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Surface and Cross-Sectional Morphology of Wood Plastic Composite Using Scanning Electron Microscopy

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Abstract

The natural-fibre-reinforced polymer materials based on wood plastic composites (WPCs) are broadly utilized because they offer better performance in terms of stiffness, dimensional stability and environmental advantages. Microstructural features, including fibre dispersion, interfacial adhesion, and the creation of void, have a very significant impact on the performance of WPCs. This study evaluates the surface and cross-sectional morphology of a commercial polyvinyl chloride (PVC)-based WPC reinforced with 40% wood fibre. Characterization was performed using Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS) to qualitatively analyze surface elemental composition. SEM measurements showed an anisotropic and non-uniform surface morphology that was exposed to the wood fibres and micro-voids. Cross-sectional observations showed heterogeneous fibre distribution, interfacial gaps and internal voids in the cross-section, which indicated the incomplete polymer encapsulation and low fibre-matrix compatibility. Analysis on the surface through EDS revealed the presence of carbon and oxygen peaks that are predominantly in the polymer matrix and lignocellulosic fibres respectively and several inorganic elements that are linked to natural fibre components and polymer additives. All in all, the findings indicate that morphological characteristics on the surface and inside are directly connected with the quality of WPC materials and the interfacial bonding, dispersing of the fibres, and the optimum processing condition play a significant role in creating high-quality wood plastic composites.

1. Introduction

One of the Natural Fibre-Reinforced Polymers that has received considerable attention as a blend of lignocellulosic fillers and thermoplastic polymer matrices like polyvinyl chloride is the Wood Plastic Composite (WPC). During processing, it undergoes extrusion, where the material is forced to flow through a die containing a form to create continuous profiles (decking, planks, or wall construction panels). Ultimately, the processing leads to the creation of natural fibre-reinforced polymers having enhanced properties of stiffness and dimensional stability [1]. Because of the benefits associated with the utilization of WPCs, they have been characterized by wide usage in the construction sector to manufacture decking, furniture, and car components. The growing popularity of environmentally friendly polymer materials has created an increasing research interest to comprehend the property relationships of WPCs [2].

Microstructural parameters of WPCs, like dispersion, bond strength of the fibre with the matrix, and the existence of voids in microstructures, can largely influence the quality of the WPCs. Weak dispersion of the wood fibres and the weakness of the fibre-to-matrix bond strength throughout the hydrophilic fibres and hydrophobic polymers can create the voids, pull-out, and stress concentrations in WPCs [3]. In this way, the topographical evaluation of surfaces plays a significant role in identifying the efficiency of the WPC production, along with the understanding of failure analysis on the microlevel. It has been demonstrated that a better penetration of load between fibres and matrix is achievable by enhancing the level of interfacial compatibility, which can be achieved either by surface treatment, compatibilizer, or both, and thereby reducing the contents of void and consequently yielding enhanced mechanical properties [4]. As an example, research has found out that there are syntactic increases in the density of microcracks and also stress transfer between composite interface because of coupling agents, hence improved tensile and flexural characteristics [2].

Characterization of microstructural features is significant to realize the connection between the characteristics in WPCs. SEM is one of such techniques of analysis. It is regarded as one of the powerful methods of morphological study due to a high level of spatial resolution and depth of focus. Through SEM, fibre dispersion, quality of interfacial adhesion, surface roughness, and through the use of the method, the void structures can be visualized, usually beyond the capacity of the traditional optical microscopy to visualize [5]. A number of studies documented that the SEM micrographs provide crucial data on the microstructural characteristics that include pulled out fibres, interfacial gaps, and void distribution that have a direct correlation with mechanical performance and failure mechanisms [3][4]. Scanning Electron Microscopy (SEM) is proven to be an efficient technique to analyse morphological properties of Wood Plastic Composites (WPCs). Previous works have made it clear that better polymer/fibre interfacial compatibility means lower voids as well as improved polymer infiltration into the fibre, and that well-dispersed fine fibres are essential to ensure well-developed stress distribution in the matrix [2][3][4]. Despite extensive studies on WPCs, limited work focuses on correlating surface and cross-sectional morphology with interfacial defects using combined SEM-EDS analysis on commercial PVC-based systems. Therefore, this study aims to evaluate the morphological characteristics of WPCs and relate them to fibre dispersion, interfacial adhesion, and processing quality.

2. Materials and Methods

2.1 Materials

The instrument used in the analysis were Scanning Electron Microscope (SEM), a Sputter Coater, Oven. The specimen used was a wood plastic composite board, which is a commercial wood plastic composite of wood fibres in a thermoplastic polymer matrix (40% wood, 60% PVC) from an online store bought as a 3x3 Feet Fluted Wall Panel (TAVA). There were no additional modifiers which were characterized in this study.

2.2 Sample Preparation for SEM Analysis

A small section (approximately 10x10 mm) was cut from the WPC board for surface analysis. Another small section (approximately 10x6mm) was cut from the WPC board for the cross-section analysis. The samples were cut manually into small sections using a sharp cutting tool for SEM observations. The WPC samples were put into the oven at 100°C for 24 hours. This drying process was performed to remove moisture and prevent artefacts such as void formation during SEM imaging. The samples were then left to cool at room temperature before securely mounted on flat aluminium stub and a 90-degree angled aluminium stub using conductive carbon tape. The samples were sputter-coated with thin layer (20 nm) of Gold. The cross-section sample was also taped with some copper tape.

2.3 SEM Analysis

Surface morphology of the wood plastic composite was observed with a COXEM scanning electron microscope with accelerating voltage set to 20.0 kV. Secondary electron imaging (SEI) mode was employed to emphasize surface topography. Images were obtained at magnifications ranging from 200x to 500x. All observations were conducted at multiple regions to ensure representativeness. The working distance was maintained at approximately 11.0 mm for the surface and approximately 9.0 for cross-section. The sputter coater used to prevent charging effect under the electron beam.

2.4 Energy Dispersive X-ray Spectroscopy (EDS)

EDS analysis was conducted as a semi-quantitative technique to identify elemental composition. EDS spectra were recorded at representative areas to elucidate dominant elements and support phase identification.

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3. Results and Discussion

3.1 Surface Uniformity of WPC

Scanning electron microscopy was used to study the surface morphology of the wood plastic composite (WPC) at a 200x magnification on the secondary electron imaging mode. Fig. 1 depicts that the surface has a non-uniform and layered texture, and its features are long with a certain direction, typical of extrusion-processed WPC material. The observed anistropic morphology suggests directional mechanical behaviour due to fibre alignment during extrusion [6]. Revealed wood fibres and coarse coverage of polymer is evident on the surface signifying that the polymer matrix has not fully covered fibres in some areas. This is a common heterogeneity of surfaces in WPCs that is affected by fibre loading, melt viscosity, and processing parameters [7]. The reason why the texture of the surface is rough is that a large fraction of lignocellulosic content may be located close to the surface, which can influence properties of the surface, such as moisture uptake and wear resistance [8].

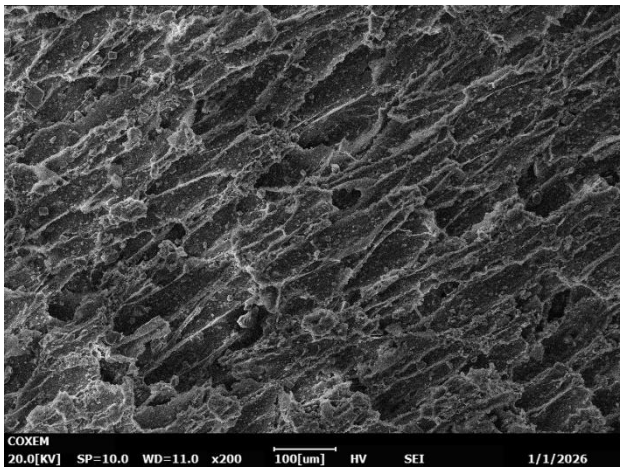

Fig. 1 SEM micrograph of WPC surface showing overall surface uniformity at 200x magnification

3.2 Surface Defects and Interfacial Features

A further inspection of surface SEM image shows that there are micro-voids and interspersed spaces amid the elongated features as indicated by the darker spaces in Fig. 2. These voids are probably created as a result of a lack of polymer flow into fibre-rich areas or extraction of moisture in wood fibres in the high-temperature processing. The presence of exposed fibre ends, discontinuities also imply the existence of weak interfacial bonds between the hydrophilic wood fibres and the hydrophobic polymer matrix [9]. The surface defects, like void and fibre pull-out, have been known to be areas of concentration of stress and may trigger crack propagation during mechanical loading. Past research [8] has established that WPCs with similar surface characteristics were less likely to have tensile and flexural strength because the WPCs were not effective in transferring stress across the fibre-matrix interface. Hence, the surface defects that are present in this study are signs of restrictions to the interfacial compatibility and processing efficiency.

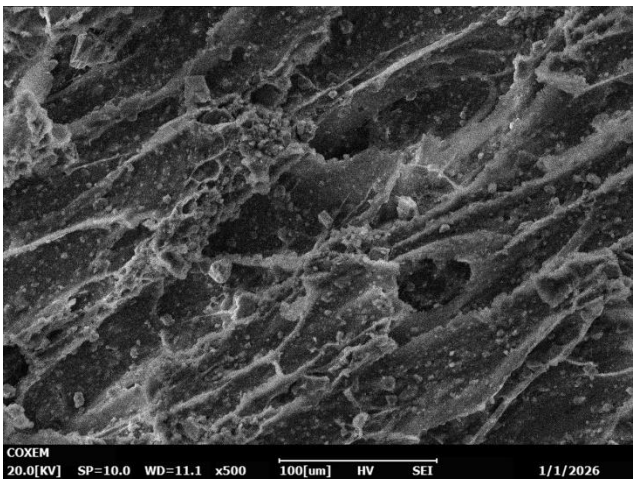

Fig. 2 SEM micrograph of WPC surface illustrating micro-voids and exposed fibres at 500× magnification

3.3 Cross-Sectional Morphology of WPC

3.3.1 Internal Fibre Distribution

Cross sectional SEM image of the WPC at 200x magnification (Fig. 3) has given an idea of the internal structure of WPC. The figure indicates a stratified internal structure with long-shaped cavities and a discontinuous arrangement of fibres in the polymer structure. Fibre-based areas are rough and appear to be textured, whereas polymers are more compact and smoother. The observed heterogeneous fibre distribution indicates insufficient mixing during processing, which may result in localized mechanical weakness. This has been observed to be similar in WPCs that have undergone inadequate shear levels, where agglomeration and non-homogenous dispersion of fibres lead to heterogeneous mechanical behaviour [7]. Even distribution of the internal fibres is essential to good load transfer and mechanical stability; therefore, the morphology that is seen internally shows that there might be potential variation in the structural performance between the composites.

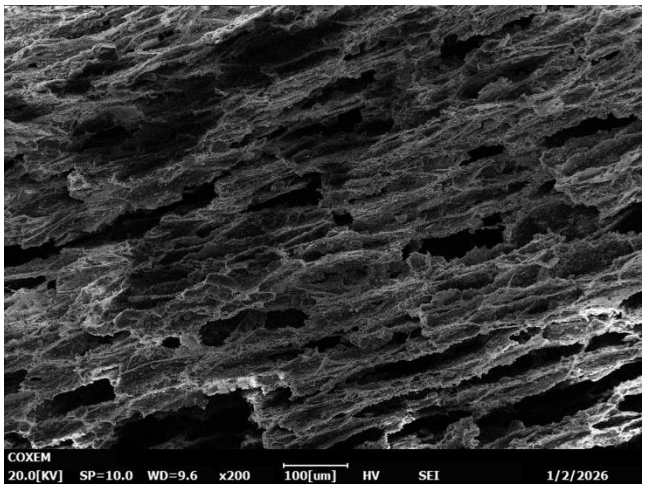

Fig. 3 Cross-sectional SEM image of WPC showing internal fibre distribution at 200× magnification

3.3.2 Interfacial Adhesion and Voids

There are clear interfaces gaps and internal spaces observed in the cross-sectional picture, especially in the darker parts of the picture following the direction of extrusion (Fig. 4). These pores are probably formed due to an entrapment of air, release of volatiles, or the inability of wetting of wood fibres by the polymer melt during processing. The existence of interfacial gaps suggests poor wettability between fibre and matrix, leading to inefficient stress transfer and increased likelihood of failure. Consequently, fibre pull-out rather than fibre fracture is expected to occur under stress [9]. Interior voids decrease the effective load-bearing cross-section and act as starting points of cracks propagation. It has been demonstrated that the addition of compatibilizers (or coupling agents) leads to a great decreasing of such void formation, by increasing the interfacial bonding and penetration of the polymer into fibre lumens [6]. Hence, the interfacial characteristics observed present a microstructural explanation of the possible decreases in the mechanical performance and durability of the analysed WPC.

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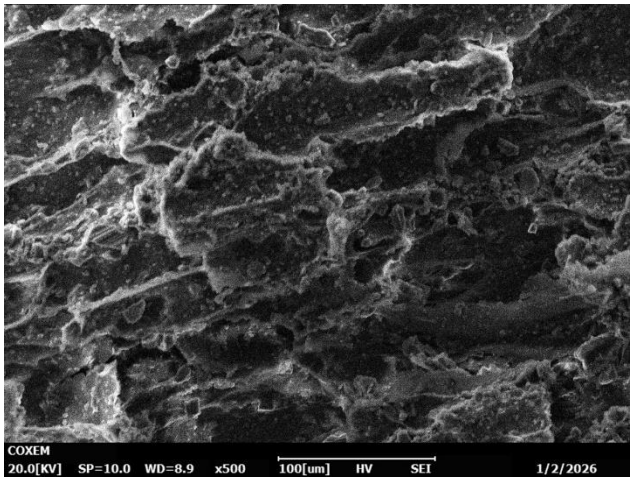

Fig. 4 Cross-sectional SEM micrograph highlighting interfacial adhesion and void formation at 500× magnification

3.4 Surface EDS Elemental Analysis

Energy dispersive X-ray spectroscopy (EDS) in combination with SEM was used to support the morphological observations through surface elemental analysis of the wood plastic composite (WPC). The EDS spectrum on the surface region is given in Fig. 5. The findings show that carbon (C) and oxygen (O) are the most prevalent elements in it with weight percentages of about 59.67 wt% and 25.04 wt%, respectively. This is due to the high carbon content, which is due to the thermoplastic polymer matrix and the high oxygen content being attributed to the lignocellulosic presence of the wood fibres, which contain cellulose, hemicellulose and lignin in high concentration [6]. Besides the carbon element and oxygen, there were other minor elemental peaks of calcium (Ca), chlorine (Cl), and potassium (K) found on the composite surface. Inorganic components that can be found in natural wood fibres are typically calcium and potassium, which are plant mineral or ash components, whereas chlorine is commonly linked with polymer additives or stabilizer, especially polyvinyl chloride (PVC)-based WPC systems [8]. The existence of these small components implies the input of both natural fibre components and polymer additives to the total surface composition of the composite.

Table 1 tabulates the values of the atomic percentages also confirm the predominance of carbon in the form of phases, with carbon constituting more than 70 atomic% showing the presence of polymer-rich surface areas with partial exposures of wood fibres. These EDS findings are in agreement with the SEM surface morphology observations, with exposed fibres and heteropolymer coverage being obvious. Elemental distributions have been previously described using similar elemental distributions in previous WPC studies, in which surface EDS analysis was employed as a qualitative tool to verify the presence of phases and aid microstructural interpretation instead of actual quantitative composition analysis [9]. This means that the surface EDS analysis would be used to supplement the SEM results with evidence of the compositional presence of polymer and wood phases on the surface of WPC.

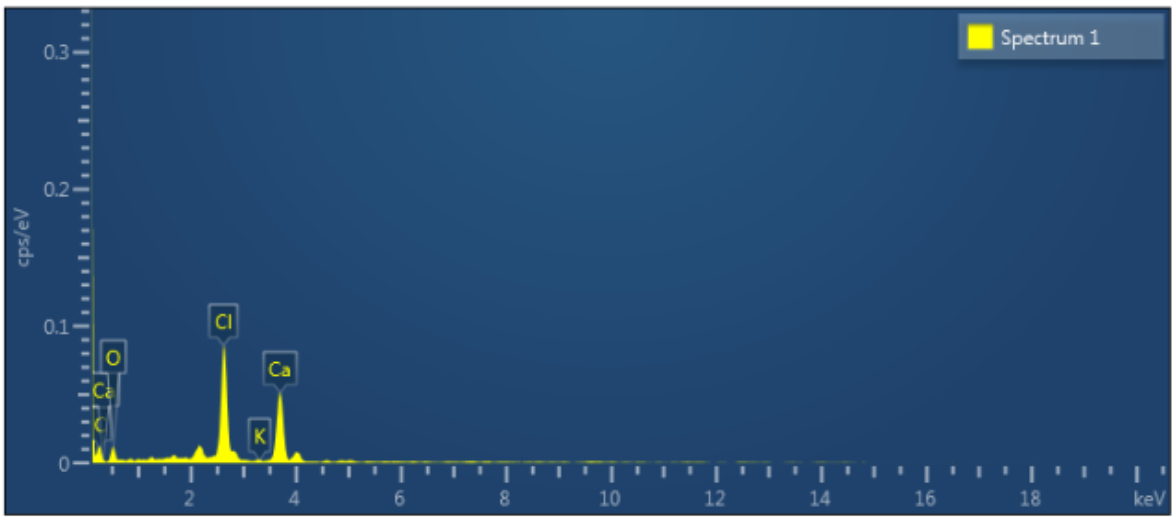

Fig. 5 Surface EDS spectrum of wood plastic composite

Table 1 Elemental composition of WPC surface determined by EDS

Spectrum 1 Element	Line Type	Weight %	Weight % Sigma	Atomic %
Cl	K series	7.95	0.47	3.23
Ca	K series	7.17	0.47	2.58
O	K series	25.04	1.75	22.55
C	K series	59.67	1.83	71.58
K	K series	0.16	0.11	0.06
Total		100.00		100.00

3.5 Relationship Between Surface Morphology and Composite Quality

Surface morphology of the WPC was also closely related to the overall quality of the composite material in terms of mechanical strength, durability, and environmental degradation in relation to the composite material. According to the current research analysis with the assistance of the SEM model, the surface morphology parameters including surface roughness, apparent wooden fibres, and microvoids present on the surface can be used as indicators of the level of efficiency of the process of the dispersal of fibres and the encapsulation process of the polymer. Similar surface morphology parameters are the key indicators of interfacial compatibility of natural fibres with thermoplastic polymer matrix [10][11]. The existence of surface irregularities and lignocellulosic fibres further indicates an incomplete wetting process between wood fibres and the thermoplastic polymer, which is related to the natural immiscibility between hydrophilic fibres and hydrophobic polymers. Surface characteristics play an indirect role as precursors related to the durability and performance of WPC materials because they provide an indication of durability problems associated with WPC products [12][13].

Cross-sectional SEM is also used to focus on the internal morphology contribution to the overall quality of the composite. In the composite structure, interfacial voids and spaces act as centres of concentration of the stresses that hinder efficient provision of the load to the fibres by the matrix. Other earlier studies have indicated the negative impact of increased voids and reduced interfacial bonding strength on tensile and flexural strength of the WPCs [14][15]. Surface and internal morphological features strongly influence the mechanical performance and durability of WPCs. The presence of voids, fibre pull-out, and poor dispersion indicates weak interfacial bonding and inefficient stress transfer. Optimizing fibre dispersion and interfacial compatibility is therefore essential for improving composite performance [16][17].

4. Conclusion

In conclusion, this research proved that wood plastic composites (WPCs) quality and performance depend largely on microstructures. SEM observations showed that there were irregular surface and cross-sections with fibre exposure, microvoids, and gaps around the interface, signifying constraints on fibre and matrix compatibility and polymer envelopment. EDS observations supported high carbon and oxygen values, composing the primary constituents of both polymers and lignocellulosic materials, while traces of secondary components derived from natural fibre substances and additional additives of polymers. Overall, successful dispersion of fibres, high fibre-matrix interactions, and low microvoids presented essential criteria to pursue enhanced strength and durability.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Muhammad Hazim Kamaruzaman, Saliza Asman;* ***data collection****: Muhammad Hazim Kamaruzaman;* ***analysis and interpretation of results****: Muhammad Hazim Kamaruzaman;* ***draft manuscript preparation****: Muhammad Hazim Kamaruzaman, Saliza Asman. All authors reviewed the results and approved the final version of the manuscript.*

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