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Effect of pressing temperature on the mechanical properties of waste styrofoam filled sawdust composite

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Abstract. This study has investigated the effect of pressing temperature on mechanical properties of waste styrofoam composite filled with sawdust. The waste styrofoam as the matrix was mixed with sawdust as filler and maleic anhydride (6%wt) as a compatibilizer. The weight fraction ratio between matrix and filler 70:30 (wt) and wood fiber size of 100 mesh were conducted. The pressing temperatures were investigated using a hot press with temperatures varied viz. 120, 130, 150, and 170 °C. Surface modification was applied to sawdust to diminish its polarity so that it could be compatible with the non-polar waste styrofoam matrix. Composites were evaluated using Instron and impact tester machine to investigate the tensile strength and impact strength of the material, respectively. The result indicated that tensile strength has decreased with the increase of pressing temperature where the largest tensile strength is at 130 °C of 33 MPa. The same trend has occurred on impact strength, where the value has reached of 300 J/cm² on pressing temperature of 130 °C. From scanning electron microscopy (SEM) analysis it is also confirmed that during impact test, the resistance of the composite which has been pressed at the temperature of 130 °C have given better morphology than the composite at 170 °C.

1. Introduction

The development of composite technology has been starting to experience a shift from the synthetic fibers composite material into natural fiber composite materials. Natural fiber is considered one of the environmentally friendly materials which have good properties compared to synthetic fiber. Some natural fibers as fillers researches have been done, among others: green coconut fiber [1], banana fibers [2], and empty fruit bunch palm oil [3, 4], Sugarcane bagasse [5]. Wood is one of Indonesia's natural resource. Each timber processing into semi-finished materials (e.g., in the form of boards or beams) or finished goods (furniture) always produces byproducts that form sawdust.

The sawdust contains high cellulose content of 69%. Besides, sawdust contains high levels of hemicellulose in general, also contains lignin in an amount of about 15-30% by weight [6]. Therefore, when added to the mixed composite as filler, it will absorb the matrix and provide additional tensile strength between the filler due to adhesion properties and dispersion [7]. Moreover, the matrix will be encapsulated the filler as well as inhibit the diffusion of water in the material due to the nature of matrix hydrophobic.

Aside from being a major product of wood, Indonesia is also among the most widely used plastic in everyday life. One type of plastic that is often used is styrofoam. Styrofoam is made from polystyrene (PS) which is plastic that is brittle.Styrofoam is produced from a mixture of 90-95% polystyrene and

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5-10% of gases such as n-butane or n-pentane. Previously, the blowing agent used is CFC (Freon), because this class of compounds can damage the ozone layer it is currently not used anymore, now blowing agent used is more environmentally friendly. Styrofoam is made from styrene monomer by suspension polymerization at a certain temperature and pressure, further heating to soften resins and evaporate the residual blowing agent. Polystyrene is a rigid, transparent, fragile, chemically inert, and is a good insulator. While styrofoam is a plastic material that has special properties with a structure composed of grains with low density, has a light weight, and there is space between granules that contain air and can melt in the temperature around 120 - 180 °C [8].

On the other hand, maleic anhydride (MAH) is a kind of compatibilizer which is often used in the composite. This compatibilizer could modify the adhesion between molecules that are not similar/incompatible. Incompatibility occurs due to the differences in polarity between the materials, in this study, the styrofoam is nonpolar while sawdust containing lignocellulose tends to be polar. This may cause a high surface tension between the matrix-filler interfaces. Therefore, the addition of MAH in this composite may be located between the sawdust and styrofoam to form a bridge thus improve the adhesion between matrix-filler interface [9].

Manufacture of composites from waste in the form of sawdust and plastic waste food wrappers types of polystyrene (styrofoam) is expected to reduce the adverse environmental impacts generated by both these materials. In this study, the effect of pressing temperature on the mechanical properties of waste styrofoam filled sawdust composite was observed.

2. Methods

2.1 Material

Sawdust was obtained from the carpenter. The chemicals such as sodium hydroxide (NaOH), maleic anhydride (MAH), and toluene were supplied by MERCK and used as received.

2.2 Modification Sawdust

Sawdust was soaked with 5% of sodium hydroxide (NaOH) at 30 $^{\circ}$ C for 4 hours. Then washed with water and dried with oven temperature 100-110 $^{\circ}$ C. Sawdust particle was screened through a mesh size of 100.

2.3 Composite Manufacturing Process

25 g pieces of styrofoam that cut with around 1,5 x 1,5 cm was diluted with toluene 20% with the addition of 6% maleic anhydride. Diluted styrofoam was mixed with sawdust with a composition ratio of 70:30 (wt). The mixture was poured into a metal mold which has been formed according to the standard tensile strength test and impact strength test. Samples were then pressed by using a hot press with a pressure of 125 psi, preheat for 5 minutes and continue with compression for 8 minutes with varied the temperature120, 130, 150 and 170°C.

2.4 Characterization

2.4.1 Fourier Transform Infra-Red (FTIR).

FTIR analysis was characterized using Shimadzu IR-21.

2.4.2 Tensile Properties.

Tensile strength and elongation at break were investigated by the standard of ASTM D 638 - 10 Type IV using Instron Machine.

2.4.3 Impact Strength.

Impact strength was investigated by the standard of ASTM D 4812 – 11 with *Unnotched Izod* method using Impact Testing Machine.

2.4.4 Scanning Electron Microscopy.

Scanning electron microscopy was employed for microscopic structure of composites fracture from impact test. The instrument used for morphology observation was SEM Evo MA 10 Zeiss.

3. Results and Discussion

3.1 Fourier Transform Infra-Red (FTIR)

FTIR spectra of the different samples are shown in Figure 1.

From the figure it shows the spectra were recorded in the range of 4000-500 cm⁻¹. Styrofoam spectra show the band at 3020, 14355, 1014 and 694 cm⁻¹ were attributed to C-H groups from benzene, C-H from alkyl, C-X fluoride, and chloride from HCFC gas. Sawdust spectra show that there are some absorption bands at 3428 and 1570 cm⁻¹ were attributed to O-H hydroxyl group and N-H amides band bonding the presence of those peaks have supported that the sample consists cellulose and lignin.



In composite spectra, the presence of MAH in the wavenumber of 1712 cm⁻¹ which indicates the existence of ketone groups (C=H). However, the composite FTIR spectra show the combination of all styrofoam, sawdust, and MAH. This spectrum shows no new peaks appeared in the figure, indicated in composite only a physical interaction has occurred.

3.2 Effect of Pressing Temperature on the Tensile Properties of Composite

The tensile strength and elongation at break of the composites are presented in Figure 2. It shows the tensile strength increases from 120 to 130 °C of pressing temperature and decreases at 150 and continued to pressing temperature of 170 °C. Heat transfer is occurred by conduction from the hot platens hot press to the composite surface. The increase of temperature during hot press process vaporizes the moisture within the fillers at the surface. The air, which also contains water vapor that resides in the voids of the composite also increases in temperature and hence vaporizes. On the other hand, the filler (sawdust) exhibits elastic expansion and voids between the filler open, thus increasing composite permeability and gas flow. As the composite is compressed, the gaps are diminished, and the permeability is considerably smaller thus the adhesion between filler and matrix increase [10]. In this case, an optimum condition to produce a composite with high tensile strength was at pressing temperature of 130 °C at 33 MPa. Here, the adhesive bonding between matrix and filler increased and subsequently has enhanced the strength.



Figure 2. Tensile Strength and Elongation at Break of Composite: Effect of pressing temperature

At lower pressing temperature (120 °C) during hot press, the process has resulted from the low strength that is (25 MPa). Here, at lower pressing temperature the ability of water vapor or gas which have trapped inside the composite has reduced to vaporize. Thus the gaps and voids remain. The consequences were decreasing the mechanical bonding strength, although the pronounced of MAH.

The reduction of tensile strength at pressing temperature of 150°C (30 MPa) and continued until 170 °C (29 MPa) could be due to the presence of voids. The voids have expanded during pressing process in higher temperature. This caused the pull-out filler during the test. In this case, the filler unable to support stress transferred from the matrix and this weaken composite. Moreover, when the very high pressing temperature was used, the degradation of the matrix may cause the brittleness of composite.

As for elongation at break, the curve shows the same pattern as tensile strength. Here, at pressing temperature of 130 °C the elongation at break of the composite is higher as compared to 120 °C. This shows the composite has relatively higher elasticity level. This optimum level of elongation at break has decreased again with the increase in pressing a temperature of 150 and continuing to the temperature of 170 °C. The presence of gaps and void have weakened interfacial regions between the filler and the matrix; then the crack propagates conveniently through the voids. This declined the elongation at break of the composite.

3.3 Effect of Pressing Temperature on The Impact Strength of The Composite

Fig 3 shows the effect of pressing temperature on the impact strength of the composite.

It can be seen that the lower value of impact strength composite on the pressing temperature of 120 °C has occurred (230 J/cm²). As the pressing temperature increase of 130 °C the impact strength has improved significantly at the value of 300 J/cm². A slight decrement of impact strength value has evaluated on the pressing temperature reached of 150 °C (293 J/cm²) and continued at 170 °C 285 J/cm²).



Figure 3. Impact Strength of Composite: the effect of pressing temperature

This trend of the curve has almost similar with has been shown in tensile strength curve as well as elongation at break. This is because the pressing temperature of 130 °C was an optimum temperature where the bonding between matrix and filler increased and subsequently has enhanced the strength. To support the analysis on the impact strength improvement in pressing temperature of 130 °C, the microstructure of the fractured surface of composite specimens tested in impact test is examined using scanning electron microscopy (SEM). Figure 4a and 4b show the morphology of the composite at pressing temperature of 130 °C and 170 °C, respectively.



Figure 4. Scanning Microscopy Analysis of Composites at (a). Pressing temperature of 130 °C (b) pressing temperature of 170 °C

It is shown in Figure 4a the uniform distribution of sawdust in styrofoam matrix and also cavities correspond to empty holes left behind by the sawdust during fracture. Moreover, it observes rougher surface that proves the matrix shows more resistance against load given. This surface of the composite confirming its effect on promoting adhesion in the interfacial region, indicating stress transfer from the matrix to the filler.

However, Figure 4b shows smooth fractured surface, and the fillers have not distributed homogeneously. The morphology has also indicated the rigid composite that corresponds to less resistance of composite during fracture. In this case, during higher pressing temperature (170 °C) the presence of voids as well as degradation of the matrix have occurred thus the consequences is the

reduction in impact strength. Therefore, Figure 4a and 4b could lead in a difference of energy absorbed in each of composites which composite at pressing temperature of 130 $^{\circ}$ C would absorb more energy to break it down compared to 170 $^{\circ}$ C.

4. Conclusion

Results have shown styrofoam filled with sawdust composite only present a physical interaction supporting from FTIR spectra. The highest impact strength, elongation at break and impact strength was achieved in pressing temperature 130 °C. Moreover, SEM micrographs showed the difference of energy absorbed in each composite which composite at pressing temperature of 130 °C would absorb more energy to break it down compared to 170 °C.

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