The utilization of *ijuk* fibre and sawdust for manufacturing composite block with plastic waste as the matrix

Abdurachman, Jamaludin Malik

Forest Products Research and Development Centre, Jl. Gunung Batu No. 5 Bogor 16610, Indonesia

*jmalik.forda@gmail.com*

**Abstract.** This paper presents the results of research on the utilization of wood waste in the form of wood-chips of sengon wood (S) and sawdust of pinewood (P), mixed with palm-fibres and plastic waste of polypropylene (PP) and polyethylene (PE), for the manufacture of wood plastic composite (WPC) products with three variations mixtures of flakes, fibres and the matrix: A = 50:25:25, B = 50:30:15 and C = 50:15:35. Physical and mechanical properties of the composite refer to the procedure and criteria of SNI 8154: 2015. The results revealed that the densities of the WPC are in accordance with the target ≥ 0.60 g/cm³ where the highest by 0.874 g/cm³ belongs to the composition of PEPB. The composite moisture content is much lower than the maximum water content required i.e 12%. MOE and MOR of the WPC that meet the standard requirement belong to the composition of PPSA and PESB by 20450.67 and 20286.67 kg/cm² (MOE) and by 187.08 and 194.11 kg/cm² (MOR). The highest screw-withdrawal strength was 71.33 kg achieved by PESC composition. Based on these characteristics, sengon and pine wood chips can be used as raw material for wood plastic composite mixed with palm-fibres as the reinforcing fiber and recycled plastic as the matrix.

1. **Introduction**

Wood-plastic composite (WPC) is one of wood products that are currently developing and experiencing an expansion of market share. According to Schwarzkopf and Burnard [1], WPC is a composite containing wood components in the form of wood particles and polymer (plastic) matrix. This product has been used in a variety of structural and non-structural applications ranging from building components/materials and home furnishings to outdoor decking products such as garden furniture. However, applications in construction and automotive are the most common throughout the world [2, 3].

The main materials of wood-plastic composite are wood particles or other lignocellulosic materials and polymers or plastics, the development of this product in Indonesia is very promising due to public awareness of environmental aspects. According to Febrianto [4], the development of wood-plastic composites will have a positive impact on forest sustainability. Forest sustainability will be more assured because the pressure on the natural forest as a producer of solid wood will be reduced. This is because the wood particles or fibers for wood-plastic composite product can be obtained from fast-growing timber, the waste of wood industry, even from natural fibres of agricultural crops.

One potential source of raw materials that can be made wood-plastic composite is wood-waste from wood industry. Data from the Ministry of Forestry in 2004 [5] showed that wood waste produced...
by plywood and sawn timber industries was around 7.5 million m³. It has not utilised optimally yet. Purwanto [6] details the amount of waste produced from plywood industries by 54.81% of the volume and from sawmill industries by 40.48% per year. Other information states that based on the results of sawn timber production data in 2007 amounting to 525,209 m³ with the sawing recovery of 50%, there is waste in the form of slabs (about 25.9%), offcuts wood (14.3%), and sawdust (10.6%). Thus, the sawdust is estimated to be 52,000 m³ [7]. This volume of the waste does not include the one from unregistered sawmills.

Beside sawdust, other organic materials that can be the component in the manufacture of wood-plastic composites, namely ijuk - Aren palm fibre produced from Aren palm trees (Arenga pinnata). These fibres are black, strands of yarn, wiry, less than 0.5 mm in diameter, rigid and ductile (not easily broken). They are non-wood ligno-cellulose fibres which are found in the base and palm leaves. Palm trees produce the fibre at 4-5 years of age. Satisfactory palm fibre is obtained from old trees, but before fruit bunches appear (around 4 years of age), because when fruit bunches appear, the fibres become small. Randing [8] stated that the addition of the palm fibre in the manufacture of composite minerals, namely concrete tiles has been proven to be able to improve the mechanical properties of the tile, such as increasing flexural strength and reducing its brittle properties. Yuwono [9] also proves that the addition of palm fibre resulted in the objects test of roof tiles and wall panels did not have any shock-fracture when loaded.

Research and characterization of wood-plastic composites (WPC) in Indonesia has been started since the early 2000s [10-14]. But in the previous studies, there has been no addition of palm fibre for the mixture of the composite material. This paper presents study on the manufacture of wood-plastic composites with the addition of the palm fibre (ijuk).

2. Experimental

2.1. Materials and equipment

The materials used in this study were pine wood (*Pinus merkussii*) sawdust and sengon (*Paraserianthes falcataria*) wood-chips (Figure 1), palm fibre from Aren tree (*Arenga pinnata*) and ore-shaped plastic waste from polypropylene (PP) and polyethylene (PE) polymers. The chemicals used to include technical acetone, hardener, deton matrix, technical MgCl₂ and NaOH. Supporting materials include silicone plastic, aluminum foil, plastic buckets, plastic tubs, and aluminum plates. The equipment used in this study was wire sieve mesh, sprayer gun, scissors, iron plate, dial caliper, mold, hot press machine, weighing scale and UTM test machine.

![Material used in this research: (a) wood powder; (b) wood chips; (c) unshreded palm fibre; (d) shreded palm fiber; (e) polyethylene (PE) dan (f) polimer polypropylene (PP)](image)

2.2. Composite making process
The manufacture of wood-plastic composites from sawdust or wood flakes passed through the same process. The sawdust or the flakes were dried in an oven at 60ºC to reduce the excess of moisture content for 3 days, then dried at the temperature of 100 ± 3 ºC for 48 hours until they reached the moisture content below 10%. The particles were mixed with plastic-ore until homogeneous, then put into a mold and pressed at the temperature of 180ºC with the pressure of 25 kg/cm$^2$ for 20 minutes. The flakes, the palm fibres and matrix mixtures were made in three variations of composition, namely (w/w): A = 50:25:25, B = 50:30:15 and C = 50:15:35. The target density of the composite was determined ≥ 0.60 g/cm$^3$ and the moisture content was not more than 12% as required by SNI 8154:2015 for wood plastic composites. The composite boards were removed from the mold and then pressed with an iron plate and conditioned for 5 days. The composite boards made of 30 x 30 x 1.5 cm. For physical and mechanics properties tests, the test samples of the composite boards were made according to the procedures of SNI 8154:2015 - Wood Plastic Composites [15].

2.3. Testing and analysis
The parameters tested consist of: (i) physical properties including panel density, thickness swelling, and internal bonding strength; (ii) mechanical strength includes flexural/bending strength (MOE and MOR), tensile strength and screw pull strength. In the analysis, all parameters were compared to the referred standards which in accordance with the parameter being tested, namely: tensile strength of palm fiber referred to ASTM D 245-88 [16], analysis of chemical components referred to TAPPI [17], shear strength test referred to ASTM-94-2000 [18], testing of product quality referred to ASTM D 7031-04 [19] and SNI 8154: 2015 [15].

3. Results and Discussion
3.1. General characteristics
The composites were made in the form of a flat board of pine sawdust and sengon flakes with the mixture of palm fiber and recycled plastic type of polypropylene (PP) and polyethylene (PE) (Figure 2 and Figure 3).

![Figure 2](image)

**Figure 2.** Wood plastic composite made from pine and Albizia wood particle with the matrix of PE (a) and PP (b)

According to Mapleston [20], the variety of plastic wood composite products makes it difficult to conduct discussions including comparing with other studies. The characteristics of wood plastic composites depend on the uniformity of their constituent material properties, the interaction between the material, the manufacturing process, product design and environmental factors. Therefore, the most important thing is the extent to which the wood plastic composite product meets the requirements of the standard. The results of this study are compared with the applicable standards in Indonesia, namely SNI 8154: 2015 - Wood Plastic Composites [15]. The average values of physical and mechanical properties of the composites made from a mixture of pine wood powder and sengon wood flakes plus palm fiber using PE and PP matrices are presented in Table 1.

| Table 1. Mean of physical and mechanical of composite board to be tested |
### Table 1. Physical and Mechanical Properties of Wood Plastic Composites

| Type of Plastic | Wood Species | Composition | Density (g/cm³) | Moisture Content (%) | Thickness swelling (%) | Water Absorption (%) | MOE (kg/cm²) | MOR (kg/cm²) | Internal bond (kg/cm²) | Screw-withdrawal strength (kg) |
|-----------------|--------------|-------------|-----------------|----------------------|------------------------|----------------------|-------------|-------------|------------------------|-------------------------------|
| PP              | Pinus        | A           | 0.827           | 5.01                 | 34.43                  | 63.32                | 12.42E+02   | 116.71      | 2.57                   | 47.87                         |
|                 |              | B           | 0.836           | 3.98                 | 59.82                  | 97.32                | 6.11E+02    | 91.50       | 1.64                   | 40.93                         |
|                 |              | C           | 0.789           | 3.21                 | 21.24                  | 48.35                | 1.32E+02    | 135.53      | 2.81                   | 63.73                         |
| Sengon          | A            | 0.810       | 2.20            |                      | 37.13                  | 61.28                | 2.04E+02    | 187.08      | 2.29                   | 63.07                         |
|                 | B            | 0.699       | 2.74            |                      | 33.92                  | 71.77                | 1.69E+02    | 146.59      | 1.63                   | 57.60                         |
|                 | C            | 0.802       | 2.76            |                      | 14.52                  | 54.63                | 1.50E+02    | 140.91      | 2.53                   | 67.60                         |
| PE              | Pinus        | A           | 0.840           | 3.94                 | 22.12                  | 45.72                | 1.24E+02    | 117.79      | 2.81                   | 56.93                         |
|                 |              | B           | 0.874           | 2.03                 | 35.52                  | 50.96                | 1.63E+02    | 119.21      | 1.70                   | 59.27                         |
|                 |              | C           | 0.832           | 2.91                 | 13.97                  | 34.94                | 7.46E+01    | 105.62      | 2.92                   | 59.33                         |
| Sengon          | A            | 0.810       | 3.92            |                      | 21.93                  | 44.59                | 1.73E+02    | 160.11      | 2.95                   | 57.53                         |
|                 | B            | 0.834       | 1.47            |                      | 29.74                  | 52.58                | 2.02E+02    | 194.11      | 1.94                   | 68.67                         |
|                 | C            | 0.787       | 2.61            |                      | 15.68                  | 34.68                | 1.38E+02    | 158.47      | 2.91                   | 71.33                         |

Remarks: PP = Polypropylene, PE = Polyethylene, A = 50:25:25 (b/b), B = 50:30:15 (b/b), C = 50:15:35

#### 3.2. Density and moisture content

From Table 1, it can be seen that the density and moisture content of the composite boards made from pine wood powder and sengon wood flakes and mixed using PP and PE matrices with the composition of A, B and C are not significantly different. This is because the density of the composite boards made with these compositions reached the target of 0.60 g/cm³. The highest density of the wood plastic composite board was 0.874 g/cm³ obtained by pine wood composite board using PE matrix with the ratio of B (50:30:15). While the lowest was 0.699 g/cm³ belongs to sengon wood composite board using matrix PP in the composition of B.

The moisture content of wood plastic composites, in general, was much lower than the maximum water content required which is ≤ 12%. Even the moisture content of plastic wood composites made in this study is lower according to JIS A5908: 2003 standard [21].

#### 3.3. Thickness swelling

The thickness swelling of the composite boards can be seen in Table 1 and Figure 4. In Figure 4 it can be seen that the largest thickness swelling is 59.82% achieved by pine wood composite board with PP matrix at B ratio and the lowest 13.97% on wood composite board pine with PE matrix. According to SNI 8154: 2015 standard [15], the maximum of the thickness swelling value of plastic wood composite should not more than 4%. Thus there is no combination of plastic wood composite results correspond to the requirements of the standard. However, it is necessary to know the effect of treatment, namely the type of matrix, the type of wood, and the composition of the mixture of particles, fibres and matrices on the thickness swelling, as presented by the analysis of variance in Table 2.

![Figure 4. Mean values of swelling of the composite block](image-url)
PPSA-C = composite block made from albizzia wood with PP matrix with the composition of A - C
PEPA-C = composite block made from pine wood with PE matrix with the composition of A - C
PESA-C = composite block made from albizzia wood with PE matrix with the composition of A - C

Table 2. Analysis of variance of the effect of wood species, matrix and composition to the thickness swelling

| Source                  | df | Sum of square | Mean squares | F_{calc}  | Sig.     |
|-------------------------|----|---------------|--------------|-----------|----------|
| Matrix type (P)         | 1  | 1059.177      | 1059.177     | 23.04**   | 0.0001   |
| Wood type (J)           | 1  | 242.996       | 242.996      | 5.29      | 0.0305   |
| P*J                     | 1  | 205.492       | 205.492      | 4.47      | 0.0451   |
| Composition (K)         | 2  | 3089.703      | 1544.852     | 33.60**   | 0.0001   |
| P*K                     | 2  | 279.232       | 139.616      | 3.04      | 0.0667   |
| J*K                     | 2  | 397.629       | 198.815      | 4.32      | 0.0249   |
| P*J*K                   | 2  | 255.318       | 127.659      | 2.78      | 0.0823   |

In Table 2 it can be seen that the type of matrix has a very significant effect on the thickness swelling at 5% confidence level. Also it can be seen that the lowest thickness swelling is 13.97% belongs to the composite board made of pine wood powder using PE plastic with the mixture composition of pine wood powder, palm fibre and matrix of 50: 15: 35.

3.4. MOE dan MOR

Graphically, MOE and MOR values of the composites can be seen in Figure 5 (a and b) and the analysis variance of the effect of matrix type, wood type, and composition of the mixture of particles, and fibres on the MOE can be seen in Table 3.

Table 3. Analysis of variance of the effect of wood species, matrix and composition to the MOE

| Source                  | df | Sum of squares | Mean squares | F_{calc}  | Sig.     |
|-------------------------|----|---------------|--------------|-----------|----------|
| Matrix type (P)         | 1  | 4802964.454   | 4802964.454  | 0.63      | 0.4364   |
| Wood type (J)           | 1  | 308403940.721 | 308403940.721| 40.23**   | 0.0001   |
| P*J                     | 1  | 5341799.521   | 5341799.521  | 0.70      | 0.4121   |
| Composition (K)         | 2  | 75989022.402  | 37994511.201 | 4.96*     | 0.0158   |
| P*K                     | 2  | 176929962.834 | 88464981.417 | 11.54**   | 0.0003   |
| J*K                     | 2  | 19366964.324  | 9683482.162  | 1.26      | 0.3009   |
| P*J*K                   | 2  | 54837075.201  | 27418537.600 | 3.58*     | 0.0437   |

Table 3 shows that the type of wood has a very significant effect on MOE while the composition of the wood particle mixture has a significant effect on MOE. The interaction between the types of matrices with the composition of particle mixture is very influential on MOE. This means that the three composing materials of the composite boards, namely wood, palm fibre and recycled plastic contribute to the properties of the composite board. From Table 1 it can be seen that the values of mechanical properties associated demonstrated different values. The highest MOE value of 20,450.67
kg/cm² was achieved by sengon wood composite board using matrix PP on the ratio of mixture: 50: 25: 25. The highest MOR of 194.11 kg/cm² was achieved by sengon wood composite board using the matrix PE in the ratio of 50:30: 15. Referring to SNI 8154: 2015, the wood plastic composites with MOE values that meet the standard requirements are PPPSA and PESB with the values of 20,450.67 and 20,286.67 kg/cm³, respectively (Figure 5). The standard requires a minimum MOE value of 20,000 kg/cm³. The minimum MOR value according to the SNI requirements is 180 kg/cm². Thus, as can be seen in Figure 6, the composition that fulfills the requirements are also PPPSA (MOR = 187.08 kg/cm²) and PESB (194.11 kg/cm²).

3.5. Internal bonding and screw holder strength
SNI 8154: 2015 - Plastic wood composites - does not require testing the internal bonding strength test. However, to find out the value, the test was carried out by referring to SNI 03-2105-2006 - Particle board - and requires a minimum value for internal bonding strength of 1.50 kg/cm². The plastic wood composites made had higher internal bonding strength values than the minimum values required. The lowest value was 1.63 kg/cm² belongs to the composition of PPSB and the highest value was 2.95 kg/cm² at PESA (the composition of 50: 25 : 25). The results of the anova of the effect of the matrix type, type of wood, and composition of the mixture, fibres and matrices on internal bonding strength are presented in Table 4.

| Source                  | df | Sum of squares | Mean of square | F_{calc} | Sig.         |
|-------------------------|----|----------------|----------------|----------|--------------|
| Matrix type (P)         | 1  | 0.792          | 0.792          | 16.27**  | 0.0005       |
| Wood species (J)        | 1  | 0.011          | 0.011          | 0.22     | 0.6438       |
| P*J                     | 1  | 0.118          | 0.059          | 1.21     | 0.0479       |
| Composition (K)         | 2  | 0.108          | 0.054          | 1.10**   | 0.0001       |
| P*K                     | 2  | 0.012          | 0.006          | 0.12     | 0.3155       |
| J*K                     | 2  | 0.212          | 4.350          | 0.0479   | 0.3478       |
| P*J*K                   | 2  | 4.020          | 82.560         | 0.0001   | 0.8845       |

From Table 4, it can be seen that the type of matrix has a very significant effect on the internal bonding strength at a 5% confidence level. The composition of the particle mixture also has a very significant effect on internal bonding strength. This means that the three forming materials of the composite boards, namely wood, palm fibre and recycled plastic contribute to the properties of the composite board.

The screw-hold strength is presented in Figure 6. From this figure it can be seen that the highest screw pull/hold strength of 71.33 kg is obtained by the sengon wood composite board with PE matrix and the composition of 50:15: 35. And the only composition meets the requirements of SNI 8154 : 2015 - Plastic wood composite [15], because the standard requires a minimum screw-hold strength by 70 kg.

![Figure 6. Mean values of the screw-withdrawal strength of the composite block](image)

4. Conclusion
Wood waste in the form of flakes or sawdust of pine and sengon wood mixed with palm fibres (ijuk) as the reinforcement can be used as raw material for wood plastic composite board using recycled plastic as the matrix. Mechanical strength properties values can provide an overview of the use of composite boards. The density of the composite boards made reached the minimum density of 0.60 g/cm³ and the moisture content, in general, was much lower than the maximum water content required which is ≤ 12%. The lowest thickness swelling is 13.97% reached by the composite board made of pine wood powder using PE plastic with the mixture composition of pine wood powder, palm fibre and matrix of 50: 15: 35.

The wood plastic composites with MOE values that meet the standard requirements are PPPSA and PESB with the values of 20,450.67 and 20,286.67 kg/cm², respectively. The composition that fulfills the requirements of MOR are also PPPSA (MOR = 187.08 kg/cm²) and PESB (194.11 kg/cm²). The plastic wood composites made had higher internal bonding strength values than the minimum values required (1.50 kg/cm²). The highest screw pull/hold strength of 71.33 kg is obtained by the sengon wood composite board with PE matrix and the composition of 50:15:35.

References

[1] Schwarzkopf, M.J. and M.D. Burnard, Wood-Plastic Composites—Performance and Environmental Impacts, in Environmental Impacts of Traditional and Innovative Forest-based Bioproducts, A. Kutnar and S.S. Muthu, Editors. 2016, Springer Singapore: Singapore.

[2] Mantia, F.P.L. and M. Morreale, Green composites: A brief review. Composites Part A: Applied Science and Manufacturing, 2011. 42: p. 579-588.

[3] Eder, A. and M. Carus, Global trends in composites: WPC. Bioplastics Mag, 2013. 8: p. 16-17.

[4] JIS, JIS A 5908:2003 - Particleboards, 2003, Japanese Standards Association.

[5] MOF, Statistic of Forestry. 2004, Jakarta: Directoart General of Forest Production Management.

[6] Purwanto, D., Analysis of types of wood waste in the wood processing industry in South Kalimantan., Jurnal Riset Industri Hasil Hutan, 2009. 1: p. 14-20.

[7] Aviliani, The rise of the forestry sector in national development, in Panel Industry Discussion of Forestry Facing Global Market Competition2010, Yayasan Sarana Wanajaya: Jakarta.

[8] Randing, Study on the effect of Palm fibre addition on concrete tile. Vol -1995, Puslitbangkim, Bandung. Jurnal Penelitian Perumukiman, 1995. 11(1).

[9] Yuwono, S., Study on the effect of adding palm fibres and coconut fibres to tile building materials and PDAM waste panels. Jurnal Penelitian Perumukiman, 1994. 10(6).

[10] Risnasari, I., Morphology of wood-plastic composites from recycled wood and plastic waste in weathering tests, 2008, North Sumatera University: Medan.

[11] Sari, E.F., Nirwana, and Bahruddin. The effect of particle size and its contain of oil palm wood level on the properties and morphology of wood plastic composites (WPC) material made from oil Palm trunk. in PROSIDING SNTK TOPI. 2011. Pekan Baru Riau: Department of Chemistry Engineering, Riau University.

[12] Setyawati, D., Physical and Mechanical Properties of Wood Plastic Composites Using Recycled Polypropylene, in Department of Forest Products, Post Graduate School2003., IPB University: Bogor.

[13] Sulaeman, Deterioration of Wood Plastic Composite Using Recycled Polypropylene Powder by Weather and Termites, in Post Graduate School2003, IPB University: Bogor.

[14] Yuniari, A., Study of recycled plastic composites with wood powder for building materials. Majalah Kulit, Karet dan Plastik, 2007. 23.

[15] BSN, SNI 8154:2015 - Wood plastic composites, 2015, National Standard Agency: Jakarta.

[16] ASTM, Standard practice for establishing structural grades and related allowable properties for visually graded lumber. ASTM D 245-88, 1988, American Society for Testing and Materials: Philadelphia, PA.
[17] TAPPI, Technical Association of the Pulp and Paper Industries (TAPPI) Standards for Procedures and Testing, 1996, Technical Association of the Pulp and Paper Industries (TAPPI): Atlanta, Georgia.

[18] ASTM, ASTM D 3044-94: Standard Test Method for Shear Modulus of Wood-Based Structural Panels, 2000, ASTM International: West Conshohocken, PA.

[19] ASTM, ASTM D 7031 – 04: Standard guide for evaluating mechanical and physical properties of wood-plastic composite products., 2006.

[20] Mapleston, P., Wood composite suppliers are poised for growth in Europe, in Modern Plastics2001. p. 41.

[21] JIS, JIS A 5908:2003 - Particleboards, 2003, Japanese Standards Association.