

INVESTIGATION OF MECHANICAL AND PHYSICAL PROPERTIES OF DATE PALM STEM FIBRE REINFORCED EPOXY COMPOSITES

DOLOČITEV MEHANSKIH IN FIZIKALNIH LASTNOSTI EPOKSIDNEGA KOMPOZITA, OJAČANEGA Z VLAKNI IZ STEBEL PRAVEGA DATLJEVCA

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The growing demand for sustainable materials, particularly date palm stem fibre (DPSF), has garnered attention in the area of engineering applications due to its advantageous traits. Its composites offer distinctive characteristics such as satisfactory mechanical properties, low density and a cost-effective production. This study examines the mechanical characteristics of epoxy (LY-556) composites reinforced with DPSF. A range of composite configurations with different compositions and fibre loadings were meticulously crafted, using a hand lay-up technique. The research meticulously examines DPSF and epoxy composites with loadings of (10, 15, 20, and 25) w%, comprehensively characterizing their flexural, tensile, impact and water-absorption behaviours. Across the varied compositions, the characteristics of flexural strength, tensile strength, impact strength and water absorption are thoroughly analysed. The conclusive findings underscore optimal enhancements in the flexural, tensile and impact strengths achieved with the DPSF loading of 20 %. This empirical understanding bears significance for designing natural fibre reinforced composites with superior mechanical attributes, reaffirming DPSF's potential as a valuable reinforcement in modern engineering applications.

Keywords: date palm stem fibre, epoxy resin, polymer composites, mechanical properties

Povpraševanje po trajnostnih materialih za uporabo v inženirskih aplikacijah narašča. Zaradi izredne kakovosti vlaken iz stebel pravega datljevca (DPSF; angl.: Date Palm Stem Fibre) so le-ta vzbudila pozornost avtorjev tega članka. Polimerni kompoziti ojačani z DPSFT bi zato lahko imeli posebne lastnosti, kot so zadovoljive mehanske lastnosti, majhno gostoto in možnost cenene izdelave. V tem članku avtorji opisujejo izvedeno študijo izdelave in določevanja mehanskih lastnosti epoksidnega kompozita (LY-556) ojačanega z DPSF. Z ročno tehniko izdelave so avtorji izdelali vrsto kompozitov te vrste z različno vsebnostjo DPSF (10, 15, 20, in 25) w%. Kompozitom so nato določili upogibno in natezno trdnost, udarno žilavost in absorpcijo vode. Ugotovili so, da je optimalna vsebnost ojačitvene faze 20 %. Ta empirična študija je pokazala, da imajo te vrste polimernih kompozitov ojačanih z DPSF nedvomno velik potencial za uporabo v modernih inženirskih aplikacijah zaradi odličnih mehanskih lastnosti.

Ključne besede: vlakna iz stebel pravega datljevca, epoksidna smola, polimerni kompoziti, mehanske lastnosti

1 INTRODUCTION

Polymer composites are recognized as modern engineering materials comprised of chemically distinct components, where a continuous matrix interlaces with reinforcing elements such as micro and nano fillers as well as synthetic and natural fibres.¹ In light of an escalating awareness of sustainable environmental practices, researchers have been spurred to prominently consider the utilization of natural fibres like jute, bamboo, kenaf, pineapple leaf, hemp, coir, flax, banana and oil palm among an array of others, as eco-friendly reinforcements for polymer composites. This strategic shift aims to curtail the reliance on synthetic fibres like carbon, glass and Kevlar.²⁻⁴ Extensive investigations have underscored the biodegradability, renewability, non-abrasive nature and

exceptional mechanical attributes of cellulosic fibres.⁵ The fabrication of distinct composites was realized through a methodical amalgamation of the hand lay-up technique with the compression moulding process.⁶ Notably, within the realm of natural fibre studies, attributes such as specific strength and specific stiffness emerged as the pivotal parameters for determining the performance of the resultant composites. Moreover, parameters such as cellulose and microfibre orientations exhibit a profound impact on the role of fibres as the reinforcements within composite materials, serving diverse purposes.⁷ However, despite an extensive body of research on the mechanical characteristics of date palm leaf fibre (DPLF), the investigations concerning date palm stem composites remain relatively scarce.⁸

Remarkably, reinforcing date palm fibre (DPF) within epoxy composites has remained conspicuously unexplored. The present study endeavours to illuminate the ramifications of varying the DPF loading (40, 50 and

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60) w/% on the critical parameters of the thermal and mechanical characteristics of epoxy composites, i.e., flexural modulus and flexural strength.⁹ Impressively, the composites crafted from epoxy date palm branches (EDPBs), epoxy date palm leaves (EDPLs) and epoxy date palm core shell (EDC) fibres exhibit exceptional tensile, flexural and composite properties. This endeavour is anticipated to significantly contribute to the advancement of sophisticated cost-effective materials with multifaceted applications in various industrial domains. Moreover, the recyclability of these materials holds promise for energy and water absorption assessments.¹⁰

In the contemporary landscape, plant-derived fibres, encompassing jute, coir, abaca, pineapple, cotton, kenaf, sisal, banana, flax, date palm and palmyra leaf have garnered commercial viability in the realm of hybrid composites, polymer composites and ecologically conscious green composites, often paired with diverse polymer matrices. Date palm fibre (DPF) emerges as an agricultural waste byproduct, particularly abundant in regions such as Saudi Arabia and Asia. The date palm (*Phoenix dactylifera*) provides us with pivotal tropical fruit, ranking second in global commercial availability, trailing only pineapple and citrus. The leaves and fruits of the date palm find extensive use in the manufacturing of natural fibres.¹¹ Notably, the elemental composition of DPSF aligns with those of the other lignocellulosic fibres characterized by holocellulose (60–75 %), lignin (20 %) and ash (1.18 %) contents.^{12,13}

Chemical treatments, encompassing techniques such as acetylation, bleaching and alkali treatment, are pivotal in improving the bonding between the fibres and the matrix. These treatments augment the surface roughness of natural fibres by removing impurities and engendering an OH-functionalized surface that impedes moisture absorption.^{14–18} Moreover, varying the drying time has been evidenced to influence water absorption behaviours, particularly in longitudinal and transverse directions, within composite materials composed of date palm fibres.¹⁹

By amalgamating residual agricultural waste fibres with bamboo fibres, a composite material emerges that

embodies ecological significance and material efficacy.²² Date palm fibres, anticipated to exhibit robust compressive strength characteristics, provide the potential for creating robust and high-strength materials.²³ It is envisaged that a composite reinforced with adhesive matrix fibres derived from date-palm and bamboo-waste residues would enhance the workability of strengthened date-palm constructs. The mechanical properties of date palm fibre bio-composites warrant an enhancement of both functional and quasi-functional applications.^{19–21} Within this context, the present study integrates alkali-treated short date palm fibre comprising four distinct weight ratios (0, 10, 20 and 30) w/% along with short glass fibres (with a consistent weight percentage of 10 w/%) into epoxy resin to forge composite materials. The meticulous incorporation and thorough mixing of fibres within the epoxy resin are executed through a methodical stirring process.²² Sustainable, eco-friendly composites can fulfil the requirements of sustainable, eco-friendly products.²⁴ The mechanical properties of short date palm mat fibre-reinforced polystyrene composites can be improved through the application of gamma radiation.²⁵ Date palm fibre/natural fibre composites with good mechanical properties can be used for low-cost building-insulation systems, including wall flooring, roofing and home furnishings.^{26,27}

2 MATERIALS AND METHODS

2.1 Materials

The materials employed in this research comprise date palm stem fibres (DPSFs), a NaOH solution, epoxy resin (Araldite LY 556) and a hardener (aliphatic amine HY 951). The DPSFs shown in **Figure 1** are extracted from the stems from a date palm farm in Bahrain. The epoxy resin, along with its corresponding hardener, came from Leo Industries Limited, India. The epoxy resin utilized is designed for curing at a low temperature, and the resin and hardener are combined in a weight ratio of 10:1. As the reinforcement, natural DPSFs with lengths ranging from 2 to 3 mm are employed.



Figure 1: Raw date palm stem fibres



Figure 2: Chopped date palm stem fibres

2.2 Fabrication of composites

The production of the composite is conducted using the conventional hand lay-up technique. These short, chopped fibres, shown in **Figure 2**, are paired with epoxy, which is selected as the matrix material. Subsequently, the short fibres undergo a chemical treatment involving immersion in a NaOH solution for a duration of 2 hours. Following this treatment, the fibres are thoroughly rinsed with water and air-dried under atmospheric conditions for approximately 48 hours.

Using these treated fibres, four composite samples are meticulously crafted, each with dimensions of (250 × 250 × 3) mm as shown in **Figure 3**. Different amounts of the fibres are (5, 10, 15 and 20) %. Similarly, the corresponding weight fractions of NaOH treated DPSFs are prepared.

Table 1 lists the composite compositions and their corresponding designations. Each composite mixture is cast and subsequently cured under a load of approximately 20 kg for a duration of 24 hours. Following this curing period, appropriately sized specimens are meticulously prepared to undergo a comprehensive characterization and testing, adhering strictly to the ASTM standard protocols.

Table 1: Specification of the composites

| Sample No | DPSF content (w/%) | Compositions |
|-----------|--------------------|-------------------------|
| 1 | 10 | Epoxy resin + 10 % DPSF |
| 2 | 15 | Epoxy resin + 15 % DPSF |
| 3 | 20 | Epoxy resin + 20 % DPSF |
| 4 | 25 | Epoxy resin + 25 % DPSF |

3 RESULTS AND DISCUSSION

3.1 Flexural test

Figure 4 shows the impact of an DPSF addition to epoxy on the flexural properties of the material. It is evi-



Figure 3: Fabricated specimen

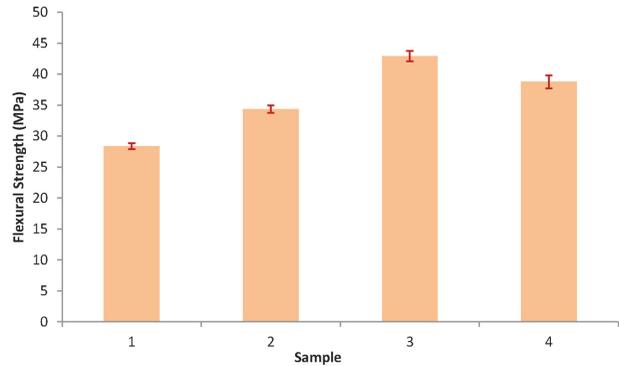


Figure 4: Flexural strength of date palm stem fibre/epoxy composites

dent from that the integration of DPSFs leads to a substantial enhancement in flexural properties. To examine the flexural properties of the composite, the flexural testing configuration was meticulously executed in accordance with the ASTM D7264 standards. A three-point bending test was carried out, measuring the flexural modulus behaviour and flexural strength of the test samples with DPSFs. Notably, the inclusion of 20 % DPSFs within the composite contributes to a heightened flexural modulus, as shown in **Figure 5**, and peak load-associated flexural strength.

Among the composite samples, Sample 3 demonstrates superior flexural properties in contrast to the other composites. This improvement can be attributed to the optimal impregnation of DPF, enhanced dispersion and strong interfacial adhesion with the epoxy. Earlier research has confirmed that the flexural strength of polymer composites is influenced by a combination of factors including the characteristics of the fibre and matrix, the quality of interfacial interactions, and the overall homogeneity of the composite.²³

3.2 Tensile test

Figure 6 provides a side-by-side presentation of the tensile strength of the investigated DPSF/epoxy composites. The assessment of the mechanical properties, modulus properties and elongation break-even point for the DPSF/epoxy composites across various loadings was

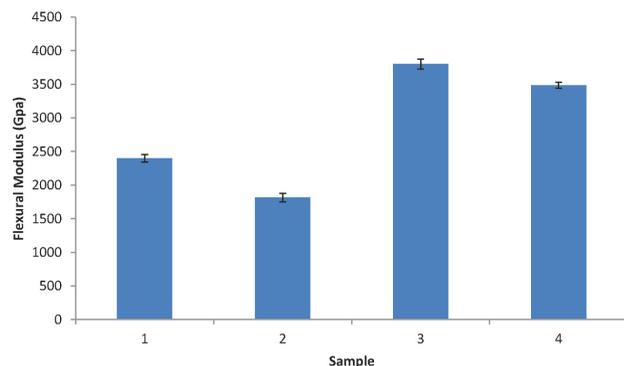


Figure 5: Flexural modulus of date palm stem fibre/epoxy composites

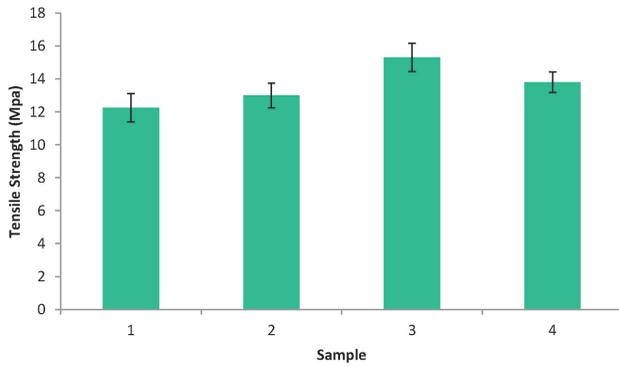


Figure 6: Tensile strength of date palm stem fibre/epoxy composites

conducted using a UTM. Prior to the initiation of tensile testing, composite samples were precision-cut into rectangular shapes measuring (250 × 25 × 3) mm using a wire cutting machine. The mechanical characterization procedures adhered strictly to the ASTM D 3039 (2014) standard. As shown in Figure 6, when the DPSF amount varies, the tensile strength is increasing until DPSF increase to 20 % as the strength of the fibres is larger than that of the matrix.

Figure 7 presents the elongation of the DPSF/epoxy composites. It also indicates that the mechanical properties deteriorated with the DPSF-amount increment as the composites became brittle after a certain limit.

3.3 Impact test

Figure 8 presents the influence of incorporating DPSF, as a filler, into epoxy on the material impact strength. The impact strength assessment for the DPSF/epoxy composites at various loadings was conducted using an impact testing machine; the composite samples were prepared according to the ASTM 256 standards. As seen in Figure 8, the introduction of DPSF yields improved impact properties when compared with pure epoxy, so satisfactory impacts of the reinforcement are achieved. This enhancement in the impact strength of the DPSF/epoxy composites can be attributed to a comparatively rigid nature of the date palm filler in contrast

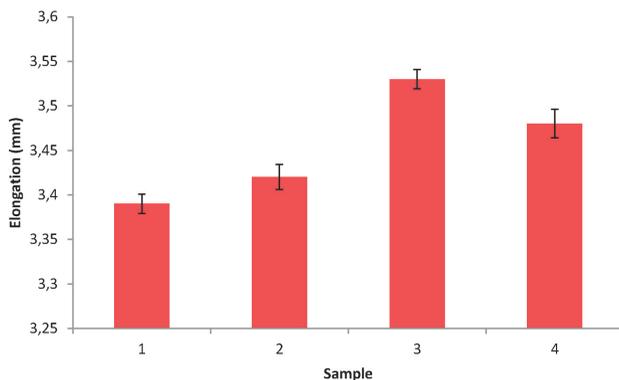


Figure 7: Elongation of date palm stem fibre/epoxy composites

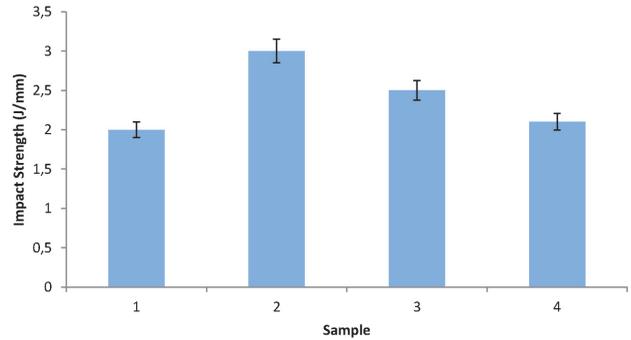


Figure 8: Impact strength of date palm stem fibre/epoxy composites

to pure epoxy. Notably, the presence of a higher cellulose content in the chemical composition of the DPSF/epoxy composites leads to an improvement in the mechanical strength and decrease in the internal damage during stress. Among the composites, Sample 2 exhibits the highest impact strength.

3.4 Water absorption

Figure 9 illustrates the water absorption of the DPSF/epoxy composites. The water absorption test conducted on the composite specimens in this study closely followed the ASTM D 570 standard procedure. Each specimen’s initial weight (Wd) and final weight (Wn) were meticulously recorded. As depicted in Figure 9, the introduction of DPSF into the epoxy matrix results in an increase in water absorption values, particularly with prolonged immersion, after approximately 24 hours. This behaviour is attributed to the hydrophilic nature of DPSF, stemming from the existence of polar groups that facilitate a robust hydrogen bonding between water molecules and cellulose constituents.

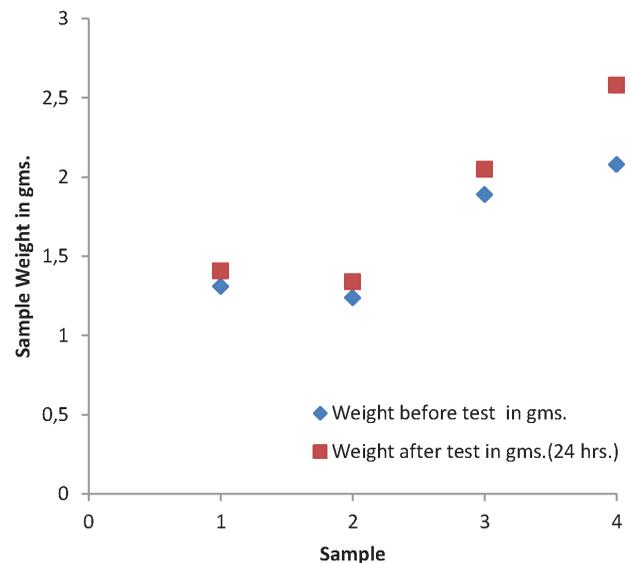


Figure 9: Water absorption of date palm stem fibre/epoxy composites

This trend is consistent with the behaviour commonly observed in natural fibre reinforced polymer composites where DPSF/epoxy composites tend to exhibit a higher moisture absorption compared to pure epoxy. This phenomenon can be caused by various factors such as pores, holes, lumens, voids, flaws and inadequate interfacial adhesion as well as microcracks at the interface between DPSF and the epoxy matrix. Effective interfacial adhesion reduces the number of sites within a composite capable of retaining water molecules, thereby leading to a decrease in the water absorption. Conversely, an increased water absorption contributes to the development of microcracks, ultimately giving rise to the formation of voids and open spaces within the composite due to the expansion of the fibres.

4 CONCLUSIONS

In this study, a systematic endeavour was undertaken to fortify the structural integrity of a more rigid composite with a varying weight percentage (10, 15, 20 and 25) w/% of DPSF, functioning as the reinforcing agent within a pure epoxy resin matrix. The scope of this research encompasses an exhaustive exploration into physical, mechanical and water-absorption characteristics exhibited by the treated DPSF composites. The analysis of the obtained results unequivocally underscores the beneficial impact of a DPSF inclusion on the key properties, including the flexural, tensile and impact strength and also the tendency of water absorption. Notably, the pinnacle of these enhancements was unequivocally discerned for the 20 % DPSF amount within the composite, attributed to an effective interplay of a fine dispersion and meticulous mixing of the DPSF filler.

Nevertheless, it is imperative to note that a discernible decline in the mechanical properties, coupled with the initiation of failure mechanisms within the composite structure, was manifested at a higher fibre amount (exceeding 20 %). This phenomenon can be attributed to the inadequacy of epoxy to encompass DPSF elements at elevated fibre proportions, thereby leading to an adverse impact on the mechanical integrity. Regarding the water absorption characteristic, a consistent upward trend is observed in the water absorption rate with an escalation in the fibre content, irrespective of the fibre orientation. Notably, the best water absorption is markedly pronounced in composites with 25 w/% of date palm stem fibres.

Furthermore, the findings of this investigation go beyond its empirical implications, extending towards the optimization of the DPSF utilization for advanced, cost-effective materials tailored for mechanical engineering applications. In consonance with sustainable practices, this pursuit also contributes to the minimization of the dependency on synthetic fibres such as carbon, glass and Kevlar. The insights garnered with this study are expected to guide future material design endeavours, fostering the development of innovative, environmentally conscious and mechanically robust composite materials.

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