Flexural Behaviour of Waste-based Natural Fibre Reinforced Composite from Palmyra Fibre and Waste Polythene

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***Abstract*— In recent years researchers are focusing on manufacturing new products by using wastes as raw materials. Among them, the products which are developed using natural fibre wastes have gained substantial attention due to their excellent properties. This research is conducted to investigate the feasibility of producing waste-based Natural Fibre Reinforced Composites (NFRC) using Palmyra fibre as reinforcement material and waste Low-Density Polyethylene (LDPE) as the matrix. To check the effect of fibre length and the fibre content on the flexural performance, two fibre lengths (20 mm, and 40 mm), and three fibre volume fractions (15%, 20%, and 25%) were used. The Hand lay-up process was used to manufacture the waste-based NFRC. A hot press machine and a cold press machine were used to prepare the moulded waste-based NFRC sheets. The flexural properties of the NFRCs were significantly influenced by the content of Palmyra fibre. According to the overall findings obtained, 15% of reinforcement content with having 40mm length of fibre can be identified as the optimum conditions to fulfil the required outcomes of this research with desirable mechanical properties.**

Keywords—Waste-based natural fibre reinforced composites, Palmyra, Low-density polyethylene, Waste management, Sustainability.

I. Introduction

In recent years, the use of natural fibres and natural fibre-based products has increased significantly [1]. Natural Fibre Reinforced Composites (NFRC) play a big role in an environmental friendly and sustainable future [2,3]. The reason for this trend is not only due to an increased environmental awareness but also due to the excellent properties of natural fibres and their composites such as abundance, biodegradability, renewability, lightweight, desirable mechanical properties (such as high tensile, impact and flexural capacities), and they accompany relatively low cost [4-6]. In addition, currently synthetic fibres (such as carbon, glass etc.) pose significant disposal problems due to their low degradability [7]. Synthetic fibres are consisting of a small unit or a polymer which is made from repeating units known as monomers. Due to the presence of some chemical contents (such as cellulose, waxes, pectin) natural fibres are also not 100% degradable. But the time takes for natural fibre to decompose is less since natural fibres are consisting of live organisms compared to the time it takes for synthetic fibres to decompose. The higher fire resistance of natural fibre provides enhanced durability to NFRC since the synthetic fibres catch fire easily compared to natural fibres. High degradability and some durability characteristics of natural fibres provide enhanced degradability and durable (under certain exposure conditions) characteristics in NFRC compared to synthetic fibre composites. During the manufacturing process of these synthetic fibres and their composites, huge amounts of CO_2 are released into the environment, which causes global warming. Due to the aforementioned reasons, in the last few years, natural fibres have attracted attention among several researchers, as an alternative reinforcement for polymer composites worldwide [8]. A vast variety of plant fibres have been investigated for use as reinforcement in composites. These NFRC are suitably applicable for household applications, building construction, and automotive applications including aerospace, sports equipment, and other stationery such as packaging [9].

This concept of developing NFRC is new in Sri Lanka, and the researchers have shown a rush in developing such materials which can replace the synthetic fibre composites. The use of waste materials in construction and building materials is a novel way to ensure sustainable consumption,

ISBN: 978-624-6150-05-1

which is a key goal highlighted by the UN Development Programme due to the massive consumption of natural resources and the environment, both of which have negative consequences for the planet [10,11]. Sri Lanka is producing a huge amount of agricultural waste and is not used as effective material, which is dumped or burned. The Palmyra palm has substantial economic potential, and so each component can be utilized in some manner either as a food or building material. Palmyra trees flourish in South East Asia's tropical and subtropical climates. It is a cheap and easily accessible agricultural resource that is abundant in Sri Lanka's dry zone. Palmyra fibres offer physical and mechanical qualities that can be used to make reinforced fibre components, and it is increasingly being employed in modern construction to conserve natural resources and enhance project sustainability. However, in Sri Lanka Palmyra fibres are not utilized effectively and are left without taking their value. Therefore, a study on the potential of implementing a waste-based NFRC using naturally-based or industrial-based waste materials and waste thermos-plastics found in Sri Lanka will add new knowledge to the scientific, social and technical aspects of waste management in the country as a developing country. Therefore, investigating the feasibility of waste-based NFRC is critical to assure the success of its applications together with socio-economic and environmental viability. To identify the effectiveness and the feasibility of proposed techniques, and the factors which contribute to the overall performance, in-depth investigations should be undertaken. Therefore, the manufacturing process involved in the production, the effect of fibre composition and its characteristics should be systematically analysed [12].

In the present study, the feasibility of developing different types of waste-based NFRC from Palmyra fibre and waste Low-Density Polyethylene (LDPE) was studied. Subsequently, These waste-based NFRC will be able to be used as alternatives for fibre composites used in household applications. Hence, the proposed technique will be able to reduce the disposal of the LDPE wastes and effectively use agricultural waste, and subsequently, walk towards an environment-friendly surrounding. This paper discusses the flexural behaviour of the developed waste-based NFRC from Palmyra fibre and wastes LDPE with different fibre weight contents and lengths.

II. MATERALS AND METHODS

A. *Materials*

Palmyra fibre and waste LDPE were used as the reinforcement and the matrix respectively in the developed composites. Palmyra fibre was bought from Jaffna region, Sri Lanka from a fibre extraction centre (Fig.1). Alkali treatment was conducted to enhance the properties of fibre by soaking 6% NaOH for three hours [13]. Before fibres were soaked into the diluted solution, the solution was continuously stirred for fifteen minutes to ensure that all the alkali was uniformly diluted in the water. Subsequently, fibres were soaked in the solution and cleaned using distilled water after three hours. After the cleaning process, fibres were dried at ambient temperature for three days, and fibres were dried for one day in an oven at a temperature of 60 ˚C before being used to prepare NFRC. LDPE waste was collected from industries, which was used for packing purposes.

Fig. 1. Palmyra fibres.

B. *Preparation of Waste-Based Natural Fibre Reinforced Composites Sheets*

The compression moulding technique was used to prepare the NFRC sheets employing hot press and cold press machines. The NFRC sheets were prepared using the hand lay-up process and pre-moulds with 3.2 mm thickness. Initially, LDPE was put into the shredder machine and they were cut into small pieces. To get homogeneous material, those small pieces of the LDPE and the Palmyra fibre were uniformly mixed according to the fraction of reinforcement required for different reinforcement volumes considered. Then the mixture was put into the mould and it was pressed using a hot press machine under 135 ˚C and 689.5 Pa (100 psi) as the working temperature and pressure respectively. After five minutes of compression, the mould was

ISBN: 978-624-6150-05-1

removed from the hot press moulding machine and it was put into the cold press moulding machine for another ten minutes. NFRC sheets were cut and removed from the mould and used for further analysis.

C. Flexural Test

Three-point bending test was conducted using a universal testing machine according to the ASTM D790 standard. Based on the requirements specified in the ASTM D790, 110 mm x 15 mm x 3.2 mm specimens were cut from the NFRC sheets in the same direction and fifteen specimens were used for each type. 48 mm effective support span length was used as specified in the standard by allowing enough overhangs from both sides. All the specimen sizes were measured before starting the test and the width and the depth of the specimen were measured to the nearest 0.03 mm at the centre of the support span. The test was conducted at room temperature and the load, displacement and time histrories were obtained.

(a) (b)

Fig. 2. (a)Test specimens; (b)Three-point bending test setup

III. Results and Discusiion

Among the fifteen samples tested for each type, ten samples were selected based on the failure pattern and errors observed during the testing. At the failure point, a clear failure in composite was not observed due to the high flexibility of developed NFRCs. The failure occurred due to the slipping of the specimen from the supports. To analyse the flexural characteristics of different NFRC, stress-strain variation, flexural modulus, maximum flexural strength, strain at maximum flexural stress, and the energy at maximum flexural stress point were used.

University of Jaffna for providing the necessary funding for this research through URG/2018/SEIT/09.

A. Stress-Strain Responses

Fig. 3 shows the variation of engineering stress-strain responses of waste-based NFC with different percentages of fibre additions under both fibre lengths. During the testing period Load, displacement and time histories were obtained. Test samples were considered as homogeneous elastic material and tested in flexure as a simple beam supported at two points and loaded at the midpoint. Therefore, maximum stress in the outer surface of the test specimen occurs at the midpoint. This stress was calculated by using (1) and with the help of load-deflection curve according to ASTM D790.

$$\rho_f = \frac{3PL}{2bd^2} \quad (1)$$

where, P = Load at a given point on the load-deflection curve, N

L = Support span, mm

b = width of the specimen, mm

d = depth of the specimen, mm

A dial gauge was used to measure the downward displacement of the midpoint of the specimen. Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. In order to calculate the strain of the test specimen (2) was used;

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (2)$$

Where, D = Displacement at the midpoint, mm

All types showed typical behaviour of elastic-plastic materials. When fibre composites are under load or pressure, the matrix transfers load and stress to fibres. The fibres bear the load and stress and are concurrently transferred to the matrix and fibre around them. This process contributes to effective and uniform stress distribution along with the fibre composite which results in greater mechanical properties of fibre matrix composite.

ISBN: 978-624-6150-05-1

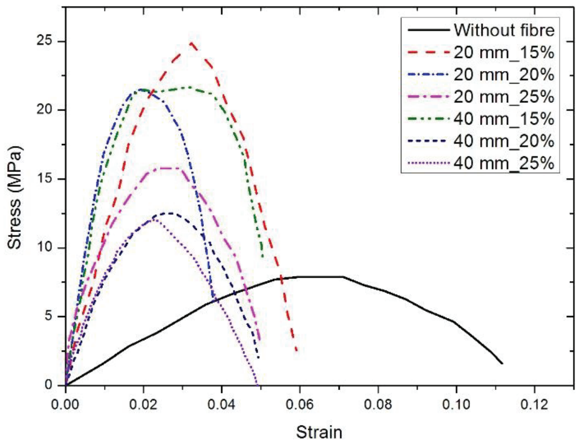

Fig. 3. Stress-strain responses of waste-based NFRC.

B. Flexural Modulus

Flexural modulus was derived using the strain offset method with 0.5% strain condition as reccommended by Callister and Rethwisch (2018) [14]. Variation of the flexural modulus of developed composites is shown in Fig. 4 for different fibre addition for both fibre lengths of 20mm and 40 mm. The average flexurel modulus of the sheets witout falmyra was 155.9 MPa and is indicated using a line in Fig.4. For 20mm fibres, a gradual reduction in the flexural modulus was observed with the fibre addition in the range of 15-25%, while an enhancement of the flexural modulus was shown at the beginning of fibre addition and consequently a reduction after the maximum value for 40 mm fibres. The highest value of the flexural modulus of 1702 MPa was obtained by 20% of 40mm fibre content. Enhancement of the flexural modulus is caused by the higher stiffness of Palmyra fibre compared to pure LDPE.

The improvement of the flexural modulus is caused by the addition of Palmyra fibre as reinforcement material up to 20% in 40mm fibres, which enhances the stiffness of the fibre composites. However, further addition of Palmyra fibre beyond the optimum level creates an insufficient matrix for a well-packed product, hence reduction in the stiffness while reducing the load and stress transfer ability.

However, the optimum fibre content for 20mm fibres was not shown within the range considered in this study, where further investigations with fibre content below 15% are needed for solid conclusions. Among the two fibre lengths considered, 40 mm fibre shows higher flexural modules compared to 20 mm fibre length except at 15% fibre inclusion.

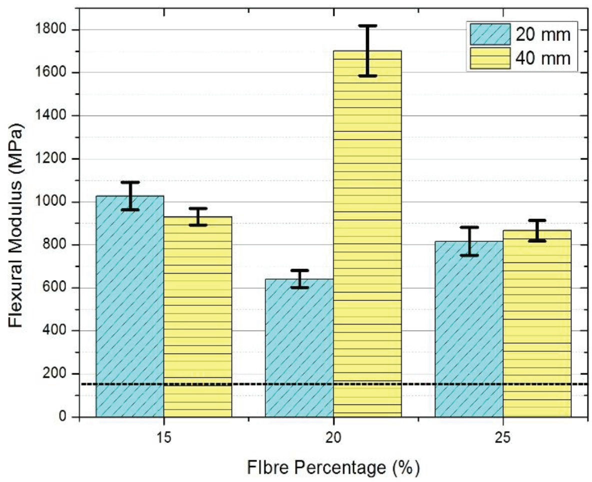

Fig. 4. Variation of flexural modulus.

C. Maximum Flexural Strength

The maximum strength of any material is highly essential since the maximum load-carrying capacity of structures and equipment are depend on the maximum load-carrying capacity of the materials used to design them. The maximum flexural strength of the fully LDPE sheet was 7.89 MPa and is displayed in Fig. 5 by a line. The variation of the maximum flexural stress is shown in Fig.5.

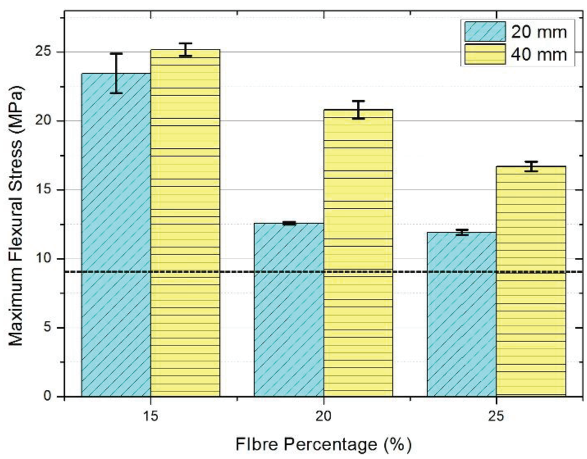

Fig. 5. Variation of maximum flexural stress.

A similar trend of the maximum flexural stress variation is shown for both fibre lengths, that maximum flexural stress was reduced with the fibre percentage in the range of 15-25%. Though the highest flexural stresses are observed at 15% of fibre inclusion, the optimum fibre content can be 15% or less which highlights the necessity of further studies with lower fibre inclusion than 15%.

ISBN: 978-624-6150-05-1

According to available literature, the flexural strength of the NFRC varies from 20 MPa to 80 MPa. Which shows acceptable strength characteristics of developed thrre types of NFRC as shown in Fig. 5 [5-7, 11].

D. Strain at Maximum Flexural Stress

The strain at maximum flexural strength of the fully LDPE sheet was 0.071. Variation of the strain at maximum flexural stress is shown in Fig.6 and it shows a gradual reduction with the increment of fibre content, with deviation at 20% fibre inclusion for 40mm fibre. The reduction in the strain is due to the reinforcement effect caused by the inclusion of Palmyra fibre. That reduces the ability of elongation of pure LDPE matrix due to the rigid network formed by the Palmyra fibre and hence attributed to the reduction in elasticity of composites, which results in a reduction in strain. In addition, 40mm Palmyra fibre composites showed higher strain at maximum stress levels under 15 and 25% of fibre inclusion, except at 20%.

E. Strain Energy at Maximum Flexural Stress

Further analysis of stress-strain curves was done to observe their energy absorption capacities. The cumulative strain energy was obtained by integrating the stress-strain curves for each type. Strain energy at maximum flexural stress of a material is important which shows the energy absorption capacity of materials at the maximum load-carrying capacity level. The energy at maximum stress level depends on two characteristics which are maximum flexural stress and strain at maximum flexural stress. The 100% LDPE sheet showed an average of 405 kJ/m^3 of strain energy absorption capacity at the maximum stress level. Reduction of the strain energy at maximum flexural stress was observed with Palmyra fibre addition within the range of 15-25% for both fibre lengths as shown in Fig.6. This was caused by the reduction of maximum flexural stress and strain at maximum flexural stress as observed in Fig.5 and Fig.6 respectively. Fibre length has a substantial effect on the energy absorption capacity, which is demonstrated in Fig.7. Among the two fibre lengths considered, 40mm fibre showed higher energy absorption capacity compared to 20mm fibre in each fibre level.

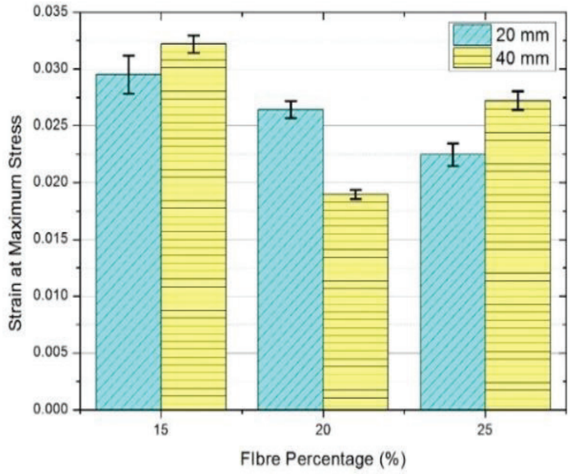

Fig. 6. Variation of strain at maximum flexural stress.

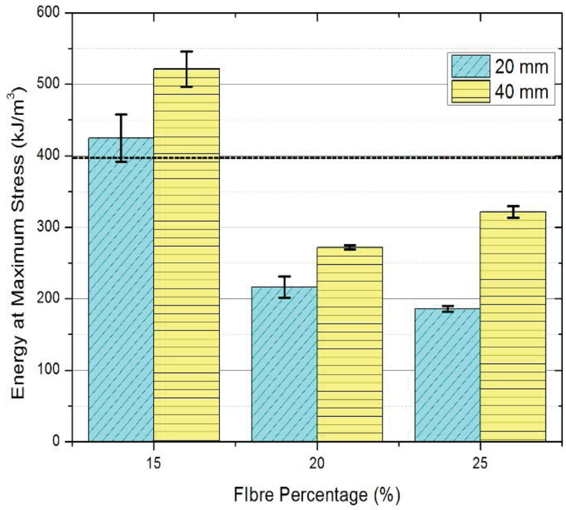

Fig. 7. Energy at maximum flexural stress

IV. CONCLUSIONS

15% of 40 mm Palmyra addition showed the highest flexural stress at the failure point, highest strain at maximum stress, maximum flexural strength, and the highest strain energy at maximum flexural stress, where the highest value of the flexural modulus was obtained by 20% of 40mm fibre content. However further analysis with lower fibre addition with narrow gaps is recommended for solid conclusions. Among the two fibre lengths considered, 40mm fibre showed better performance compared to 20mm fibre. Developed NFRCs will be able to use as an alternative for available synthetic fibre composites. Particularly, windows and door frames, roof tiles for low loading applications, panels for partition and false ceilings, mobile structures which can withstand natural calamities, interior panels, door-frame profiles, food trays, lampshades, helmets, storage boxes, furniture elements, etc. In addition, this will help to encourage starting waste-based manufacturing products which will generate new employment opportunities. Furthermore, this will provide an engineering approach to industrial waste management, securing available natural resources, and sustainability of the future world. The development of waste-based NFRC with Palmyra fibre and waste LDPE is a sustainable approach for better waste management.

Acknowledgment

The authors would like to extend their gratitude to University of Jaffna for providing the necessary funding for this research through URG/2018/SEIT/09, and to the Department of Civil Engineering, University of Jaffna for the generous supply of materials and laboratory facilities.

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ISBN: 978-624-6150-05-1