was carried out according to BS EN ISO 527-2:1996 using a MTS machine with a maximum load capacity of 100 kN.Five to six sets of specimens were prepared for each mechanical properties. An extensometer was attached at the middle of specimen's gauge length in order to measure longitudinal and transverse deformation for the determination of Poisson's ratio. In order to prevent any damage to the testing equipment, the extensometer was removed from the specimen once the longitudinal strain reached 3000 microstrain. The machine was set-up to apply a pressure of 8 MPa at the gripping area in between the gauge length of the specimen. The testing speed applied was 2 mm/min. The testing program for the tensile test of laminate is presented in Figure 3, while the results of the tensile test are presented in Figure 4.

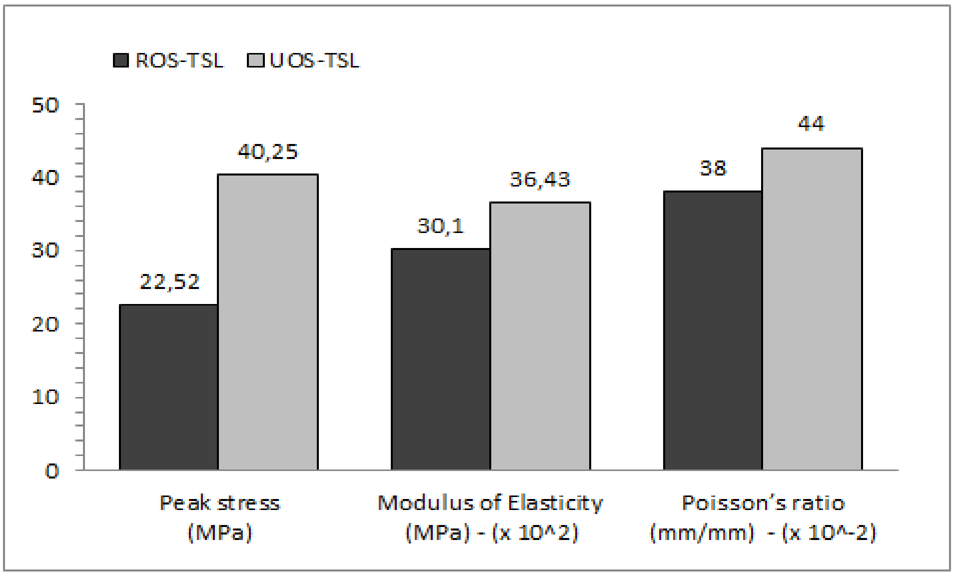

Figure 4. Tensile properties of Sisal fibre reinforced epoxy composite

As clearly shown in Figure 4, fiber orientation gives a significant contribution to the tensile properties of sisal fiber reinforced epoxy composite. The peak tensile stress of epoxy composite reinforced with unidirectional oriented sisal fiber (UOS-TSL) is approximately 78,7% higher than composite reinforced with randomly oriented sisal fiber (ROS-TSL). The average tensile stress of ROS is 22,53 MPa, while UOS-TSL reaches a maximum stress of 40,25 MPa. Similarly, the modulus of elasticity of UOS-TSL is also higher than ROS-TSL by around 21%. In addition, the Poisson's ratio of UOS-TSL also exceeds the value of ROS-TSL by 15,8%. The peak tensile stress of UOS-TSL examined in this study is almost comparable to the result of a previous study reported by Mwaikambo (2006), where the tensile stress of sisal fiber reinforced polyester composite reached a value of 47 MPa. A similar studyon reinforcing polyester resin with sisal fiber reported by Prassad and Rao (2011) provided much higher tensile stress of around 65,5 MPa. However, the value of modulus of elasticity (MOE) differs by what seems considered as significant. The current research provides the MOE value of 3643 MPa for UOS-TSL and 3010 MPa for ROS-TSL. Meanwhile, Mwaikambo (2006) and Prasad and Rao (2011) reported the MOE value of 12900 MPa and 1900 MPa, respectively.

For a comprehensive comparison, the tensile stress and tensile modulus of different natural fiber composites found in the literature are listed in Table 3. A quick visual assessment of data presented in this table implies that the tensile strength of natural fibre composites differ for each reported research work. The reason for this phenomenon is probably due to each investigator having employed different types of fibres and material composition, fabricating process or may arise from different testing standards. As can be noted in the table, the ranges of tensile strength are about 20,40 MPa for coir/polyester composites to 65,5 MPa for sisal/polyester composites. For the data of tensile modulus, there is a considerable fluctuation on the available published data in which the lowest value was possessed by jute/PVA composites (1300 MPa) and the higher value belonged to the sisal/polyester (12900 MPa). However, the tensile modulus of jute/polyester composite is pretty close to the tensile modulus of sisal/epoxy composite examined in this study. It can be said that the tensile properties of sisal fiber reinforced epoxy composite examined in this work were reasonably acceptable.

4.2. Flexural properties

In this work, the flexural test was conducted based upon ISO 14125, which is a standard test for the determination of flexural properties of fibre-reinforced plastic composites. The test was carried out using a MTS machine with a maximum load capacity of 10 kN.Six specimens of recommended dimensions were prepared and tested. A flat rectangular specimen was supported close to the ends and centrally loaded in three-point bending. A typical roller and pin support was used allowing the specimen to rotate in order to minimize membrane stress. The testing speed applied was 2 mm/min. The testing set up for flexural testing of laminate in this work is as shown in Figure 3. The flexural test results are presented in Figure 5.

Table 3. Tensile stress and tensile modulus of different natural fibre composites from several literatures

No	Fibre	Matrix	Tensile properties		References
			Tensile Stress (MPa)	Tensile Modulus (MPa)	
1	Jute	Polyurethane Chloride	59.3	1300	Khan et al (2012)
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); Mohanti et al (2005)
5	Hemp	Polyester	32.90	1421	Rouison et al (2005); Ticoalu et al (2010)
6	Flax	Polyester	61	6300	Rodriguez et al (2005), Ticoalu et al (2010)
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)

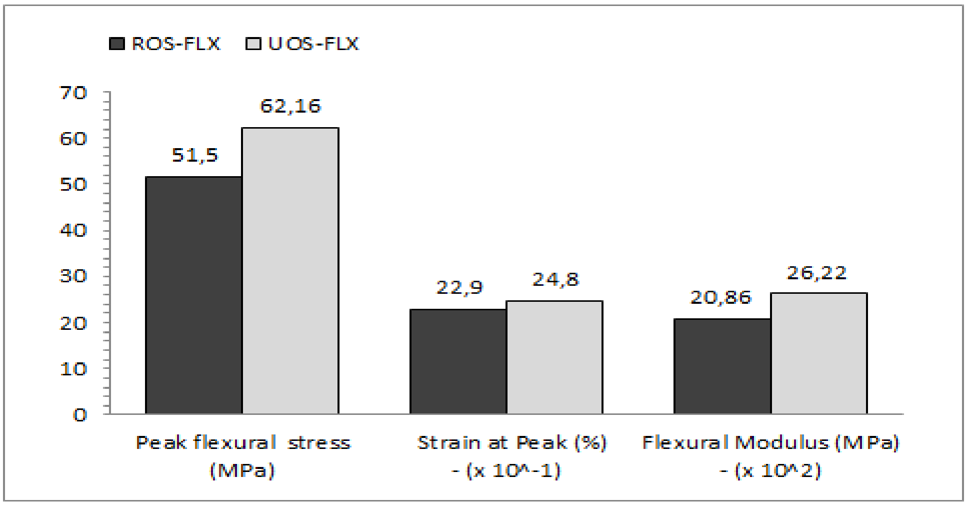

Figure 5. Flexural properties of Sisal fibre reinforced epoxy composite

As can be seen in Figure 5, the average peak flexural stress of epoxy composite reinforced with unidirectional oriented sisal fiber (UOS-FLX) and randomly oriented sisal fiber (ROS-FLX) is around 62.16 MPa and 51,5 MPa, respectively. The difference between the two values is approximately 17%. The two sample categories have a comparable strain at peak load with only about 7,6% difference, which is 2,29% and 2,48%. In addition, the flexural modulus of UOS-FLX is about 25,6% higher than those of ROS-FLX. Overall, the flexural properties of composite reinforced with unidirectional sisal fiber performs better than composite reinforced with randomly oriented sisal fiber. However, the flexural stress provided in this study is much less than the result of previous study reported by Prasad and Rao (2011), where sisal fiber reinforced polyester composite has the flexural stress of 99,5 MPa. In general, however, compositelaminate developed in this work has a reasonable flexural properties compared to the natural fiber composites studied previously as listed in Table 4. The value of flexural modulus obtained in this work is 2086 MPa (ROS-FLX) and 2622 MPa (UOS-FLX), while published literatures give a range of 2490 MPa to 5020 MPa. In short, it can be concluded that the values provided in this work were reasonably acceptable.

Table 4. Flexural stress and flexural modulus of different natural fibre composites from several literatures

No	**Fibre**	**Matrix**	**Flexural properties**		**References**
			Flexural Stress (MPa)	**Flexural Modulus (MPa)**	
1	Jute	PVC	62,6	3200	Khan et al (2012)
2	Banana	Polyester	65	-	Pothan et al (2002)
3	Gomuti	Epoxy	64,71	3150	Sastra et al (2005, 2006)
4	Gomuti	Polyester	47,82	3400	Ticoalu et al (2010)
5	Sisal	Polyester	99,5	2490	Prasad and Rao (2011)
6	Hemp	Polyester	54	5020	Rouison et al (2006); Ticoalu et al (2010)

4.3. Shear Properties

The Iosipescu test which also known as V-notched test was used for the shear testing. This particular shear test is described in ASTM standard D5379M. The test uses a rectangular beam with a symmetrical centrally located v-notched. The beam is loaded by a special fixture applying a shear loading at the v-notch. The specimen is inserted into the fixture with the notch located along the line of action of loading by means of an alignment that references the fixture. The two halves of the fixture are compressed by a testing machine while monitoring load. In this test, five specimens of tested NFC laminates were prepared. The testing was conducted using a MTS machine with the maximum capacity of 10 kN. The testing machine was set-up to apply the load with the speed of 2 mm/mnt and the test was set-up as shown in Figure 3. The summary of shear test result is given in Figure 6.

The average values of shear stress obtained in this work is 12 MPa (ROS-SHR) and 15,3 MPa (UOS-SHR). The two average values only slightly differs by just around 4,5%, where the laminate reinforced with unidirectional sisal fiber provided higher shear stress than the laminate reinforced with randomly oriented sisal fiber. The deflection at peak load of UOS-SHR is also 27,5% higher than those of ROS-SHR. This result seems comparable to the work of Herera and Gonzales (2005) in which they found that the shear strength of natural fibre composites made of short henequen fibre reinforced polyethylene (HDPE) matrix ranges from 14 MPa to 19 MPa. It is worthwhile to note here that the work of the above cited references were using a similar method for examining the shear properties of their composites. It is also important to mention that only a single reference can be presented for the comparison purpose.

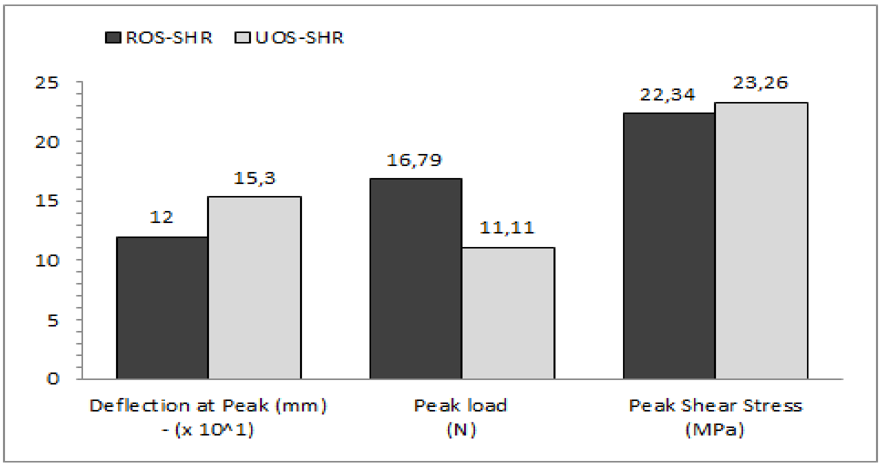

Figure 6. Shear properties of Sisal fibre reinforced epoxy composite

4.4. Compressive Properties

Compressive test is a fundamental type of test used to characterize materials. Static compression tests apply an escalating compressive load until failure or apply a specific load and hold it for a certain period. In reality, fibre reinforced plastics are particularly valued for their high tensile strength. However, the comparatively low compression strength of some composite reduces their potential application. Therefore, measuring the compression strength of natural fibre composites is of particular interest as well as their tensile strength.The compression 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 fibre based composites are not very strong. The test was carried out using a MTS machine with a maximum load capacity of 100 kN. Five specimens were prepared for each panel. The testing speed applied was 1,3 mm/mnt, as recommended by the referred standard. The testing set up for the compression test is shown in Figure 3 and the results are summarised in Figure 7.

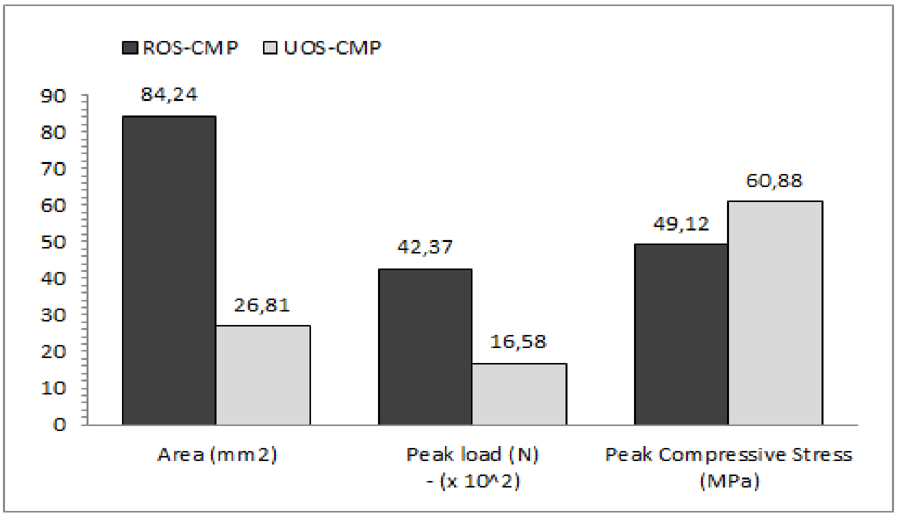

Figure 7. Compressive properties of Sisal fibre reinforced epoxy composite

For a comparative purpose, the results of previous work dealing with compressive properties analysis are summarized in Table 5. As can be seen in the table, the compressive stress of natural fibre composites spreads from 16,75 MPa to 108.07 MPa. This result indicates that the average value of compressive stress obtained in this work were acceptable. In previous study reported by Samuel et al. (2012), the shear stress of sisal fiber composite is 42 MPa, which is reasonably close to the shear strength obtained in this work.

Table 5. Compressive stress and compressive modulus of different natural fibre composites from several literatures

No	Fibre	Matrix	Compressive properties		References
			Compressive Stress (MPa)	**Compressive Modulus (MPa)**	
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)
5	Banana	Resin	16.75	-	Samuel et al (2012)
6	Sisal	Resin	42	-	Samuel et al (2012)
7	coconut	Resin	30.35	-	Samuel et al (2012)

5. Conclusions

Four types of mechanical testing have been conducted to evaluate the mechanical properties of epoxy composite reinforced with Indonesian grown sisal fiber.The fibers were placed in two different fiber orientations; unidirectional and randomly oriented fiber. Overall, the results showed that the mechanical properties of the examined sisal-epoxy composite in this study has a comparable properties with some of the previous reported studies.More detailed findings are as follows:

1) Epoxy composite reinforced with unidirectional oriented sisal (UOS) fiber has the tensile, flexural, shear and compressive stress of 40.25 MPa, 62.16 MPa, 23.26 MPa and 60.88 MPa, respectively.
2) Epoxy composite reinforced with randomly oriented sisal (ROS) fiber has the tensile, flexural, shear and compressive stress of 22.52 MPa, 51.5 MPa, 22.34 MPa and 49.12 MPa, respectively.
3) The study confirms that reinforcing epoxy composite with unidirectional oriented sisal fiber provides laminate with higher mechanical properties than laminate reinforced with randomly oriented sisal fiber.

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