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Study and Analysis of Fibre Reinforced Textile Composites Developed by using Recycled Viscose and Polyester Fibres from Apparel industry Cut Panel Wastes

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ABSTRACT

Garment cut wastes from the apparel industry are used in a variety of sectors. Apparel cut wastes and recycled fibres from apparel cut wastes are typically employed in the textile, home textile, automobile, architecture, and agrotextile industries for low performance applications. The major aim of this research work is to study and to develop high-performance composite materials using recycled fibres acquired from apparel cut wastes. Based on its properties, these composites can be used as replacement of wood panels in furniture industries, partition boards, electrical boards etc. To create these composites, recycled fibres from viscose, polyester, and viscose/polyester apparel cut panel wastes are utilized as reinforcements. Epoxy resin, kaolinite, and polypropylene sheets are used as matrices in the manufacturing of these composites. These composites were developed using a variety of reinforcement and matrix combinations. One of the fibre reinforced composites key advantages is combining the various features of many materials to create another unique, high-performance material. Technical characteristics of developed composites, including thickness, mass per unit area, tensile strength, flexural strength, impact strength, water absorption, and scanning electron microscopy, were investigated and evaluated. The findings suggest that viscose/polyester blended fibre reinforced composite exhibit higher mechanical performances when compared to other viscose and polyester fibre reinforced composites, and they are therefore recommended for a wide range of possible and potential applications.

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KEYWORDS

Textile composite, recycled fibre, composite, apparel cut wastes, recycled viscose, recycled polyester

1. INTRODUCTION

Natural resources including soil, clay, and wood are being used more and more frequently in the production of various composite materials for household and structural objects [1]. New concepts and workable goods can be generated using a variety of recycling techniques to meet this demand for necessities while also consuming fewer natural resources to safeguard the environment [2]. The demand for environmentally friendly items has increased recently, and it is vital to do so in order to maintain our ecosystem by consuming minimal natural resources. The demand for composite materials is increasing across a range of industries for both low- and high-end performance applications [4]. Depending on the various clothing product styles, the cutting efficiency in the apparel business ranges on average from a minimum of 70% to a maximum of 90%. Therefore, during the process of making clothes, 10 to 30 percent of the textiles are wasted as garment cut wastes in apparel industry cutting segment [5]. These cut wastes are majorly used for low performance applications like fibre fill, carpet manufacturing in home textile industries. We can enhance the efficient utilization of apparel cut wastes recycled fibres by using it to develop high performance composite panels and the unitization and consumption of various natural resources for new composite panel manufacturing can be minimized.

Reinforcement and matrix are the two distinct structural elements of composite materials [6-8]. While integrating different type of materials as reinforcement and matrix, the

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composite material structure would display better functional characteristics than individual and separate components [9-11]. Two or more components of materials with dissimilar physical and chemical properties are combined to create composites [12]. Different new novel materials for composite development are preferred for numerous reasons, such as materials that are stronger, lighter, or more affordable when compared to conventional composite materials [13]. One of the best ways to utilize recycled fibres for various end uses and high-performance applications is to create composite materials utilizing recycled natural and synthetic fibre [14]. Apparel cut panel waste from apparel manufacturing industry can be used to make these recycled fibres. In a variety of applications, including automotive and structural composites, natural and synthetic fibres are already used as successive reinforcing elements [15]. Fiber reinforced polymer composites are typically made by reinforcing glass, carbon, aramid, and wood fibres with a matrix of epoxy, polyester thermosetting plastic, and phenol formaldehyde resins for high-performance applications in the aerospace, automotive, marine, and construction industries [16]. The major purpose of this study is to create composite materials from apparel cut wastes to match and replace the structural materials and applications that rely on wood products. The recycling of clothing cut wastes to create high-performance products and the reduction of the use of wood for various commercial products such partition boards, doors, furniture items, electrical switchboards, and fall roofing are the main needs for these current project studies [17].

Reinforcement fibres can be extracted and individualized from apparel cut wastes by using willowing machine technique. The iron spikes on the inside of a large drum in willowing machines separates, individualizes, and free the fibres from the apparel cut waste fabric panels. Then, to acquire the various properties of the finished composite, the loosening fibres can be organized in various orientations and bonded with various matrices. To keep the reinforcement in the proper orientation within the composite structure, many types of matrices can be utilized as resins. The reinforcement fibres and matrices form a link that improves protection against external and chemical attacks and successfully transfers applied loads to the entire composite structure. In this research, an effort has been made to create a composite material employing several types of matrices and recycled fibres from viscose and polyester apparel cut wastes [18].

2. MATERIALS AND METHODS

2.1. Materials

Epoxy resin, kaolinite, and polypropylene sheet are used as matrices in the development of composites, which are reinforced with recycled fibres extracted from apparel cut wastes that are 100% viscose, 100% polyester, 50/50% viscose/polyester blend. 100% viscose, 100% polyester, and blends of 50% polyester and 50% viscose apparel cut fabric wastes were collected from apparel industries in south India. The willowing machine was used to turn the collected apparel cut fabric panel wastes into fibres. Recycled viscose, polyester, and viscose/polyester fibres were used to make needle-punched nonwoven textiles, which were then used as reinforcements in composite materials. Kaolinite (clay powder), polypropylene (120 gsm, 0.2 mm thickness) sheets, and epoxy resin (Tensile strength 80MPa, Glass transition Tg: 124.22°C) sheets were chosen as matrices for the development of composite samples. Kaolinite, a dioctahedral phyllosilicate clay, is a mineral commonly found in a soft and earthy form, often exhibiting a white coloration. It possesses a relatively low shrink-swell capacity as well as a low cation-exchange capacity, typically falling within the range of 1 to 15 meq/100 g. The formation of kaolinite primarily occurs through the process of chemical weathering, specifically the breakdown of aluminum silicate minerals like feldspar [20]. Within the domain of composite samples, the term "ratio" denotes the relative proportion of reinforcement material to matrix material employed in the fabrication of the composite. It signifies the ratio of these components in the composite's composition, which can be quantified in terms of weight, volume, or other suitable units of measurement, as dictated by the requirements of the composite manufacturing procedure. As mentioned in Table 1, four distinct types of composite samples were created in each ratio using various combinations and compositions of reinforcement and matrices.

2.2. Methods

The composites were developed using three different types of matrices (epoxy resin, kaolinite and polypropylene) and four distinct ratios of reinforcement (viscose, polyester, and polyester/viscose). Recycled fibres were used directly as reinforcements for the first and second ratio of sample preparations, and needle-punched nonwoven fabrics manufactured from recycled fibre were used as reinforcements for the third and fourth ratio of sample preparations. The composites were created using a compression moulding machine with high volume and pressure. A composite material was developed utilizing the unipolymer model high-pressure compression molding machine. As shown in Table 1, the reinforcement and matrices were mixed and stacked in various ratios. Then, it was compressed at a pressure of 50 kg/cm2 and at the temperature as specified in Table 1 in the compression moulding machine. The compressed composites were taken after 30 minutes of compression from the machine and left for 24 hours.

Table 1. Reinforcement vs matrices ratio, fibre components and Proportions samples with sample code

S. No	Sample Ratios	Sample Code	Reinforcement fibre (Recycled)	Sample components	Compression moulding Temperature &weight/sq.ft
1.	**RATIO - I** Reinforcement1: matrices 3.	V1	Viscose fibre 100%	1. Fibre RF-57g (RF-Reinforcement) 2. Kaolinite MT - 35g (MT-Matrice) 3. Epoxy MT - 135 g 4. Hardener - 16g- for better compression	135°C & 243g
2.		P1	Polyester fibre 100%		135°C & 243g
3.		PV1	Polyester/Viscose fibre blend 50/50%		135°C & 243g
4.	**RATIO - II** Reinforcement 1: matrices 3.	V2	Viscose fibre 100%	1. Fibre RF - 131 g 2. Kaolinite MT - 110 g 3. Epoxy MT - 284 g 4. Hardener - 20 g - better compression	135°C & 525 g
5.		P2	Polyester fibre 100%		135°C & 525 g
6.		PV2	Polyester/Viscose fibre blend 50/50%		135°C & 525 g
7.	**RATIO - III** Reinforcement 1: matrices 3. Three reinforcement layers were arranged among the four matrices layers.	V3	Viscose fibre 100%	1. Fibre RF - Needle punched non-woven fabric-30 g - 3 webs - 12 g/each lay 2. PolyPropylene sheet MT- 350 denier 8 sheets were used as 4 layers (2 sheets per lay)	160°C & 70 g
8.		P3	Polyester fibre 100%		160°C & 70 g
9.		PV3	Polyester/Viscose fibre blend 50/50%		160°C &70 g
10.	**RATIO - IV** Reinforcement 1: matrices 3. Matrice coating was applied to the top and bottom of the reinforcement.	V4	Viscose fibre 100%	1. Fibre RF - Non-woven fabric (Needle Punched) - 37 g 2. Epoxy MT - 72 g - 2 coatings top and bottom with 37 g/coating 3. Hardener - 4 g – for better compression	135°C &150 g
11.		P4	Polyester fibre 100%		135°C & 150 g
12.		PV4	Polyester/Viscose fibre blend 50/50%		135°C & 150 g

*****V-Viscose, P-Polyester, PV- Polyester/Viscose, RF-Reinforcement, MT-Matrices

Figure 1.a Top surface view of recycled fibre reinforced composite sample

Figure 1.b Cross sectional view of recycled fibre reinforced composite sample

To evaluate and analyze the technical performance and properties of the twelve distinct developed composite samples shown in Table 1, tests for tensile strength, flexural strength, impact strength, and water absorbency were carried out. To assess the technical characteristics of composites, thickness, mass per unit area, and fracture surface are also examined. Prior to testing, all samples were prepared conditioned at the standard room temperature of

23°C and relative humidity of 62%. Five specimens were tested for each sample, and the findings were displayed as the average of those specimens.

2.2.1. Tensile strength

The force necessary to break composite specimens is measured using the ASTM D3039 tensile testing procedure, and the findings are presented as tensile strength in MPa. Universal testing equipment with a load cell capacity of 500 KN and a speed of 20 cm/min was used to conduct the tensile tests. The thickness of the sample varies from 2 mm to 8 mm, and the specimen size for tensile testing is a constant rectangular cross-section, measuring 25 mm width by 250 mm length.

2.2.2. Flexural Strength Test

Flexural testing evaluates a material's strength when a force is applied perpendicular to the sample's longitudinal axis. Flexural strength, a mechanical property of a material also known as modulus of rupture, bending strength, or fracture strength, is described as a material's capacity to withstand deformation under load. According to ASTM D 790 standards, the flexural test was performed on the universal strength testing apparatus. Flexural strength is expressed in kg/sq.cm. The specimen size is 3.2mm x 12.7mm x 125mm for measuring flexural strength.

2.2.3. Impact Strength Test

The Charpy impact test, commonly referred to as the Charpy V-notch test, is a standardized high strain-rate test that quantifies how much energy a material absorbs prior to fracture. A material's capacity to sustain a high-energy impact without breaking or cracking is impact strength. In the Charpy impact strength tester, the test was conducted in accordance with ASTM D6110-10 standard. The pendulum was released to calibrate the apparatus before the test samples were placed to it. The force needed to break the test samples was then released from the freely swinging pendulum while the test samples were held horizontally in a vice. The machine's calibrated scale was used to read the angle the pendulum had swung before the test sample was broken, which corresponded to the amount of energy used to break the sample. KJ/m2 is the unit used to measure impact strength.

2.2.4. Water Absorbency Test

The test was conducted in accordance with ASTM D570 standard. Rectangular specimens with dimensions of 15x2.5 cm were constructed in order to assess the water absorption properties of the composites. The samples were conditioned at 23°C and 62% relative humidity before being weighed. Weight was measured using a high accuracy electronic weighing balance. The dried, weighted samples were submerged in water for a whole day. The specimens are then taken out, dried with a lint-free cloth, and weighed. Samples were once more submerged in water for a week before being removed and weighed to analyze the long-term water absorbency characteristics of composites. Similarly, the cycle was repeated for 1.5 months (6cycles). With the help of these findings, the sample's water absorption capacity over a specified period to determine its water absorption characteristics. The formula shown below was used to compute the specimen's increased weight.

$$\text{Water absorbency} = \frac{\text{(Final weight – Original weight)}}{\text{Original weight}} \times 100 \text{ (Unit is \%)}$$

2.2.5. Scanning Electron Microscope (SEM)

Using a JEOL JSM 5400 high-resolution SEM image, the morphology and microscopy of composite samples were examined. To prevent charging under the electron beam, the specimen was mounted on a stub and coated with a thin layer of gold using a sputter coater before analysis. With different magnification levels, such as x50, x60, x100, x110, x250, x300, and x700, the findings are obtained as an image of a morphological representation of the developed composites.

3. RESULTS AND DISCUSSION

3.1 Thickness and Mass per unit area

The results are shown in Table 2 for the thickness and mass per half square foot of created composite samples. The findings demonstrate that the thickness and mass per unit area are always directly proportional to the ratios of reinforcement and matrices. As a result, the ratio of reinforcement to matrices has a significant impact on the technical characteristics of composites.

Table 2. Composite sample thickness and mass per unit area

Sample Ratio code	Samples	Avg. Thickness in mm	Avg. Weight in g
I	V1	5	257.9
	P1	5.2	258.12
	PV1	5.1	258.01
II	V2	7.4	527.15
	P2	7.5	528.02
	PV2	7.4	527.8
III	V3	1.1	71.43
	P3	1.2	71.77
	PV3	1.1	71.52
IV	V4	2.8	154.69
	P4	2.7	156.74
	PC4	2.8	154.7

3.2 Tensile Strength

The tensile strength analysis of reinforced composite samples comprising polyester, viscose, and

polyester/viscose blends is depicted in Figure 2. Upon careful observation and analysis of the results, it is evident that samples PV1 and PV2, belonging to ratios I and II, respectively, exhibit significantly higher tensile strength compared to all other samples. This notable enhancement can be primarily attributed to the superior cohesion and bonding achieved between the epoxy resin and kaolinite matrices and the fiber reinforcement utilized in these samples. The robust interfacial bonding plays a crucial role in determining the overall tensile strength of the composite. In the same ratio categories (I and II), sample P1 demonstrates superior tensile strength due to the inherent bonding nature between the synthetic resin and the 100% synthetic polyester fibers employed. Furthermore, sample P3 exhibits commendable tensile strength, mainly attributed to the enhanced bonding between the PP sheet and the polyester fiber reinforcement.

Conversely, samples V4, P4, and PV4 demonstrate lower tensile strength compared to the other samples. This discrepancy can be attributed to the utilization of pure epoxy resin as the matrix and needle-punched non-woven fabric as the reinforcement in these samples. The needle-punched non-woven fabric possesses a tightly packed structure that inhibits the complete penetration of the epoxy resin. Furthermore, it should be noted that the samples V4, P4, and PV4 lack the incorporation of the kaolinite matrice component. As a result, the bonding between the reinforcement and the matrices remains moderate, leading to a comparatively lower tensile strength. In contrast, the other samples benefit from the direct incorporation of loosely mixed fibers with the matrices, facilitating a stronger bond between the constituents. This comprehensive analysis highlights the critical role of matrix-reinforcement compatibility and interfacial bonding in determining the tensile strength of composite samples. The findings underscore the significance of carefully selecting and optimizing the reinforcement materials, matrices, and their respective ratios to achieve superior mechanical properties in composite structures.

3.3 Flexural Strength

Figure 3 illustrates a comparison of the flexural strength exhibited by composite samples reinforced with viscose, polyester, and polyester/viscose fibers. The results reveal that the V2 composite material achieves the highest flexural strength value of 145.03 MPa, surpassing all other samples. This superior performance can be attributed to a higher proportion of reinforcement and matrix composition, as well as an optimized blending process that greatly influences the flexural strength of the composite material.

Sample V1 also demonstrates a commendable flexural strength value of 107.32 MPa, ranking second among all the samples tested. This outcome can be attributed to the utilization of the same material and composition as V2, highlighting the significance of consistent reinforcement and matrix selection. The data analysis suggests that the cohesion and bonding between the reinforcement fibers and the kaolinite and resin matrices significantly contribute to the overall flexural strength of the composite samples. The superior cohesion and bonding characteristics observed in these samples play a vital role in enhancing flexural strength. These findings underscore the importance of selecting appropriate reinforcement materials, optimizing their composition and blending process, and ensuring strong interfacial bonding between the constituents.

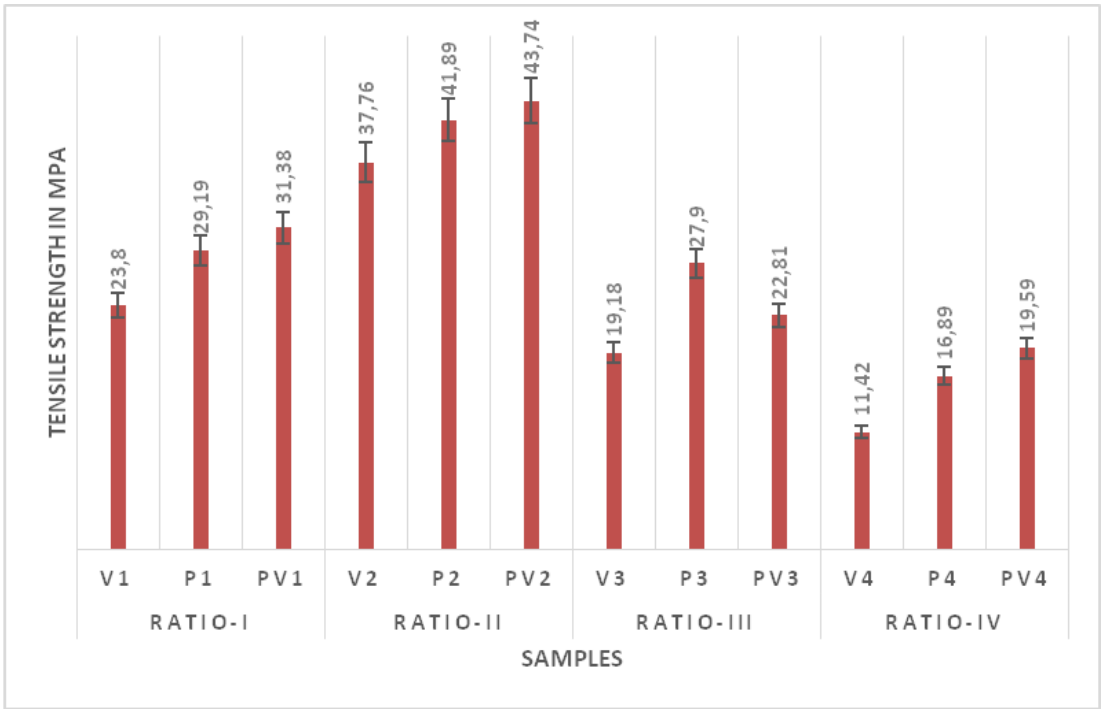

Figure 2. Comparison of tensile strength between viscose, polyester and polyester/viscose blended composites

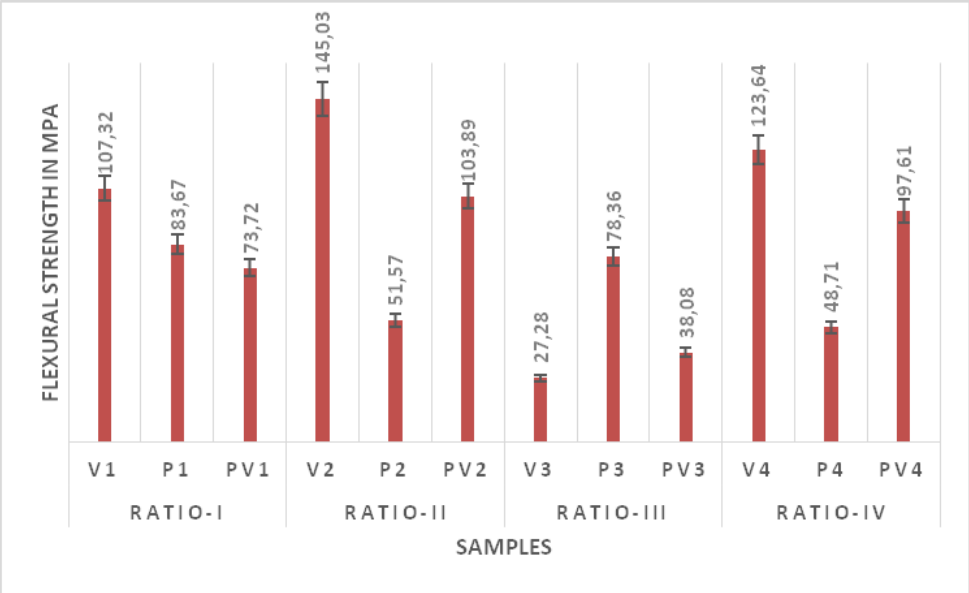

Figure 3. Comparison of flexural strength between viscose, polyester and polyester/viscose blended composites

3.4 Impact Strength

The impact strength analysis, as depicted in Figure 4, reveals important insights into the performance of composite samples reinforced with viscose, polyester, and polyester/viscose fibers. Among the samples tested, PV1, consisting of epoxy and kaolinite as matrices, exhibits the highest impact strength. This superior performance can be attributed to the specific composition of PV1, which incorporates 50% synthetic polyester fiber as the reinforcement material. The synthetic polyester fibers possess a higher crystalline content, enabling improved bonding with the synthetic epoxy resin matrix. This enhanced interfacial bonding contributes significantly to the overall impact strength of the composite sample PV1. Furthermore, the impact strength of sample P3 is also found to be satisfactory. In this case, both the reinforcement material and the matrices are synthetic in nature, thereby facilitating effective bonding within the composite structure. This bonding mechanism plays a vital role in enhancing the impact strength performance of the P3 sample.

These findings highlight the crucial role of reinforcement-matrix compatibility and interfacial bonding in determining the impact strength of composite materials. The presence of synthetic materials, such as polyester fibers and epoxy resin, fosters stronger bonding and, consequently, improved impact strength. The results underscore the significance of carefully selecting and optimizing the composition of reinforcement materials and matrices to enhance the impact strength of composite structures.

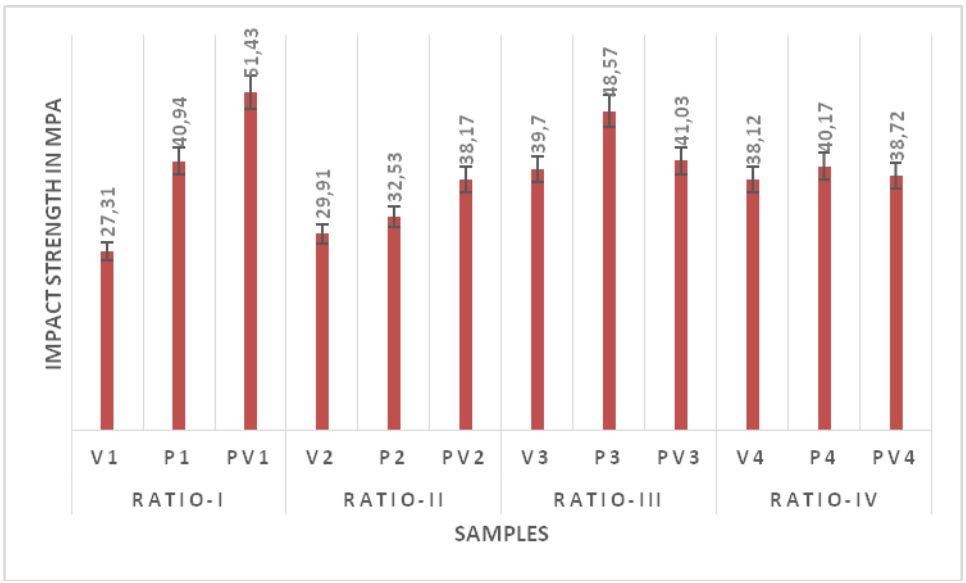

Figure 4. Comparison of impact strength between viscose, polyester and polyester/viscose blended composites

3.5 Water Absorption

The water absorbency percentage of the reinforced composite samples, as illustrated in Figure 5, provides valuable insights into their water absorption characteristics. Notably, samples P1, P1, P2, and P4 demonstrate lower water absorption levels from the initial 24 hours up to 1008 hours. Comparative analysis reveals that these samples exhibit reduced water absorption when compared to all other samples tested. The low water absorption observed in samples P1, P2, P3, and P4 can be attributed to several factors. Firstly, the close packing and reduced porosity within the composite structure, facilitated by the presence of epoxy and kaolinite matrices, contribute to the lower water absorption. These matrices provide a barrier against water penetration, limiting the ingress of moisture into the composite. Additionally, these samples are composed of synthetic polyester fibers, which possess lower moisture regain properties compared to other fibers used in the samples. The inherent characteristics of synthetic polyester fibers, including their hydrophobic nature and lower affinity for water, further contribute to the reduced water absorption observed in these samples.

These findings emphasize the importance of matrix selection, porosity control, and fiber composition in managing water absorption in composite materials. The incorporation of epoxy and kaolinite matrices, along with the use of synthetic polyester fibers, aids in minimizing water uptake, thereby enhancing the composite's resistance to moisture.

3.6 Scanning Electron Microscope (SEM)

Figure 6 exhibits the morphological representation of the composite samples at different magnification levels, offering visual evidence of the uniform distribution and adhesive nature of the matrices and reinforcements within the composites. The morphological analysis confirms that the PV sample series, incorporating two different fiber blends and matrices, demonstrates superior cohesion between the reinforcement and matrices when compared to other samples. The morphological images validate the successful integration and dispersion of the reinforcement materials within the matrix, indicating a well-blended composite structure. The uniform distribution of the fibers throughout the matrix signifies effective interfacial bonding, resulting in enhanced mechanical properties.

4. CONCLUSION

The primary objective of this research was to explore the potential for high-performance applications of recycled fiber reinforced composites. Experimental investigations were conducted to evaluate key properties such as tensile strength, flexural strength, impact strength, water absorption and SEM analysis. A total of twelve composite samples were tested, incorporating varying types and quantities of recycled fibers as reinforcement, along with different matrices in varying ratios. The results of the study revealed that polyester/viscose fiber reinforced composites exhibited superior tensile strength compared to other recycled fiber reinforced samples. These composites can be further tailored to specific application requirements by designing different lay-up angles and orientations, incorporating various preformed layers of reinforcements. The versatility of these composite materials extends to structural applications, including thermal and acoustic insulation. By utilizing recycled garment cut wastes, the scope of recycling can be expanded, allowing for increased utilization of these composites. This not only contributes to resource conservation but also offers potential benefits in terms of reduced cost and weight of the composites. Overall, this research highlights the promising potential of recycled fiber reinforced composites in high-end performance applications. Further research can focus on optimizing the composition and manufacturing processes to enhance the mechanical properties and explore additional functional attributes of these composites.

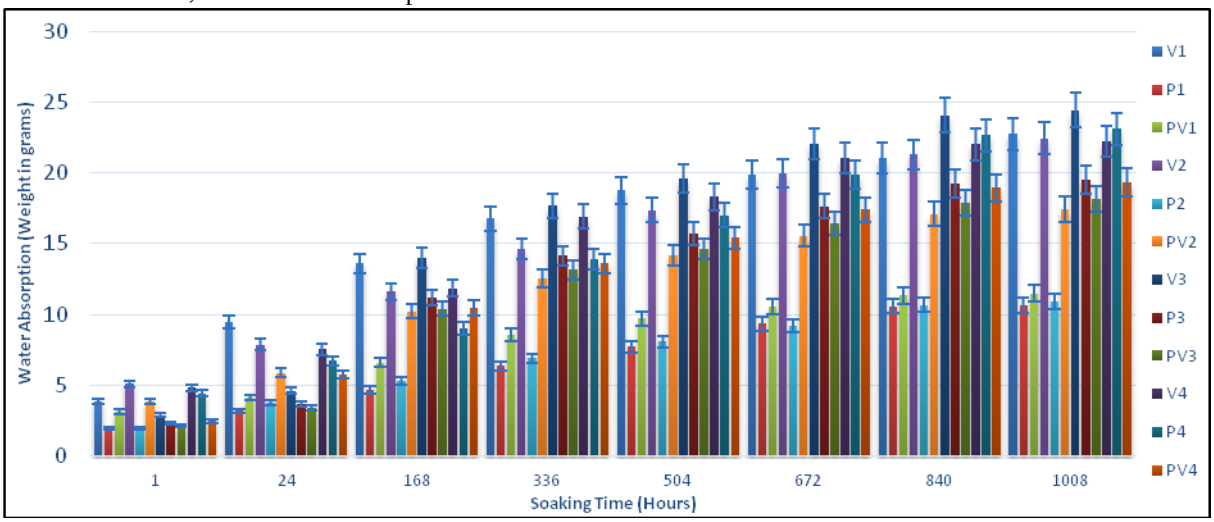

Figure 5. Comparison of water absorption between viscose, polyester and polyester/viscose blended composite samples

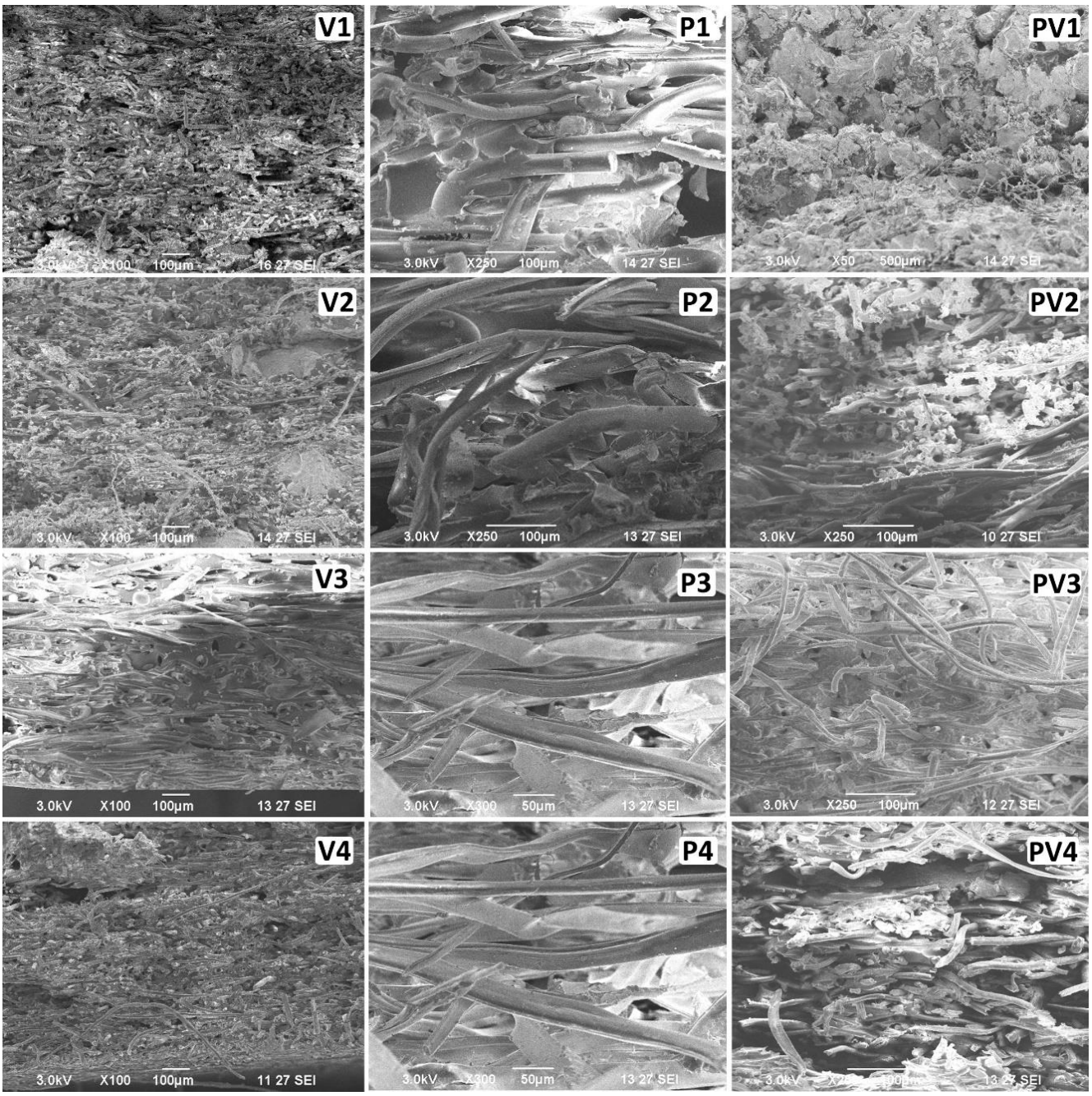

Figure 6. SEM images of different composite samples

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