



EFFECT OF EPOXY CONTENT AND NBR MODIFIER ON MECHANICAL PROPERTIES OF COIR FIBRE-POLYESTER NONWOVEN COMPOSITES

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ABSTRACT: Coir fibre from coconut husk is an abundant agro-waste with potential as a sustainable composite reinforcement. However, poor interfacial compatibility and high variability limit its applications. This study investigates hybrid coir fibre-polyester nonwoven composites to evaluate the effects of epoxy content and nitrile butadiene rubber (NBR) modification on mechanical properties. The novelty lies in combining NBR-toughened epoxy with layers of coir fibre-polyester needle-punched mats consolidated through hot-press compression moulding. Three layers of coir fibre-polyester mat (50/50%) were produced by needle-punching and impregnated via hand lay-up using 60, 70, 80, 90 vol% epoxy matrixes, with or without 8% NBR. The laminates were consolidated by hot pressing and evaluated through tensile (ASTM D638), flexural (ASTM D790), and Izod Impact (ASTM D256) tests. Fracture mechanisms were analysed using scanning electron microscopy (SEM). B80 achieves the highest tensile (24.93 MPa) and flexural strengths (89.53 MPa). Meanwhile, the addition of 8% NBR reduced tensile and flexural strengths but significantly improved impact strength, C90 (23.46 kJ/m²). Furthermore, C70 and C80 exhibited CoV below 3%, indicating an excellent reproducibility. SEM observations revealed improved fibre-matrix bonding in the Series C, the NBR-modified systems. The findings demonstrate that B80 is more suitable for applications requiring higher stiffness and load-bearing capacity, while C90 is preferable for impact-resistance and energy-absorbing non-structural applications, such as roofing panels, interior building components and protective lightweight panels.

Keywords: Coir Fibre, Polyester Fibre, Epoxy Composites, NBR Modification, Nonwoven Composites

1. INTRODUCTION

In recent years, natural fibres (NF) have gained significant popularity and are essential in polymer composites for engineering applications and construction industry, aiming to replace synthetic fibres. NF from waste offers several advantages like cost-effectiveness, biodegradability, recyclability, resistance to extreme weather, and environmental sustainability [1]. Coir fibre derived from coconut husks has attracted considerable attention due to its high lignin content (40 – 50%), excellent toughness, good impact resistance, and widespread availability in tropical nations, which has remained largely underutilised for technical applications [2].

Coir fibre in polymer composites offers considerable potential, particularly for non-structural applications. Recent studies have proven the great capability of coir fibre composites in areas that require lightweight construction, ease of fabrication, and moderate mechanical properties.

These include automotive interior panels and door trim, partition boards and ceiling panels, furniture components, flexible design components, as well as general building envelope materials [3-6]. However, the inherent hydrophilicity of coir fibre and the hydrophobic nature of most polymer matrices create interfacial incompatibility that compromises the mechanical properties of the resulting composites [7].

Nonwoven mat technology, particularly needle-punching, has gained increasing interest due to its ability to mechanically entangle natural fibre with other fibres, thereby improving fibre integrity and preventing fibre dispersion during composite fabrication [8]. Polyester fibre commonly used in the production of needle-punched nonwoven mats with the natural fibre. It has a high modulus, good physical and chemical properties, dimensional stability, weather resistance, recyclability and melts at 265°C [9,42]. Combining coir fibre with polyester in a nonwoven architecture can potentially balance the

ecological benefits of natural fibres with the mechanical consistency of synthetic fibres.

Epoxy matrix is a widely used thermoset matrix for NF composite fabrication due to good dimensional stability, high stiffness, good chemical resistance, and suitability with a wide range of fabrication processes such as compression moulding and hand lay-up [10]. Research by Howlader found that the coir fibre-epoxy matrix composite outperformed the polyester matrix-based composite in all mechanical tests. Tensile, flexural and impact strengths increased by 65.74%, 111.07% and 24.43% [11]. Mahmud reported that epoxy biocomposites reinforced with CF exhibited higher impact resistance (4.67 J) than those reinforced with jute and banana fibres (3.67 J and 4.33 J) [12]. Prabhu found that incorporating 15 wt% of CF resulted in the highest flexural strength of 77.3 MPa and an impact strength of 2.4 J/mm² [13].

Despite the favourable mechanical properties reported for coir fibre-reinforced epoxy composites, the incompatibility between the hydrophilic coir and hydrophobic epoxy matrix remains a significant challenge. Poor interfacial adhesion often results in fibre pull-out, matrix cracking, interfacial debonding, and void formation, which adversely affect the mechanical properties of the composite [14].

Nitrile-butadiene rubber (NBR) is a synthetic elastomer of acrylonitrile and butadiene, known for its good flexibility, toughness, and resistance to oils and chemicals. In polymer composites, NBR is commonly used as an epoxy modifier to improve phase compatibility and enhance interfacial bonding with fibre [15]. Chudzik reported that the effective addition of NBR to completely modify epoxy is in the range of 5-10 wt%. If the NBR content is below 5%, the rubber phase volume is insufficient to disperse well in the epoxy. If it exceeds 15-20 wt%, there is a risk of phase inversion and a co-continuous rubber morphology, which leads to a reduction in impact and tensile strength [16]. Hence, the selection of 8 wt% NBR as the modifier in this study is within the range mentioned in the previous study.

Although numerous studies have investigated coir fibre reinforced epoxy composites, most have employed randomly dispersed or woven fibre configurations. Research on needle-punched coir fibre-polyester nonwoven composites remains limited. Furthermore, the combined effects of epoxy matrix and NBR modifier on the mechanical properties of coir-polyester nonwoven composites have not been systematically investigated. Therefore, the objective of this study is to evaluate the effect of varying epoxy matrix volume fractions (60, 70, 80, and 90 vol% relative to the mould cavity), combined with a fixed addition of 8 vol% NBR as an epoxy-

modifier, on the mechanical properties (tensile, flexural, and impact) of the coir fibre-polyester nonwoven composites.

2. RESEARCH SIGNIFICANCE

This research is significant for its contribution to sustainable composite development [41] by using coir fibre, an agricultural waste material, in a coir-polyester nonwoven mat while reducing the petroleum-based epoxy usage from 90% to 60%. The incorporation of 8% NBR improves toughness and reducing voids during hot-press moulding, hence promotes better fibre-matrix interaction. By evaluating mechanical properties across four epoxy ratios, this study can determine which formulation gives the best overall results. These findings provide a practical, greener path for non-structural applications in automotive, furniture, and construction, showing that waste can perform comparably to neat matrix.

3. EXPERIMENTAL

3.1 Materials

Coir fibre, polyester fibre, epoxy resin and NBR used in this study were sourced from local supplier known for its high-quality materials. The physical properties and characteristics of the coir fibre, epoxy, polyester, and NBR are summarised in Table 1.

Table 1. Properties of materials used in this study

Material	Properties	Values
Epoxy matrix	Mixing ratio	3:1
	Density	1.16 g/cm ³
	Cure condition	Room temp.
	Physical state	Transparent liquid resin
Coir fibre	Diameter	120 µm
	Length	6-8 cm
	Density	1.15 g/cm ³
	Colour	Brown
Polyester fibre	Surface condition	Untreated
	Diameter	30 µm
	Length	64 mm
	Melting temperature	265 °C
NBR	Physical state	Liquid
	Colour	Milky white
	pH	8.0 – 9.0
	Degradation	≥ 250 °C

3.2 Methods

3.2.1 Needle punching nonwoven process

The coir fibre-polyester nonwoven mat was produced by mixing-carding-needling technology developed by CETELOR machine (Épinal, France). At first, coir fibre was cut into 6 cm lengths, while polyester fibres were supplied in continuous strand form. Both fibres were initially opened manually on a conveyor system. Process of coir fibre-polyester nonwoven mat starting from both coir fibre and polyester fibre were initially opened manually on a conveyor system, Fig.1 (a) then, both fibres were mixed together and undergo the carding process, Fig.1 (b). Lastly, the needle punching process to produce coir fibre-polyester nonwoven mats, Fig.1 (c).

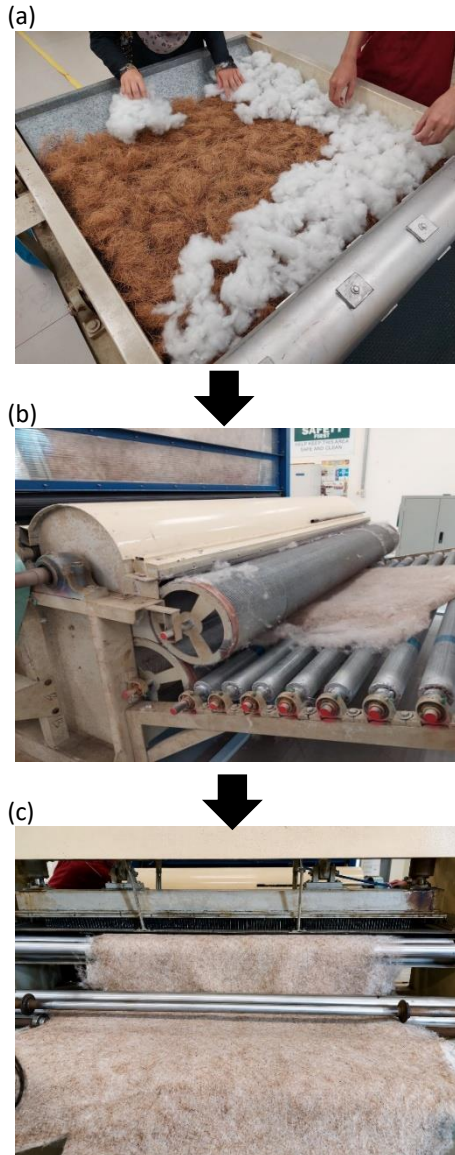


Fig.1 Process of needle-punching: (a) coir fibre and polyester fibre on conveyor, (b) carding process, and (c) needle punching process.

A 50%:50% ratio of coir fibre-polyester was used, with 4 kg of coir and 4 kg of polyester fibre fed into

the opener. This ratio was selected based on Armel, which indicates that a 50%:50% weight ratio is the optimal standard for natural fibre-reinforced thermoplastic in nonwoven mat to achieve high strength, lower thermal conductivity, and improved sound properties [17]. They were fed into a hopper at 3.92 rpm, blended, then conveyed to a loader and the Bonino carding machine for fibre carding. The carding machine operated with feed roller speed of 0.83 rpm, cylinder speed of 298.9 rpm, and delivery roller speed of 3.92 rpm. Fibres cross-lap and form fibrous webs of specific density, then are consolidated by needle punching, which uses a machine with 1328 needles spaced 6 mm apart, punching at 50 times per min with a feed rate of 25 mm/stroke and 2 mm penetration depth. The mat then was cut to 300×300×3.5 mm.

3.2.2 Composites fabrication

The composite was fabricated according to the formulations in Table 2. Epoxy matrix (EM) at 60, 70, 80, and 90 vol% was selected relative to the total volume of the mould cavity (300×300×3.5mm) to systematically reduce the EM usage compared to the control sample with 100% EM. Coir fibre-polyester mat was kept constant at a fixed 3-layer stack to ensure a consistent reinforcement architecture for all B and C series samples. Additionally, 8 vol% NBR relative to the mould volume was incorporated as an epoxy modifier. 5 replicates have been tested for each sample in accordance with ASTM guidelines.

Table 2. Formulations of coir fibre-polyester with epoxy-NBR composites

Sample	EM (vol%)	NBR (%)	Mat (3L)	Total (vol%)	R (vol%)
A	100	-	-	100	0
B60	60	-	Fixed	60	40
B70	70	-	Fixed	70	30
B80	80	-	Fixed	80	20
B90	90	-	Fixed	90	10
C60	60	8	Fixed	68	32
C70	70	8	Fixed	78	22
C80	80	8	Fixed	88	12
C90	90	8	Fixed	98	2

Note: EM=Epoxy matrix, Mat (3L)=3 Layers of coir fibre-polyester mat, Total (vol%)=Total matrix+NBR, R=Remaining fraction contains coir fibre+polyester fibre+voids, A=Control sample with 100% EM, B60=60% EM, B70=70% EM, B80=80% EM, B90=90% EM, C60=60% EM+8% NBR, C70=70% EM+8% NBR, C80=80% EM+8% NBR, C90=90% EM+8% NBR

The coir fibre-polyester mat with epoxy-NBR composite was made using hot-press compression

moulding with a 300×300×3.5mm mould. Fig. 2 is the fabrication process of the composite using hot-press compression moulding. The hot press was set to 27 MPa and 120 °C for 15 minutes, following the previous study by Hanan [18]. The mould was prepared with a flat metal plate covered in aluminium foil to prevent adhesion. A silicone sheet was added as a release layer, then the coir-polyester nonwoven mat was placed inside. Epoxy resin and hardener were mixed at a 3:1 ratio using a mechanical mixer at 75 rpm for 8 minutes, following Albadrani [19].

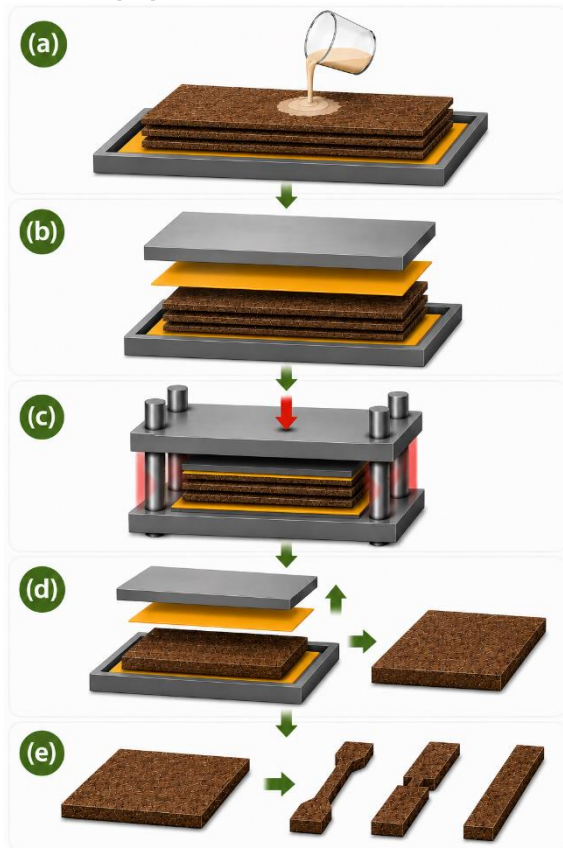


Fig.2 Fabrication process of coir-polyester mat with epoxy-NBR composite: (a) pour the mixture of epoxy-NBR onto the mat, (b) cover the mats with another silicone sheet and place the metal plate on top, (c) place the assembled mould in the hot press machine and apply the pressure and heat, (d) remove from the hot-press machine and cool down the composite, and (e) final product is the rigid coir-polyester with epoxy-NBR composite panel, then laser cut to the required dimensions for tensile, izod impact, and flexural test.

The mixture was stirred gently to minimise air entrapment and achieve a bubble-free system, then 8 wt% NBR was added as the modifier of epoxy. Then, the mixture was poured onto the coir fibre-polyester mat layers. Another silicone sheet and a metal plate

were placed on top of the sample. The assembled mould was then placed in the hot press machine. Upon completion of the compression process, the mould was removed and allowed to cool before demoulding. The final product was a rigid coir fibre-polyester composite sample. It was then cut to the required dimensions for mechanical testing.

3.2.3 Measurements and characterisation

The tensile strength of the composite samples was determined in accordance with ASTM D638 [20]. A total of 45 samples, measuring 210×20×3mm, were tested at a crosshead speed of 5 mm/min. The flexural strength of composite samples was determined in accordance with ASTM D790 [21]. A total of 45 samples, each measuring 125×12.7×3mm, were tested at a crosshead speed of 1.5 mm/min. The impact strength of composite samples was determined using the izod pendulum impact system in accordance with ASTM D256-10 [22]. A total of 45 samples, measuring 60×12.7×3.3 mm. Each sample was prepared with a 45° notch angle and a notch depth of 2.5 mm. The SEM analysis was carried out using COXEM CX-200 Plus.

4. RESULTS AND DISCUSSION

4.1 Tensile Strength Result

Tensile strength of Series B in Fig.3 shows a bell-shaped trend with epoxy content, increasing from B60 (20.43 MPa) to B80 (24.93 MPa) then declining at B90 (20.30 MPa). This trend reflects better fibre-matrix wetting and penetration, reducing voids and enhancing bonding [23]. At lower EM, B60 is insufficient to fully impregnate the coir-polyester mat, creating voids (R=40%) that weaken it and serve as crack initiation sites, causing early failure [24].

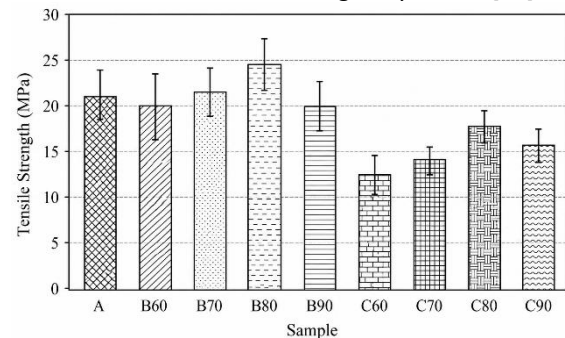


Fig.3 Tensile strength result for coir-polyester mat with epoxy-NBR composite

The tensile strength at B90 drops to 20.30 MPa with R=10%, mainly because EM occupies most of the composite, leaving limited coir-polyester mat reinforcement. The composite becomes matrix-

dominated, reducing the mat's reinforcing role. Shifa reported that tensile properties improve with more fibre up to an optimum level due to better load transfer. However, too much fibre can reduce strength by disrupting matrix and reinforcement balance [25].

The 8% NBR addition to the composite in Series C produces a substantially lower tensile strength than in Series B, across all epoxy contents. The reduction is 23% from B80 (24.93 MPa) to C80 (18.05 MPa) and 37% from B60 (20.43 MPa) to C60 (12.82 MPa). This reduction is mainly due to the elastomeric properties of NBR, which softened the EM by disrupting its rigid network [26]. Although NBR improved bonding and compatibility between EM and coir-polyester reinforcement, its lower tensile strength compared to epoxy reduced the stiffness and load capacity of the composite. This aligns with studies that rubber toughening improves impact strength but reduces tensile strength by adding flexible rubber domains to the rigid epoxy network [27].

The highest standard deviation (SD) among the results is for B60 (SD = 4.08 MPa). This is consistent with incomplete impregnation of EM into the coir-polyester mat and non-uniform void distributions across samples cut from the same panel. B70 (SD = 0.98 MPa) and B80 (SD = 1.33 MPa) show markedly lower scatter, indicating that adequate EM produce more uniform composite microstructures. C70 (SD = 0.16 MPa) and C80 (SD = 0.38 MPa) generally show lower SD value than the Series B. These findings show that the NBR modifies epoxy's rigid structure, homogenising the matrix by filling micro-voids within the EM. Even though Series C has lower tensile strength than B, it offers better fibre dispersion and uniformity, resulting in more consistent properties.

The highest coefficient of variation (CoV) among the results is for B60 (CoV = 19.96 %). The highest value of CoV of B60 is due to the insufficient EM to fully wet the coir-polyester mat, resulting in incomplete impregnation with inherently non-uniform porous nonwoven mat at R = 40%. B70 (CoV = 4.39 %) and B80 (CoV = 5.34%) show reliable results in Series B. Moreover, the exceptionally low CoV values of C70 (CoV = 1.09%) and C80 (CoV = 2.13%) indicate excellent experimental repeatability and suggest a stable composite fabrication process. This shows the relatively homogenous microstructure and consistent fibre-matrix interaction throughout the samples.

Comparative analysis of the tensile strength of the present study with other composites fabricated by compression moulding. B80 (24.93 MPa) and C80 (18.05 MPa) is comparable to treated coir mat composites (22.33 MPa) [28]. It is also exceeded the untreated short coir fibre/epoxy composite (15 MPa)

[29]. This improvement may be attributed to the needle-punched coir-polyester mat architecture, which promotes better fibre distribution and mechanical interlocking within the epoxy matrix. Treated coir fibre with addition clay recorded 77.99 MPa [30] and hybrid banana, coir, and jute recorded 56.63 MPa [31]. Although B80 and C80 show lower tensile strength than chemically modified or hybrid fibre systems, the coir-polyester nonwoven reinforcement effectively sustain loads, supporting its use as a sustainable option for non-structural applications.

The excellent fibre-matrix interaction for C80 is supported by an image of SEM, Fig.4. C80 exhibited a more compact fibre-matrix interface with reduced interfacial voids and reduced fibre pull-out compared with B80 in Fig.5. The improved fibre-matrix contact suggests enhanced compatibility between the reinforcement and the modified matrix. However, despite the improved interfacial bonding, the tensile strength of C80 remained lower than B80. Seid has reported that matrix modification with flexible rubber can enhance the impact strength but reduced the tensile and flexural properties [32].

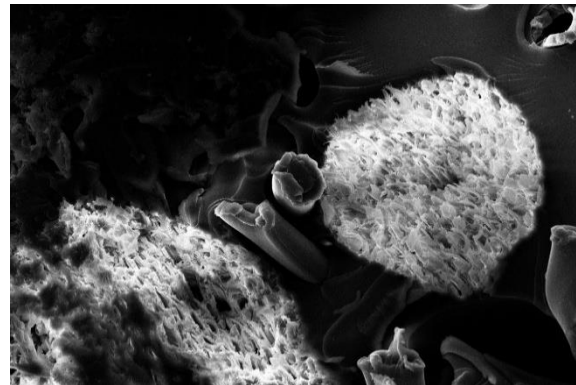


Fig.4 SEM image of tensile fracture for C80

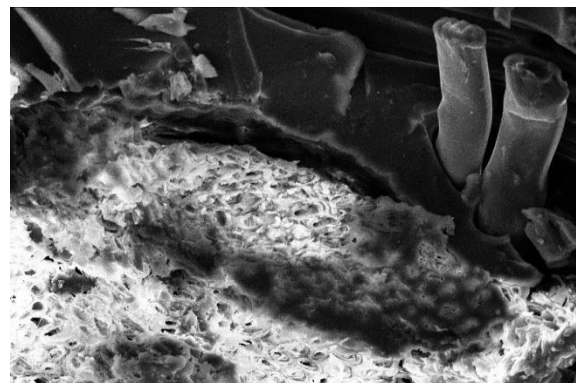


Fig.5 SEM image of tensile fracture for B80

4.2 Flexural Strength Result

The flexural strength of Series B in Fig.6 exceeds the tensile strength. The range from B60 (56.42 MPa) to B80 (89.53 MPa) shows that EM content is important for improving strength. B60 does not completely impregnate the coir fibre-polyester mat, leaving voids and poorly wetted fibres that cause cracks under stress. As epoxy increases, voids decrease, and bonding improves. B80 (89.53 MPa) outperforms A (37.24 MPa).

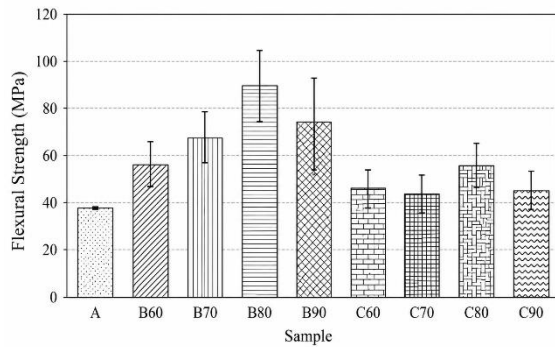


Fig.6 Flexural strength result for coir-polyester mat with epoxy-NBR composite

B90 (73.85 MPa) is reduced, consistent with the tensile results. At 90% EM, fibre volume drops ($R = 10\%$), diluting reinforcement. The matrix is well-consolidated with few voids, but the low reinforcement makes flexural behaviour more matrix-dominated. B80 is 140% higher than A (37.24 MPa), aligning with previous studies showing natural fibre-epoxy composites can reach 80-100 MPa when fibre volume and matrix are balanced. [33,34].

Series C consistently shows lower flexural strength than Series B at all epoxy contents. B80 (89.53 MPa) while C80 (46.01 MPa). NBR particles act as a soft dispersed phase, reducing strength while increasing impact resistance. This strength-toughness trade-off is common in NBR and ENR-toughened epoxy. Under bending, tensile stresses localise around NBR domains, causing micro voiding and earlier crack initiation, leading to failure at lower outer-fiber stress [35].

B80 (89.53 MPa) exceeds A (37.24 MPa) by 140%, showing high reinforcement efficiency. All Series C samples (44-47 MPa) exceed A by 19-25%, indicating NBR-added fibre reinforcement enhances flexural strength. However, Series C tested below A (21.33 MPa). These findings highlight the importance of evaluating multiple mechanical properties to fully understand the performance of natural fibre-reinforced epoxy composites.

The higher SD in Series B (B80, SD = 15.72 MPa) compared to Series C (C80, SD = 8.03 MPa) shows NBR as an epoxy modifier greatly enhances flexural property reproducibility. This aligns with tensile results, where NBR also reduced variability,

especially in flexural testing. The moderate SD in Series C (6.87-9.46 MPa) indicates NBR stabilises processing, leading to more uniform matrix flow, better fibre wetting, and consistent void removal during compression moulding.

B80 offers the highest flexural strength but with significant variability (SD = 15.72 MPa, CoV = 17.55%). For maximum strength, B80 is ideal, but quality control must be strict. C80 (46.01 MPa, SD = 8.03 MPa, CoV = 14.22%) and C60 (46.67 MPa, SD = 6.87 MPa, CoV = 14.71%) provide reasonable strength and better consistency for quality-critical applications.

4.3 Izod Impact Strength Result

Impact strength in Fig. 7 displays a bell-shaped trend, similar to tensile and flexural strength but with a less prominent peak. It rises from B60 (10.22 kJ/m²) to B80 (12.40 kJ/m²), showing better energy dissipation at optimal matrix content. B60 does not completely impregnate the coir-polyester mat, leading to a high void fraction ($R = 40\%$). The peak at B80 is a 77% increase over the control, A (7.00 kJ/m²).

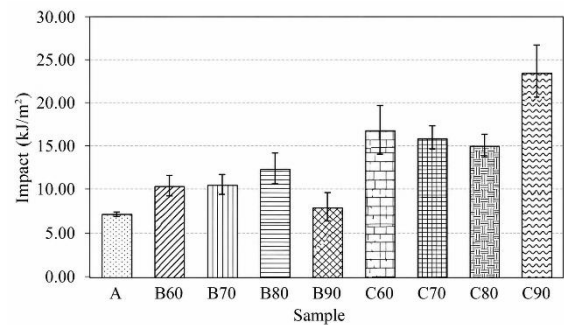


Fig.7 Impact strength result for coir-polyester mat with epoxy-NBR composite

B80 shows a 77% improvement in impact strength, lower than the flexural strength at 140% and tensile strength at 17%. This difference stems from distinct failure mechanisms, in which the impact loading involves rapid crack propagation, influenced by interfacial debonding, fibre pull-out, and matrix cracking [36]. The B90 decline (7.69 kJ/m²) aligns with tensile and flexural results, indicating a shift towards matrix-dominated behavior.

Adding 8% NBR in Series C significantly increases with epoxy content, reaching C90 (23.46 kJ/m²), a 235% rise from A (7.00 kJ/m²) and 89% over sample B80 (12.40 kJ/m²). Unlike tensile and flexural tests, where NBR reduced strength, impact results show NBR improves toughness, especially at higher epoxy levels.

The high impact strength of C90 (23.46 kJ/m²) results from the elastomeric toughening of NBR. NBR

absorbs energy and creates flexible rubber-rich domains in the epoxy matrix, aiding crack deflection, reducing stress concentration, and delaying crack growth [37].

Series C shows very low variability at C70 and C80 ($SD = 0.43 \text{ kJ/m}^2$), indicating excellent repeatability. Higher SDs at C60 and C90 suggest less consistency. The improved reproducibility in C80 aligns with SEM findings of a more compact fibre-matrix interface with NBR. Sample A is consistent ($CoV = 2.03\%$), with C70 and C80 also showing low variability, comparable to high-quality materials [38].

C90 (23.46 kJ/m^2) has the highest impact strength, surpassing many natural fibre composites, like ramie, sisal, and flax (highest impact strength only at 13.52 kJ/m^2), coir/polyester composite (5.0 kJ/m^2) and coir/sisal epoxy (2.85 kJ/m^2) [38,39,40]. Its superior performance results from NBR and high epoxy content, boosting energy absorption, crack deflection, and resistance. Adequate epoxy ensures good impregnation of the coir–polyester nonwoven, improving fibre–matrix stress transfer. NBR modification effectively enhances impact resistance in natural fibre epoxy composites.

5. CONCLUSION

This study shows a strength-toughness trade-off in coir-polyester composites. B80 had the highest tensile and flexural strength due to effective fibre wetting, stress transfer and fewer voids. C90 had the highest impact strength, a 235% increase over control A. NBR addition improved result consistency, with C70 and C80 having CoV below 3%. B80 suits high-stiffness, load-bearing uses, while C90 is better for impact resistance and energy absorption, suitable for roofing and lightweight panels. Future work should optimise NBR content, improve fibre-matrix bonding via surface treatment, water absorption test and durability.

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