

Effects of number of ply, compression temperature, pressure and time on mechanical properties of prepreg kenaf-polypropylene composites

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Abstract. Composite material thermoplastic was prepared from polypropilen granule as matrix, kenaf fiber as reinforcement and grafted polypropylene copolymer maleic anhydride as coupling agent. Composite products were produced as sandwich structures using compression molding. This research aimed to observe the influence of number of ply, temperature, pressure, and compression time using factorial design. Effects of variables on tensile and flexural strength were analyzed. Experimental results showed that tensile and flexural strength were influenced by degradation, fiber compaction, and matrix – fiber interaction mechanisms. Flexural strength was significantly affected by number of ply and its interaction to another process parameters (temperature, pressure, and compression time), but no significant effect of process parameters on tensile strength. The highest tensile strength (62.0 MPa) was produced at 3 ply, 210 °C, 50 Bar, and 3 min compression time (low, high, high, low), while the highest flexural strength (80.3 MPa) was produced at 3 ply, 190 °C, 50 Bar, and 3 min compression time (low, low, high, low).

1. Introduction

The development of composite technology and the use of natural fiber as reinforcernent come to better direction from year to year. The uses of natural fiber as reinforcement on composite material are cost as well as environmental reason. For example, the use of natural fibers as otomotif parts may save 60% more of energy consumption [1]. However, as different polarity between polymer matrix and natural fiber, coupling agent is needed to improve interfacial bonding between fiber and matrix [2-6]. Another aspect that commonly applied to improve fiber – polymer adhesion is alkali treatment as aqueous sodium hydroxide (NaOH). The purpose of this treatment is to remove cementing substance as lignin and hemicellulose [7-9].

It is common of using melt compounding technique to produce natural fiber thermoplastic composites [10-12]. However, this technique is not efficient to produce large product as building panel. Hence, prepeg method using compression molding may be useful to be used. In this technique, polymer sheets are prepared before composite processing. The sheets are then arranged as sandwich structure along with the fiber for reinforcement, and molten using compression molding. This technique was applied for



some natural fibers composites as coconut husk [13], kenaf [14], and jute composites [15]. However, the study on the effect of number of ply as well as hot press conditions is still limited.

This research explored the effect of number of ply as process conditions to produce PP/kenaf fiber composites using compression molding. Experiment was run according to factorial design to achieve better understanding on the effects of variables on mechanical properties. Number of ply, temperature, pressure, and compression time were varied. Significant factors, main effects, as well as interaction influenced tensile and flexural strengths were determined and analyzed.

2. Experimental

2.1. Materials

Polypropylene (PP) used in this research was homopolymer PP HE 2.0 TF, with 2.4 g/10 min melt flow index (MFI), from PT. Chandra Asri, Banten, Indonesia. Kenaf fiber was obtained from local producer in Malang, East Java, Indonesia. Epolene G3003 maleated PP (PP-g-MA) from Eastman Chemical Industry was used as compatibilizers between PP and kenaf fiber.

2.2. Kenaf Fiber and PP Sheet Preparations

Kenaf fibers were chopped with length of ± 20 mm. The cut fibers were then immersed in alkali solution (NaOH 5%, 24 h) to remove lignin structure and improve matrix-fiber interaction [8]. After that, the fibers were strained and washed using demineralized water and dried using oven at 80 °C for 12 h.

Table 1. Processing parameters in extruder

| Temperature (°C) | | | | | | | | | | Screw Rotation (rpm) |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 200 | 210 | 220 | 230 | 230 | 240 | 240 | 250 | 250 | 250 | 90 |

PP sheets were produced using Collin E 30 M single screw extruder equipped with callendering system. PP and 5 wt% of PP-g-MA were dry mixed prior to processing. The extruder setting parameters are shown in Table 1. Zones 1 to 7 were applied at extruder barrel, while 8 to 10 were at extrusion sheet die.

2.3. Composite Preparations

Composite samples were produced using Collin 300 P compression molding. Composite samples were prepared as sandwich structures (PP-fiber-PP or PP-fiber-PP-fiber-PP). The fiber content was set at 40 wt% as favourable amount to produce better mechanical properties [16]. Number of composite plies,

temperature, pressure, and compression time were varied according to Factorial Design as shown in Tabel 2. The conditions were set at low and high setting to explore effect of each parameter on tensile and flexural strength.

Table 2. Variables used in this research

| Sample | Number of ply | Temp (°C) | Pressure (Bar) | Time (Min) |
|--------|---------------|-----------|----------------|------------|
| 1 | 3 | 190 | 50 | 3 |
| 2 | 3 | 190 | 40 | 3 |
| 3 | 3 | 190 | 50 | 5 |
| 4 | 3 | 190 | 40 | 5 |
| 5 | 3 | 210 | 40 | 3 |
| 6 | 3 | 210 | 50 | 3 |
| 7 | 3 | 210 | 40 | 5 |
| 8 | 3 | 210 | 50 | 5 |
| 9 | 5 | 190 | 40 | 3 |
| 10 | 5 | 190 | 50 | 3 |
| 11 | 5 | 190 | 40 | 5 |
| 12 | 5 | 190 | 50 | 5 |
| 13 | 5 | 210 | 50 | 3 |
| 14 | 5 | 210 | 40 | 3 |
| 15 | 5 | 210 | 50 | 5 |
| 16 | 5 | 210 | 40 | 5 |

2.4. Composite Characterizations



Figure 1. Test specimens: (a) tensile test, (b) flexural test

Mechanical properties were analyzed from tensile and flexural strength. Tensile specimens (Figure 1) were prepared from compressed composites using puncher according to ASTM D638 type IV. Flexural specimens (Figure 2) were prepared according to ASTM D790. All specimens were conditioned at 23 ± 2 °C and 50% RH for 40 h. Both tensile and flexural tests were carried out using Universal Testing Machine (UTM) SHIMADZU type AGS-10kNG. Crosshead speed was applied at 5 mm/min for all tensile spesimens, but it varied from 0.8 to 1.8 mm/min, which was respected to each specimen thickness, for flexural specimens. The average of 5 (five) specimens were reported and analyzed using Minitab software.

3. Results and Discussions

Tabel 3 shows tensile and flexural strength data of PP/kenaf fiber composites. Tensile strength varied 19.1 to 62.0 MPa, while flexural varied from 43.1 to 80.3 MPa. The highest tensile strength was produced at 3 ply, 210 °C, 50 Bar, and 3 min compression time (low, high, high, low), attributed to better fiber – matrix interaction.

Table 3. Tensile and flexural strength data of PP/Kenaf Fiber Composites

| Sample | Number of Ply | Temp (°C) | Pressure (Bar) | Time (Min) | Tensile Strength (MPa) | Flexural Strength (MPa) |
|---------|---------------|-----------|----------------|------------|------------------------|-------------------------|
| 1 | 3 | 190 | 50 | 3 | 39.3 | 80.3 |
| 2 | 3 | 190 | 40 | 3 | 34.3 | 72.5 |
| 3 | 3 | 190 | 50 | 5 | 19.1 | 77.2 |
| 4 | 3 | 190 | 40 | 5 | 43.7 | 45.0 |
| 5 | 3 | 210 | 40 | 3 | 33.4 | 43.1 |
| 6 | 3 | 210 | 50 | 3 | 62.0 | 64.3 |
| 7 | 3 | 210 | 40 | 5 | 26.5 | 70.5 |
| 8 | 3 | 210 | 50 | 5 | 39.5 | 77.4 |
| 9 | 5 | 190 | 40 | 3 | 53.0 | 54.9 |
| 10 | 5 | 190 | 50 | 3 | 46.7 | 54.4 |
| 11 | 5 | 190 | 40 | 5 | 38.4 | 64.3 |
| 12 | 5 | 190 | 50 | 5 | 46.7 | 50.3 |
| 13 | 5 | 210 | 50 | 3 | 47.8 | 44.2 |
| 14 | 5 | 210 | 40 | 3 | 34.3 | 68.1 |
| 15 | 5 | 210 | 50 | 5 | 31.3 | 53.9 |
| 16 | 5 | 210 | 40 | 5 | 25.5 | 52.5 |
| Average | | | | | 38.8 ± 11.4 | 60.8 ± 12.6 |

In these conditions, the matrix viscosity decrease as high temperature, with less degradation due to short compression time. This matrix, with high compression pressure, would able to penetrate the fiber structure and improve the fiber – matrix interaction. In contrast, the matrix difficulty to penetrate the fiber reduced the fiber – matrix interaction. This suggested why the lowest tensile strength was produced at 190 °C (low temperature). This condition might be worsen by matrix embrittlement on the composite layer due to high pressure and long compression time 50 Bar, and 5 min compression time (high, high) The highest flexural strength was produced at 3 ply, 190 °C, 50 Bar, and 3 min compression time (low, low, high, low), might be caused by the fiber compaction and void removal between fiber and matrix [17], while the lowest was

produced at 3 ply, 210 °C, 40 Bar, and 3 min compression time (low, high, low, low) suggested some fiber decomposition at high temperature (210°C) [18] and fiber compaction at low pressure (40 Bar) [17].

Different conditions to produce highest and lowest tensile and flexural strength suggest variation effect of each parameter (number of ply, temperature, pressure, and compression time) and its interaction (for example: number of ply – pressure interaction, number of play – temperature – compression time interaction, etc) on the mechanical properties. It is of interest to explore effect of each variable on tensile and flexural strength. However, to give better explanation, significant effect of variables on desired properties should be observed to focus further analysis.

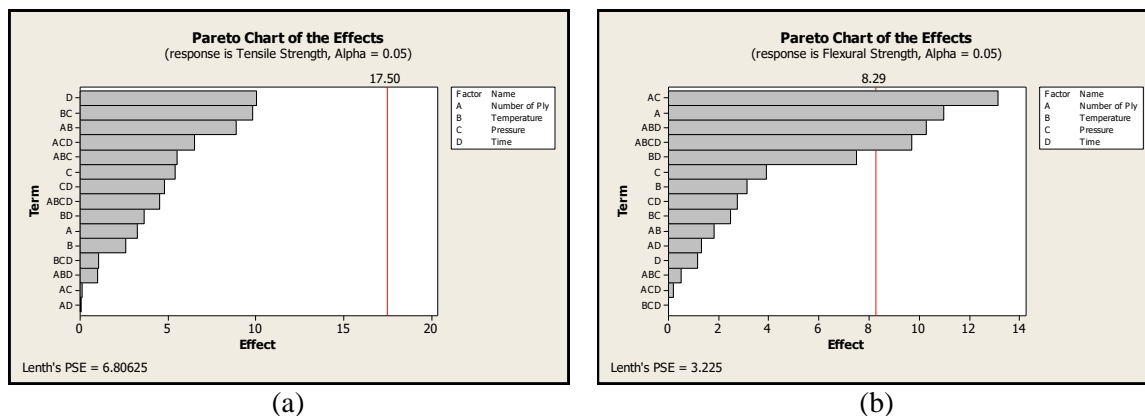


Figure 2. Pareto chart of tensile and flexural strength of PP/kenaf fiber composites

Figure 2 shows significant factors to change tensile and flexural strength in 95% of confidence level. Variables significantly affected the tensile and flexural strength would have effect higher than minimal value (shown by vertical line on the graphs). There is insignificant effect of variables used in this research on tensile strength, in between boundaries at 40 wt% of kenaf. This suggested that there were complex interactions among process parameter that caused fiber compaction, degradation, and fiber – matrix interaction, etc. Unfortunately, as far as we know, it is still limited to find literature that explore the interaction effect of process parameters on tensile strength for kenaf/PP composite prepared by sandwich technique. Meanwhile, some factors as number of ply – pressure interaction, number of ply, and number of ply – temperature – time interaction, as well as all factor interaction have significant effect on flexural strength. Because of this, exploration on the effect of variables on flexural strength is more interesting than on tensile strength.

Figure 3 presents main effect plots of flexural strength of PP/kenaf fiber composites. The figure shows that flexural strength decreased as higher number of ply as well as temperature, but increased as

higher pressure and compression time. The decrease on flexural might be caused by lower density with the higher number of ply as well as voids between fiber and matrix and fiber degradation on higher temperature [17, 18]. On the other hand, the increase on flexural strength might attribute to fiber compaction and matrix penetration which improved matrix – fiber interaction as well as composite density.

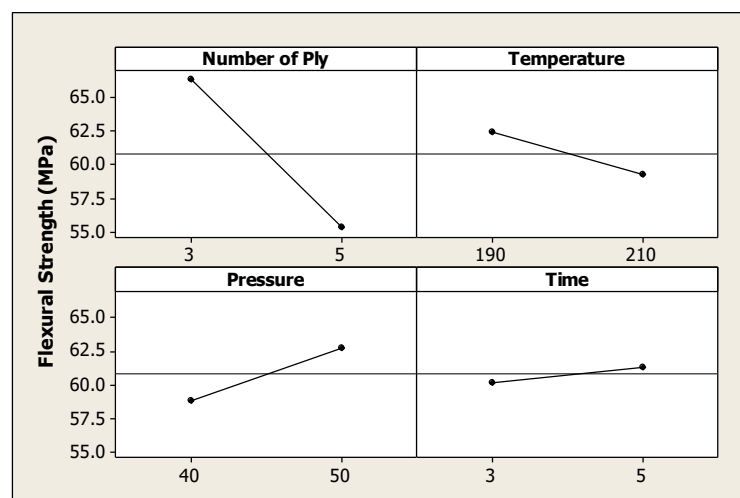


Figure 3. Main effects plot of flexural strength of PP/kenaf fiber composites

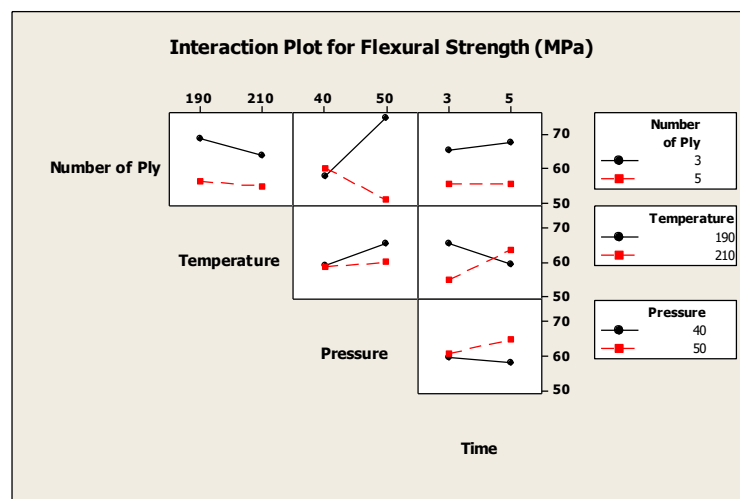


Figure 4. Interaction plot for flexural strength of PP/kenaf fiber composites

Main effect plots are useful to explain effect of individual variable on desired properties. However, as shown in Figure 2 (b), the flexural strength is significantly influenced by interaction between

number of ply and other variables. For this reason, interaction plots should also be observed to analyze effect of interaction among process variables (number of ply, temperature, pressure, and compression time) on flexural strength.

Effects of interaction plots on flexural strength are shown in Figure 4. In general, higher flexural strength might be produced at less number of ply at any temperature, pressure, and compression time. This might be caused by the ease of molten polymer to penetrate the fibers and produce better interfacial bonding. In contrast, the figure also shows lower flexural strength at higher temperature suggested some degradation of kenaf fiber that started from 150 °C [18]. Exception at temperature and time interaction, the flexural increase might be caused by improvement interfacial bonding as the ease of polymer penetration. Further analysis on interaction plots shows higher result as pressure increase suggested the effect of fiber compaction and void removal on flexural [17]. While, flexural improvement as longer compression time was attributed to longer compaction process and interaction between matrix and fibers.

4. Conclusions

PP/kenaf fiber composites were prepared using prepreg technique. Compression molding was used to produce the composite samples. The results show that the highest tensile strength was produced at low number of ply, high temperature, high pressure, and low compression time, while the highest flexural strength was produced at low number of ply, low temperature, high pressure, and low compression time. However, analysis on the effects of number of ply, temperature, pressure, and compression time on tensile and flexural strength shows no significant effect of variables on tensile strength in between the boundaries, while number of ply, and its interaction to other parameters significantly influenced flexural strength. The decreased on flexural strength was attributed to degradation due to high temperature and less matrix – fiber interaction, while the increase was caused by fiber compaction and better interfacial bonding.

Acknowledgment

Authors would like to thank to Center for Polymer Technology, Agency for Assessment and Application of Technology, Indonesia for financial support.

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