Investigation and effect of PVC and PVTMS on sintering, physical and mechanical features of chipboard wood

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Abstract: Due to their unique combination of properties, wood-plastic composites (WPC) have proven to be a promising alternative to conventional wood and plastic materials in various applications. This article provides a new insight into WPCs consisting of chipboard wood as matrix and polyvinyl chloride (PVC) and poly vinyl trimtehoxy silane (PVTMS) as reinforcement. Overall, this paper highlights the significant advances and opportunities in the field of wood-polymer composites and their potential as sustainable, high-performance materials with a wide range of applications. Continuous research and development efforts are essential to further improve the properties and expand the use of WPC in various industries. In the manufacturing process, wood and thermoplastic polymers are blended together, often using additives and binders to improve compatibility and performance. The resulting composites have desirable properties, such as a high strength-to-weight ratio and the ability to be molded into complex shapes. The differential scanning calorimetry (DSC), flourier transform infrared (FTIR), X-Ray diffraction (XRD), X-ray photoelectron spectroscopy and scanning Electron Microscopy (SEM) characteristics and mechanical properties were discussed in detail. As a result, the composite material sintered at 80 °C showed better mechanical behavior, with the compressive strength calculated to be 28.73 MPa.

Keywords: Chipboard wood; composites; PVC; PVTMS; Mechanical behavior

I. Introduction

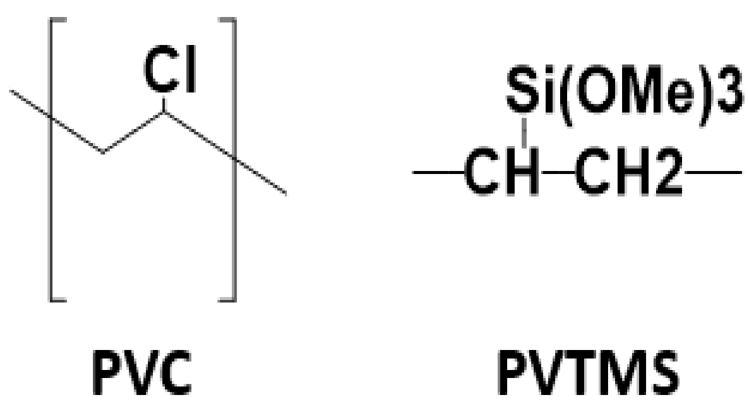
Chipboard wood, also known as chipboard, is a type of wood-based material made from wood shavings, sawdust or sawdust together with a synthetic resin or binder[1]. These materials are compressed and bonded together under high pressure and heat to form panels[2]. Chipboard is often used in construction, furniture manufacturing and interior design due to its affordability, versatility and ease of processing[3]. The manufacturing process begins with the wood raw materials being mixed with resin and additives in a mixer. The mixture is then spread out in a continuous mat or layered in a mold box[3]. Hydraulic presses apply pressure and heat, usually between 140 and 220 °C, to compress the material and cure the resin, creating a dense and uniform board[4]. The density and properties of particleboard depend on factors such as the size and type of wood particles used, the resin content and the manufacturing process. Low density chipboard is often used for packaging, while higher density chipboard is suitable for furniture, cabinets, flooring and wall panels. Despite its affordability and versatility, chipboard has some limitations compared to solid wood or other wood-based materials[5]. They tend to swell and warp when exposed to moisture, and their strength and durability can be less than that of plywood or oriented strand board (OSB)[6]. However, with the right finishing and protective coating, chipboard can be used effectively in a variety of applications and is a cost-effective and sustainable alternative to solid wood. Wood plastic nano-composites (WPC) have attracted a great deal of attention in recent years as a sustainable alternative to conventional materials in various industries[7]. This innovative nano-composite material combines the natural esthetics and structural properties of wood with the durability and versatility of plastics[8]. The development of WPCs has been driven by the need for environmentally friendly materials that offer better performance, durability and reduced environmental impact compared to conventional wood or plastic products[9]. The concept of combining wood fibers or flour with thermoplastic polymers emerged in the 1980s, and since then WPCs have evolved into a diverse class of materials with a wide range of applications[10]. The manufacturing process typically involves blending wood particles or fibers with polymers such as polyethylene, polypropylene or polyvinyl chloride, as well as additives and bonding agents to improve compatibility and performance[11]. This mixture is then formed into various shapes using processes such as extrusion, injection molding or compression molding. One of the main advantages of WPCs is the balance of their properties, that are superior to those of wood and plastic alone[12]. These include resistance to moisture, rot and insects, dimensional stability, low maintenance and the ability to form complex shapes[13]. WPCs are therefore used in various industries, e.g. construction, automotive, furniture, landscaping and consumer goods. In addition, WPCs contribute to sustainability efforts as they are made from recycled materials, reduce the need for virgin plastics and wood and are recyclable at the end of their life cycle[14]. However, challenges such as long-term durability, material variability and recyclability still require further research and development[15]. In summary, wood-plastic nano-composites are a promising solution for sustainable material innovation as they offer a compelling combination of natural esthetics, performance and environmental benefits. With further advances in manufacturing processes, material formulations and end-of-life options, WPCs have the potential to revolutionize various industries while reducing their environmental footprint[16].Polyvinyl chloride (PVC) is a synthetic polymer used in numerous applications due to its versatility, durability and cost-effectiveness[17]. It is one of the most widely produced and used plastics in the world. PVC is produced by the polymerization of vinyl chloride monomers. PVC comes in two main forms: Rigid and flexible PVC. Rigid PVC, often referred to as PVC-U (soft PVC), is often used in the construction industry for pipes, window frames and cladding due to its excellent strength, chemical resistance and flame tendency[18]. Flexible PVC, also known as soft PVC, contains additional plasticizers to give it flexibility and is used for applications such as vinyl flooring, cables, hoses and medical tubing[19]. One of the main advantages of PVC is its durability. It is resistant to moisture, weather, chemicals and abrasion, making it suitable for use outdoors and in harsh environments[20]. PVC is also relatively lightweight, easy to work with and has good electrical insulation properties. Poly Vinyl trimethoxy silane (PVTMS) is a chemical compound that belongs to the organo silane family[21]. These are organ functional silanes that are used in various industrial applications, particularly in materials science and surface modification processes. PVTMS consists of a vinyl group (C_2H_3), which provides reactivity, and three methoxy groups (C_2H_3) bonded to a silicon atom (Si), as well as a trimethylsilyl group. PVTMS is generally used as an adhesion promoter in the modification of surfaces, especially surfaces made of inorganic materials such as glass, ceramics or metals[22]. It is used to improve the compatibility between organic polymers and inorganic substrates by forming covalent bonds with hydroxyl groups on the surface. This leads to improved adhesion, wetting and bonding properties[23]. In addition to surface modification, PVTMS is also used as a crosslinking agent in the synthesis of organic-inorganic hybrid materials, where it facilitates the formation of covalent bonds between organic polymers and inorganic nanoparticles or fillers[24],[25]. This can lead to the development of nano-composite materials with improved mechanical, thermal or barrier properties. In addition, PVTMS is used in the production of functional coatings, sealants and adhesives, where it provides adhesion and durability to the treated surfaces. It is also used in the production of silicone-based materials, where it serves as a precursor for the synthesis of siloxane polymers. Overall, PVTMS plays a crucial role in surface modification, crosslinking and the development of advanced materials, helping to improve performance and functionality in various industrial applications. In this study, 90 wt.% chipboard wood and 5 wt.% of PVC and 5wt% of PVTMS were utilized to prepare two types of nano-composites sintered at 50 °C and 80 °C, respectively.

II. Materials and methods

Chipboard wood is made from reconstituted wood-often shavings, shavings or sawdust - which is compressed and held together with natural or synthetic resin and then formed into panels. It became popular thanks to its low price, as it's much cheaper than normal, pure wood such as pine or oak. PVC and VTMS were manufactured by Merck. Differential scanning calorimetry (DSC) is an analytical method for measuring the heat flow associated with thermal transitions in materials as a function of temperature. The STA-BAHR DSC was used. Fourier transform infrared spectroscopy (FTIR) of the compounds were performed in the potassium bromide (KBr) powders, and the instrument was the Perkin-Elmer Spectrum BX FT-IR spectrometer. X-ray diffraction were performed at 40 kV and 40 mA and recorded from 20 to 50 degrees for 2θ at a scan rate of 2.5 degrees/minute and an increment of 0.02 degrees. The resulting patterns were analyzed with the High Score X'Pert software using the procedure implemented in the ASC suffix files for basic parameters. To study the morphology of the samples, the XPS UHV analysis system was selected and the Phillips/FEI Quanta 200 scanning electron microscope (SEM) analysis was used. SANTAM STM-50 and H-25KT were used to study the mechanical properties and the samples were prepared according to the ASTM-E9 standard.

a. Synthesis and merge of PVC and PVTMS

PVC and VTMS were mixed and tertiary butyl peroxide was considered as initiator under reflux and stirred for 6 hours at 60 °C in flowing nitrogen. In addition, the chemical structures of PVC and PVTMS are shown in **Scheme 1**[23].



Schematic 1. Chemical structures of PVC and PVTMS

III. Result and discussion

a. Thermal investigation

The DSC analysis of the nano-composites was performed and as a result the thermal curve is shown in **Figure 1**. The endothermic temperature ranges at 196 °C of chipboard wood can be associated with this, indicating a high amount of water molecules and the removal of the external water or bulk water inside the structure[26]. Therefore, the resin may soften or melt when the chipboard wood is exposed to heat before the wood particles undergo significant thermal decomposition. In addition,

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the resin used in chipboard typically has a higher melting or softening point than the wood particles. Therefore, this endotherm may dominate when the chipboard is exposed to heat and the resin softens or melts before the wood particles undergo significant thermal decomposition. However, it should be noted that chipboard itself does not melt like a pure substance, but can soften, deform or decompose under high temperatures. It is noteworthy that three thermal peaks occurred at 135, 190 and 297 °C by adding PVC and PVTMS when only the heat flow area of the sintered nano-composite was increased to 80 °C[27]. Since the melting point of PVC is usually between 75 and 100 °C, the removal of water and the melting of PVC occurred simultaneously at 135 °C[28],[29]. Therefore, the sintering temperature was not chosen to be higher than 80 °C. The endothermic region at 297 °C was attributed to the breakage of the Si-Si bond in the PVTMS structure.

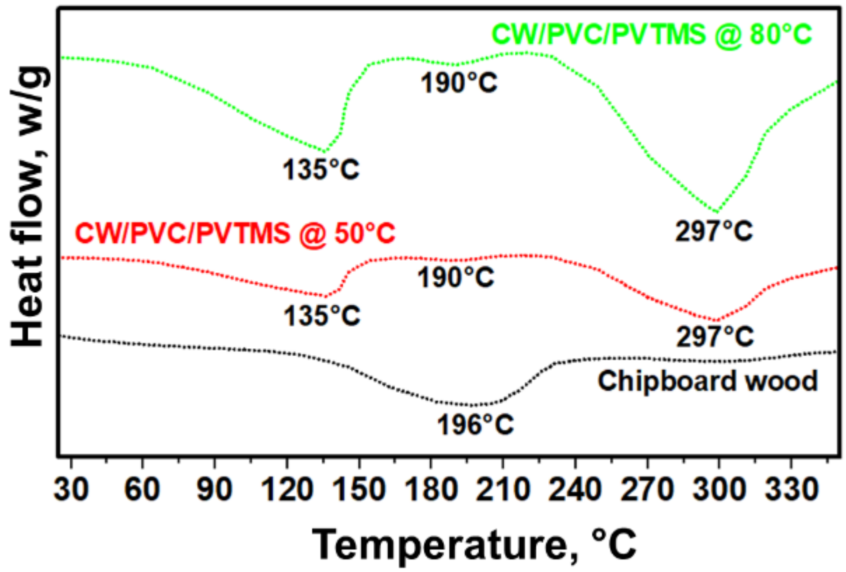

Figure 1. DSC curve of chipboard wood and sintered nano-composites at 50 and 80 °C

b. Study of FTIR and X-ray diffraction

According to the FTIR spectra of chipboard wood and sintered nano-composites at 50 and 80 °C (**Figure 2-a**), the resulting spectrum represents the unique fingerprint of the sample's chemical composition. The FTIR spectrum of chipboard wood (black dash) can provide valuable information about the chemical composition, including the type of wood used, the presence of additives or binders (e.g. resins) and any chemical changes due to manufacturing processes. This information can be useful for quality control, process optimization and understanding the properties of chipboard wood in various applications[30]. Hydroxyl (–OH), carbonyl (C=O), methylene (–CH_2) and aromatic (C=C) groups. In addition, the C-H stretching vibrations of the vinyl group ($CH=CH_2$) typically occur at 3000-3300 1/cm in the FTIR of the nano-composites[31]. In addition, the small and inconspicuous C–H stretching vibrations of the (–CH_2) groups typically occur at 1800-2400 1/cm. The C=O stretching vibrations of the carbonyl groups (C=O) can be observed at about 1500 1/cm. For XRD analysis, the particle boards were usually prepared by cutting or milling into small pieces to ensure uniformity and flatness. Moreover, XRD analysis of chipboard wood can provide valuable information about its composition, including the types and relative proportions of minerals or crystalline phases present, as well as any structural changes due to manufacturing processes or environmental factors. This information is useful for understanding the properties and performance of chipboard wood. The main peaks at 2θ values of approximately (14° and 16°), (21° and 23°) and 35° are surmounted by planes (101), (002) and (311) in tandem[32]. In addition, there is no crystalline phase when the narrow and sharp peaks were not observed and the amorphous phase was above the crystalline phase.

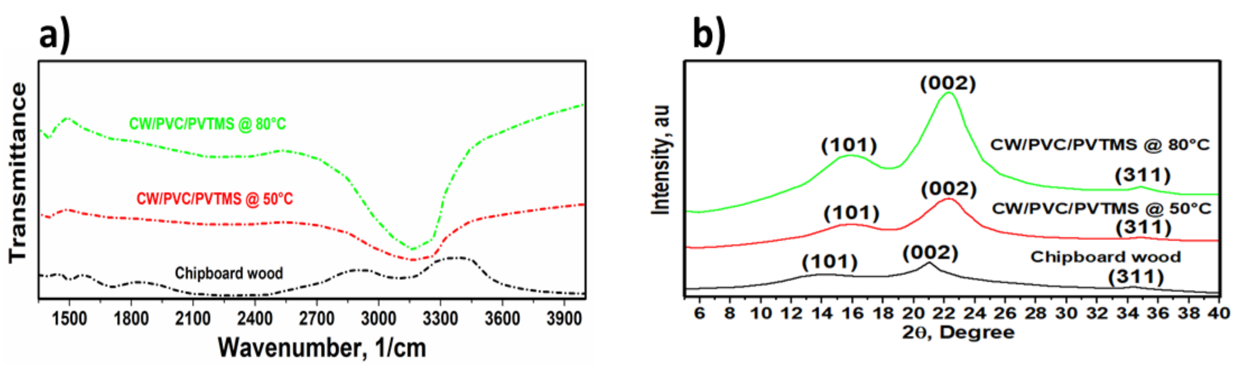

Figure 2. a) FTIR and b) X-ray diffraction of chipboard wood and sintered nano-composites at 50 and 80 °C

c. XPS evaluation

The XPS spectrum of chipboard wood usually contains peaks corresponding to the photoelectron emissions of elements such as carbon (C), oxygen (O), nitrogen (N) and possibly other elements present in the wood or in the surface treatment. By analyzing the positions and intensities of these peaks, researchers can identify the elemental composition of the chipboard wood surface and gain insight into the chemical environment[33]. Overall, XPS analysis is a powerful tool for characterizing the surface chemistry of chipboard wood and gaining insight into its composition and properties at the atomic level. The XPS spectrum of chipboard wood typically contains peaks corresponding to the core-level photoelectron transitions of elements such as carbon (C 1s), oxygen (O 1s), nitrogen (N 1s) and possibly other elements, depending on the specific composition of the wood and any surface treatments or impurities present[34]. By analyzing the positions, shapes and intensities of these peaks, researchers can identify the elements present and gain insight into their chemical environments and bonding states. XPS analysis of chipboard wood can provide valuable information about the surface chemistry of the material, including the presence of organic constituents (such as cellulose, lignin and resins) as well as surface treatments, impurities or degradation products. Furthermore, in nano-composites, the binding energy of the C 1s peak associated with C–Cl bonds in PVC is typically lower than that of the C 1s peak associated with C–C bonds, reflecting the different chemical environments of these carbon atoms[35]. In nano-composites, carbon-carbon (C–C) bonds typically have binding energy values around 283 eV. Carbon-chlorine (C–Cl) bonds have lower binding energy values compared to C–C bonds due to the electron-withdrawing nature of chlorine atoms. The binding energy values for C–Cl bonds in PVC can vary depending on factors such as the degree of chlorination and the local chemical environment. Carbon-oxygen (C–O) bonds[36]. Also, the binding energy values for Cl 2p in PVC are also around 284.3 eV and reflect the chemical environment of the chlorine atoms bonded to carbon atoms in the polymer chain[37],[38].

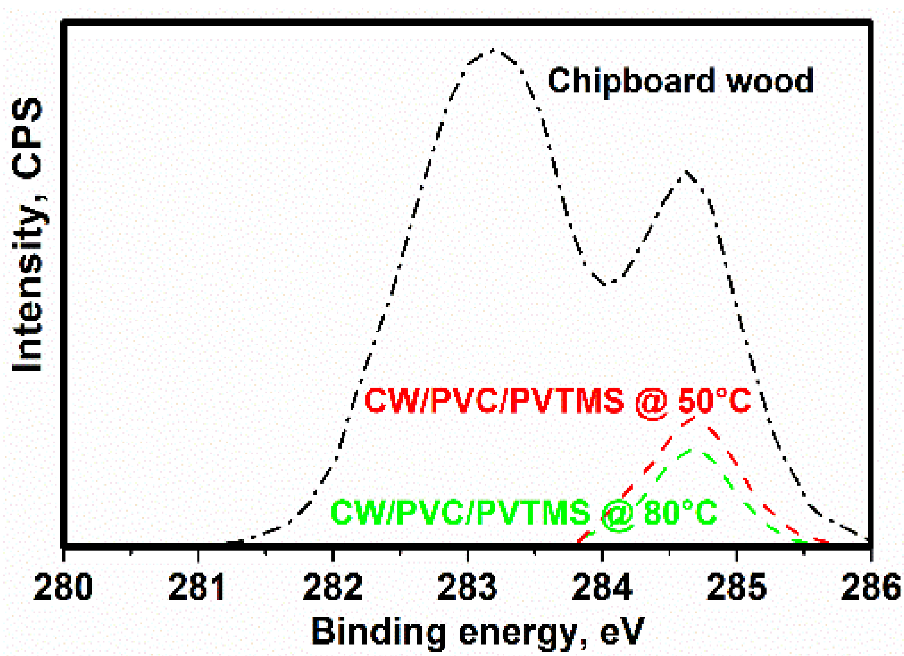

Figure 3. XPS curve of chipboard wood and sintered nano-composites at 50 and 80 °C

d. Investigation of morphology

SEM analysis (Figure 4) of chipboard wood and nano-composites can provide valuable information about the distribution, size, shape and organization of wood particles as well as pores, voids or defects in the material. Furthermore, SEM analysis can help to identify the presence of additional components such as resin binders or additives and investigate their distribution within the chipboard matrix. SEM images can reveal surface features such as cracks, fractures, delamination and surface roughness. These features can be caused by manufacturing processes, environmental influences or mechanical stress[39]. The surface characteristics can provide information about the durability, wear resistance and aging behavior of chipboard wood and nano-composite materials. Porosity was observed in sintered nano-composites at 50 °C more than 80 °C, and the sintering temperature had a very strong effect on the morphology, as the content of porosity was reduced with increasing sintering treatment. Shiny cracks were not observed in the composites, but were observed in the particleboards (**Figure 4-a**). During the manufacturing process of composites, the wood particles are bound together with resins, creating voids between the particles that can contribute to the porous structure of the material[39]. Overall, the presence of porosity in the SEM images of these nano-composites is a common feature resulting from the natural structure of the material, processing conditions, composition and environmental factors[40]. Understanding the factors that contribute to porosity is essential for assessing the microstructure and properties of chipboard and optimizing its performance in various applications.

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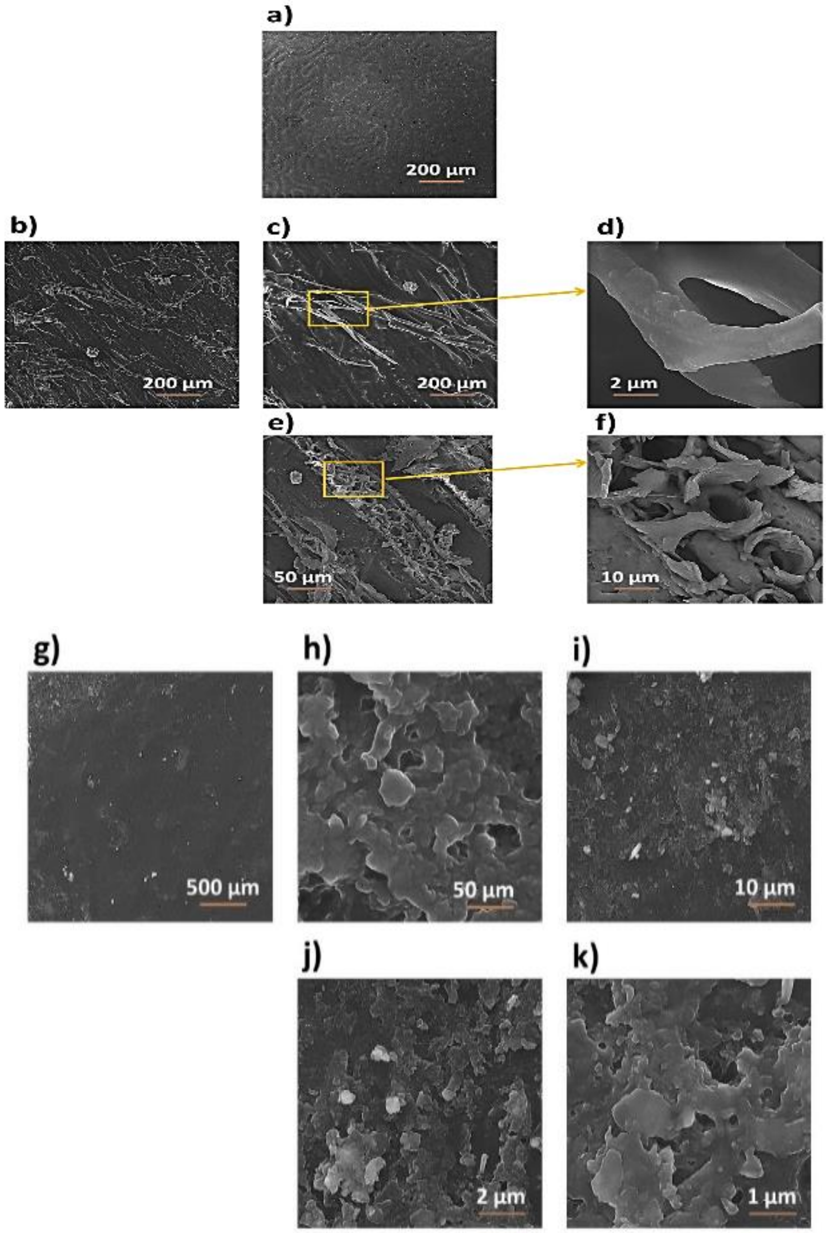

Figure 4. SEM images of [a) chipboard wood], [b), c), d), e), f) sintered nano-composites at 50 °C] and [g), h), i), j), k) sintered nano-composites at 80 °C] at different magnifications

e. Stress-strain curve of samples

Here is a general overview, elastic range, in the initial phase of loading, chipboard wood behaves elastically, i.e. it deforms reversibly under the applied stress. This elastic deformation is generally linear and can be described by Hooke's law[41],[42]. The material returns to its original shape as soon as the load is removed. In the yield range, chipboard wood can deform plastically with increasing stress, especially in areas where the resin bond between the particles begins to fail or when local buckling occurs. This leads to a deviation from the linearity of the stress-strain curve. In the failure region, nano-composites reach their ultimate strength, beyond which they deform significantly or fail. This failure can manifest itself as crushing, cracking, splitting or delamination of the material, depending on the specific conditions and load configuration. The stress-strain-compression curve of the samples is shown in **Figure 5**. The maximum value of compressive strength was measured at 28.73 MPa at a strain of ~ 2. According to Hooke's law, the elasticity coefficient was calculated to be ~ 4.96 MPa when selecting the difference values of two points in the elastic region, and this value is higher than chipboard wood when the polymers were added as reinforcement. The material returns to its original shape as soon as the load is removed, and the strain is directly proportional to the stress according to Hooke's law. The behavior of chipboard wood under increasing load depends on several factors, including composition, density, moisture content, resin type and manufacturing process. It's important to understand the mechanical properties of the material and its response to stress to ensure its performance and durability in practical applications. Experimental tests, such as tensile or compression tests, can provide valuable data on the behavior of the material under different loading conditions.

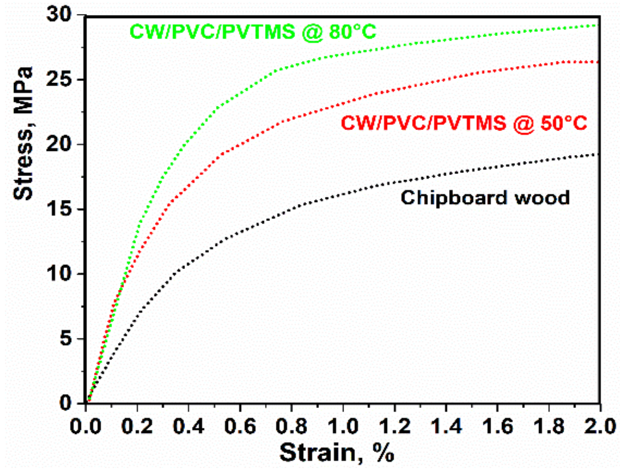

Figure 5. Stress-strain curve of chipboard wood and sintered nano-composites at 50 and 80 ℃

IV. Conclusions

The characterization of chipboard wood and nano-composites was discussed in detail. The incorporation of PVC and PVTMS is a promising approach to improve the mechanical properties of chipboard and offers opportunities for the development of durable, sustainable and high performance products in various industries. As the melting point of PVC is normally between 75 and 100 °C, the sintering temperature was chosen to be no higher than 80 ℃. The FTIR studies showed that the bonds were in good agreement with the precursors. The XRD of the samples showed that there is no crystalline phase in the particle boards and also in the nano-composites. The impressive value of binding energy for Cl 2p in PVC was observed at 284.3 eV. SEM analysis revealed that the porosity in the sintered composites at a temperature of 50 to 80 ℃ was very high due to the chemical structure and bonding at this temperature. It has been shown that the addition of PVC and PVTMS significantly improves the mechanical properties of wood-based materials. The composites sintered at 80 ℃ exhibited better strength than the nano-composites sintered at 50 ℃ and the chipboard, where the maximum value of compressive strength was calculated to be 28.73 MPa. In addition to strength, PVC and PVTMS also contribute to a significant improvement in the stiffness of wood. The nano-composites become stiffer and can withstand higher loads without excessive deformation. This improvement in stiffness is critical for applications that require structural integrity and dimensional stability. In summary, the effect of PVC and PVTMS on chipboard is truly impressive, resulting in a remarkable change in mechanical properties, durability and sustainability. By utilizing the unique properties of polymers, wood-polymer nano-composites offer versatile solutions with improved performance and functionality, paving the way for a wide range of applications in various industries.

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