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Utilization of bagasse and coconut fibers waste as fillers of sandwich composite for bridge railway sleepers

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Abstract. The bridge railway sleepers is an essential component in the construction of railways, as the foundation of the rail support in order to withstand the load a train that runs above it. Sleepers used in bridge construction are expected to have a longer service life, lighter weight and durable so that can be used more efficient. This research was carried out to create a model of bridges railway sleepers made of sandwich structured composite from fiber glass, epoxy resin with fillers waste of bagasse (sugar cane pulp mill) or coconut fiberboard (copra industry) that using polyurethane as an adhesive. The process of making was conditioned for small and medium industrial applications. Railway sleepers' specifications adapted to meet the requirements of end user. The process steps in this research include; lay-up fiberglass combined with bagasse/coconut fiberboard (as fillers), gluing with epoxy resin, molded it with pressure to be solid, curing after solidification process. The specimens of composite, bagasse and coconut fiber board were tested for tensile and compressive strength.The prototype were tested of mechanical test: flexural moment test to the stand rail, flexural moment test to the middle of the sleepers and tensile strength test on one side of the sleepers, in accordance to SNI 11-3388-1994 Method testing of single block concrete sleepers and bearing single rail fastening systems. The results of mechanical testing all variations meet the technical specifications of end user such as test results for flexural moment on all prototypes, after load test, there is no visible crack. While in the tensile strength test, it seem the prototype with coconut fiberboard filler, shows better performance than bagasse fiberboard filler, the decisions is just depended on techno economic and lifetime

Figure. Bridge railway sleepers

1. Introduction

Sleepers of the railway bridge made of hefty wooden. In indonesia, the demand of wooden sleepers is 12.371 unit per year, it came from Java and Sumatra region. The source of timber is restricted nowadays, it effects the price of wooden sleepers and difficult to get, especially for size of sleepers 18 by 24 by 180 cm or 22 by 24 by 200 cm. This situation increases act of illegal logging in Indonesia. This research

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purpose is to find a solution for these matter, a substitute material which can easily reproduced. Composite material which combined in shape of sandwich structure is one solution from several alternative [1]. It has an improvement aspect, such as ; weather resistance, better compresive, tensile and flexural strength, lighter compared to concrete sleepers. This sandwich structure can consist of glass fiber, filler component (bagasse or coconut fibres, in shapes as a fiberboard) combined with epoxy resin as a matrix. Coconut fibers is natural resource which placed Indonesia as 2nd coconut producer in the worlds. Bagasse is a side-product of sugar mill which haven't optimized in Indonesia [2]. In consideration of manufacturing technology is appropriate technology, as well as the acquisition of raw material is quite easy and cheaper. The research that has been done is bridge railway sleepers from sandwich structure composite. Sandwich structure made up of a minimum of three parts, namely laminate top; core and laminate bottom. As it has been known that a plate, when the thicker plate is bent required the greater force compared to thinner plates. This happens because they relate to the value of the moment of mass inertia. Moment of mass inertia of thick plates is greater than the thin plate [3]. In the sandwich structure, the core is useful to strengthen the structure by means of insert between the two laminate that is a laminate top and bottom laminate. In addition to increasing the flexural strength with a layered arrangement of the mechanical structure is more resistant to damage rate. Another advantage gained by using a sandwich structure when compared to the solid structure (full laminate) is flexural rigidity sandwich will increase 8 times higher than the flexural rigidity solid [4]. Laminate structure composed of sheets of glass fiber piled such that the dough is mixed with an epoxy resin [5], hardener by way of lay-ups. At preparation, to achieve the optimal of tensile strength, compressive strength and flexural strength, fiber orientation (0^o, 45^o, 90^o) is set properly. Preparation of fiber orientation, the number of layers of fiber, the type of glass fiber construction, arrangement and the pile fiber volume fraction between the fiber and the matrix, pressure is needed to regulate and control the fiber volume fraction [6,7]. It is no less important is the pressure and lay up process must be equitable to reduce the air or gas which may be trapped within the composite cause voids in the composite due to trapped air or gas that would weaken the structure. The void will be the initial cracks or delaminating of the structure receiving cyclic loading. Void will also cause stress concentration at the time of receiving the structure of static load. An epoxy resin matrix is best for all kinds of fibers in composites manufacture; it is there are several reasons including: the epoxy resin is attached very well with many kinds of fillers, reinforcing agent and the substrate. The chemical structure of epoxy resin is the result of reaction between diepoxy and diamine joint together and going crosslink to form large molecules and a substance that is hard and very strong [8,11].

2.Material and Methods.

2.1 Material and Equipment.

Materials are epoxy resins, epoxy hardener, epoxy thinner, catalyst, glass fiber S.B (Stitch Bonded), Woven Roving (WR) 200, WR400, WR600 and WR800) [7], fiberboard bagasse / coconut fibers, polyurethane thinner cleanser The equipment used is mold and pressure regulating device to sleepers of the railway bridge in the form of test specimens and prototype.

2.2 *Methods.*

The First Preliminary Study.

Experiment that have been done in autoclave to set the condition of process, used variations of fabric construction, orientation, number of layers, the specimens size 10x300x400mm with specimen code : 1.7SB (room), 2.6SB (60°C), 3.40WR200 (room temperature , 4. 20WR400 (room temperature), 5.20WR400 (30^0C), 6.20WR400 (60°C), 7.8WR200 + 14WR400 (30°C), 8.16WR200 + 6SB (room temperature), 9. 2WR200 + 7SB (room temperature), 10.4WR200 + 2SB + 6WR400 (room), 11. 4WR200 + 2SB + 10WR400 (room temperature), and then Mechanical Properties testing: Hardness, tensile strength, flexural strength, evaluation and analysis of data test and Conclusions.

The Second Preliminary Study.

1. Specimens Size 25x300x400mm with orientation fabric 0^0, 90^0.
   a.100WR200, b. 67WR400, c.44WR600, d. 33WR800, e. 20SB
2. Specimens size 10x300x400mm with orientation fabric 0^0, 90^0
   a.40WR, b. 27WR400, c.18WR600, d. 13WR800, e. 20SB,

The Third Preliminary Study

1. 2 WR200 + 4 Stitch Bonded+ 2WR200, lay up epoxy resin, with total thickness of 6 mm

2 .1 WR400 + 4 Stitch Bonded+ 1 WR400, lay up epoxy resin with a total thickness of 6 mm

3 .3 WR200 + 2 Stitch Bonded+ 3 WR 200, lay up epoxy resin with a total thickness of 6 mm

Making of Bagasse Fiberboard

Bagasse filtration to separate the fine fiber and coarse fiber

Every type of bagasse fibers blended with 13% polyurethane and 10% MC catalyst and then press 2 minutes using mold, next make sandwich : layer I: fine fiber bagasse dough (15%), layer II: coarse fiber

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bagasse dough (70%) and layer III: Fine fiber bagasse (15%), density 250kg / m^3 Press time 3 min, steam 170^o C, release, cutting & coating (size 20x140x1800 mm)

Making of Coconut Fiberboard

Coconut fiber is described to be separated between the long fibers, short fibers and coco pith, then weighed 90%, was added 10% poly urethane, 10% MC catalyst and then mixing in mold arrangement with density 200 kg/m^3 , pressed 2 min , steam 170^{0}C, curing with blower 10-26^{o}C 2 days, press about 2 min, release, cutting and coating (size 20x140x1800 mm).

Making of Bridge Railway Sleepers from Composite Sandwich Structure with Filler Sandwich of Bagasse or Coconut Fiberboard

Fiberglass lay-up process layer by layer in the mold for composite filling left and right sides 4WR200, 28 SB,4WR200 (Size 40X140x1800mm), laminate bottom 2WR20, 14 SB, 2 WR200 (size 20x240x 1800mm), inserting 5 pieces bagasse or coconut fiberboard as core/ filler sandwich (size 20x140 x1800mm), Fiberglass lay-up process layer by layer in the mold for laminate top (size 20x240x1800mm), variation using (2WR20, 14SB, 2 WR200), pressed, curing at room temperature one day/ curing using autoclave at 60^{o}C 1 h, finishing, nut and bolt installation. Bridge railway sleepers mechanical testing.

3. Results and Discussion.

3.1 The First Preliminary Study.

Result of Fiberglass Composite Mechanical Testing in the First Preliminary study shown in table 1. From the evaluation and analysis of test data can discuss things as follows: Table 1 shows the relationship between the number of layers, temperature and time of curing on the results of the testing of tensile and flexural strength and hardness by grouping variety of fabrics of glass fiber which is stitch bonded, woven roving 200 (WR200) and woven roving 400 (WR400). Can be explained that the characteristics of the fabric is determined by the fabric construction, namely: Stitch bonded a fabric of glass fiber yarns coated with long fibers were shown irregularly, intended to improve the physical properties of the fabric. Woven roving is a fabric of glass fiber yarn, which in WR200 has a finer cross-section of a cross than WR400, WR200 so widely used as the outer layer of the composite to produce a smooth surface [6,8].

Test result from Table 1, codes 3, 4, 5 and 6 which has a less number of layer composite 20 WR400 but have a good result compare to composite 40WR200, especially for hardness, tensile and flexural strength value. This condition is caused by a larger cross-section of WR 400 compared to WR200. WR 400 consist of pile of fabric which bulkier, contain more pores of microfibril and thicker than WR200 (0.4 mm compare to 0.2 mm). During impregnation process, the epoxy resin will enter and disperse into pores of microfibril fiber.

Table 1. Mechanical Testing Result of Fiberglass Composite at the First Preliminary study

Code	Type	Tempature & Time	Orientation of fabric (°)	Tensile strength (kg/cm^2)	Flexural strength (kg/cm^2)	Hardness (HRr)
1	7 SB	room 1 day	0/90	1524.97	3122.3	120.0
2	6 SB	60°C 1 h	0/90/45	1893.99	**3216.1**	112.7
3	40 WR200	room 1day	0/90	1198.78	2374.1	116.7
4	20 WR400	room 1day	0/90/45	1763.51	2982.7	117.2
5	20 WR400	30°C 1 h	0/90	1320.08	2801.2	117.7
6	20 WR400	60°C 1 day	0/90/45	1612.64	2877.7	121.0
7	8 WR200 14 WR400	30°C 1 day	0/90/45	1620.80	2324.2	118.7
8	16 WR200 6 SB	room 1 day	0/90/45	1996.94	2252.8	105.0
9	2 WR200 7 SB	room 1 day	0/90/45	**2064.22**	2079.5	**123,0**
10	4 WR200 2 SB 6 WR400	Room 1 day	0/90/45	1997.96	2909.3	104.3
11	4 WR200 2 SB 10 WR400	Room 1 day	0/90/45	1569.83	1932.7	103.5

This will form better polymerization so it produces better bond between polymer epoxy resin and glass fiber. The composite will have solid and stronger bond which increase the value of hardness, tensile and flexural strength. WR 200 has smaller cross section, more dense and smaller pores between microfibril. During impregnation process the epoxy resin will be more difficult to enter and cause fewer chemical bonding between epoxy resin and glass fiber. This will form the composite less solid and less robust. The composite of WR 200 produces hardness, tensile and flexural strength values less than composite of WR400. Table 1 code 4, 5 and 6 shown that polymerization of the epoxy resin and glass fiber using 20WR400 at room temperature need curing time up to 1 day . The shorter curing time due to the higher temperature, is needed to improve production efficiency. This experiment was done by varying the temperature of 30 and 60°C. At temperature curing of 60°C for 1 h, the polymerization process will be more perfect than curing at room temperature as those in the code 6, and code 5. Consequently, testing

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results of hardness, tensile strength and flexibility are high enough. In terms of tensile and flexural test, when compared between code 5 with of orientation $0^o/90^o$ and code 4 and 6 with orientation of $0^0/90^0/45^0$, the overall orientation of fabric greatly affect the results of physical tests where the orientation of the combined $0^o/90^o/45^o$ better than the orientation of $0^o/90^o$. The composite of epoxy resin and glass fiber are composite types of stitch bonded, WR200 and WR400. Test results are shown in Table 1 of the code 7, code 8, code 9, code 10 and code 11. The amount of the stitch bonded layer which gives more hardness and higher tensile test, can be seen in code 9 (2WR200 7SB) with the highest grades of hardness and tensile. It is because stitch bonded fabric consists of coated glass fiber (long fiber) were shown irregular resulting in such fabrics have excellent strength in diagonal direction, especially composites with $0^o/90^o/45^o$ orientation. Additionally, stitch bonded more bulky than WR200 and WR400, so that when the epoxy resin is impregnated it can be more evenly distributed among the pores of the fiber micro fibrils well. Therefor during the curing process epoxy resin will polymerize well so as to have a good physical test results. In this experiment epoxy resin used is type 3, namely the type of diglycidyl ether of bisphenol A (Bakelite EPR 174) in the presence of a catalyst (curing agent) types polyaminoamide (Bakelite EPH 340) will be formed polymerizes to form composite [11]. The composite quality was also affected by temperature and time of curing; epoxy resin type 3 can be polymerized at room temperature up to about 60^oC. Provision of heat at the time of polymerization allows the voids (air trapped in the composite). The Void is an initial crack at the time of testing physical/mechanical. Voids can also occur during the impregnation into glass fiber, coating overcrowding will cause epoxy resins difficult to enter the pores of the glass fiber micro fibrils. Hardness test results on code 10, 8 and 11 had low values. This may be due to the variation that a layer number is high enough, so that when the epoxy resin impregnation difficult to enter the pores of the resin means micro fibrils epoxy is not well dispersed into the glass fiber, which resulted in a void that is the initial crack, so that by the time their hardness testing void will make the test result is lower than that void. Thus the hardness and tensile test results have a higher value because more dominant fiber strength is supported with a combination of fiber orientation $0^o/90^o/45^o$ [10].

3.2 The Second Preliminary Study.

The effect of variety of construction and the number of layers of glass fiber on tensile strength (kg/mm^2), flexural strength (kgf/mm^2), compressive strength (kg/mm^2) and hardness (R-HRr) test result can be seen at Table 2 [6,8].

Table 2. Mechanical Testing Result of Fiberglass Composite at the Second Preliminary Study

Code	Tensile Strength (kg/cm^2)	Flexural Strength (kgf/cm^2)	Compressive Strength (kg/cm^2)	Hardness (R-HRr)
WR200	1883	**3227**	**3208**	112
WR400	2395	2558	1790	**118**
WR600	2017	1935	2162	**118**
WR800	1757	1773	2004	105
SB	**3324**	3222	1671	96.5

The highest tensile strength as achieved on code SB of 3324 kg/cm^2, while the highest flexural strength test results is achieved in code WR200 of 3227 kgf/cm^2. The highest compressive is achieved on code WR200 of 3208 kg/cm^2 and the highest hardness achieved on WR400 and WR600 118 HRr. This can be explained as follows: Characteristics of composites generated from these experiments is determined by a two-phase forming composite:

First phase strong (reinforcement), in this experiment used glass fiber in the form of fabric with construction of WR 200, WR 400, WR600, WR800 and Stitch bonded [11] and the second phase binder (matrix) used epoxy resin. It is also affected by temperature and curing time, epoxy resins can be polymerized at room temperature up to about 60°C [12]. Curing at room temperature necessary drying time up to 24 h with elevated curing temperature curing time is expected to be shorter to improve production efficiency. The experiments have been done at 60°C. Provision of heat at the time of polymerization allows the voids (air trapped in the composite). The Void is an initial crack at the time of testing physical/ mechanical [13]. Voids can also occur during the impregnation into glass fiber, coating overcrowding will cause epoxy resins difficult to enter the pores of the glass fiber micro fibrils. From the above data value tensile strength and flexural strength highest in the testing code SB because It is because stitch bonded consists of a cloth coated glass fiber (long fiber) were sown irregular resulting in such fabrics have strength diagonal direction is excellent, especially composites this orientation has $0^0/90^0/45^0$. Additionally stitch bonded more bulky than woven roving, so that when impregnated epoxy resin can be evenly distributed among the micro-porous fiber fibrils well, during the curing process will polymerize well so as to have the results of tensile strength and flexural strength are good. Hardness values are closely related to the compressive strength which in this experiment the best value achieved in the code WR200 use WR200 has a thick fabric that is thinner so the use of more fiber, specimens were produced having comparisons % of the fibers is higher than % resin, this causes the composite generated more solid, so as to have hardness and compressive strength is higher.

3.3 The Third Preliminary Study

Mechanical Testing Result of Fiberglass Composite in the Third Preliminary Study show in table3

Table 3. Mechanical Testing Result of Fiberglass Composite at the Third Preliminary Study

Code	Tensile Strength (kg/cm^2)	Flexural strength (kgf/cm^2)	Compressive Strength (kg/cm^2)
1	2487.6	5527.9	**3654.75**
2	1922.9	**6080.0**	2848.3
3	**2612.8**	**6080.0**	1909.99

The tensile strength, the flexural strength and the compressive strength test results do not really give a significant difference this means all variations gave no effect on the tensile strength, flexural test compressive strength of the composite of glass fiber and epoxy resin, it is because the number of layers of glass fiber in an amount equal only distinct variation amount 2 layer WR 200 more give the tensile, flexural and compressive strength is slightly higher. Therefore for making bridge railway sleepers, use code 1. From this research obtained information that WR 200 will provide high tensile strength properties and provide a smooth surface material, while Stitch Bonded will give flexural strength properties and high compressive strength. Therefore, the manufacture of products Railway Bridge sleepers WR200 and SB use of glass fiber and epoxy resin. The mechanical properties of coconut fiberboard have an higher the mechanical properties of bagasse fiberboard.

3.4 Mechanical Testing Result of Coconut and Bagasse Fiberboard at the Third Preliminary Study

Table 4. Mechanical Testing Result of Coconut and Bagasse Fiber board at the Third Preliminary Study

code	Tensile strength (kg/cm^2)		Flexural strength (kgf/cm^2)		Compressive strength (kg/cm^2)	
	Coconut fiber	Bagasse fiber	Coconut fiber	Bagasse fiber	Coconut fiber	Bagasse fiber
1	10.42	7.81	11.34	8.51	3.11	2.33
2	9.70	7.28	11.85	8.89	3.20	2.40
3	9.88	7.41	10.15	7.61	3.07	2.30
4	8.32	6.24	9.97	7.48	3.17	2.38
5	8.78	6.59	10.65	7.99	3.40	2.55

In Table 4 seen that bagasse fiberboard have lower mechanical properties than coconut fiberboard on tensile strength, flexural strength and compressive strength , therefore if the bagasse or coconut used as a sandwich filler for Bridge Railway Sleepers, the mechanical properties of coconut fiberboard will have an higher mechanical properties than bagasse fiberboard, it is because coconut fiber have a longer fiber and higher tensile strength than bagasse, and also bagasse fiber more brittle than coconut fibers.

Mechanical Testing Result of Bridge Railway Sleepers from Glass Fiber and Epoxy Resin Material Composite with Sandwich Filler of Bagasse or Coconut Fiberboard.

The Static Load Bridge Railway Sleepers

Table 5. Testing Result of the static load on the Bridge Railway Sleepers

No	Type Testing	Design Moment (kg.m)	Design load (kg)	Description	Requirements
1	Seated vertical load rail (Type I)	1500	13139	no structural cracks	fulfilled
2	Seated vertical load rail (Type II)	1500	13139	no structural cracks	fulfilled
3	Moment at midspan (Type I)	930	3750	no structural cracks	fulfilled
4	Moment at midspan (Type II)	930	3750	no structural cracks	fulfilled

Static load test performed on Bridge Railway Sleepers for each type I is Bridge Railway Sleepers using bagasse fiberboard as filler and type II is bridge railway sleepers using coconut fiberboard as filler Results of testing the static load on the Bridge Railway Sleepers can be seen on table 5 shows that the bridge railway sleepers that were tested did not experience structural cracks during the design moment and when the moment of the design work for 3 minutes, so that the the bridge railway sleepers are eligible

Lift Test Rail Fastening Systems the Bridge Railway Sleepers

lift Test rail fastening systems carried on one of the stand bearing the number 2 for each types (type I and II) shows Table 6 Testing result of the lift Test rail fastening system

Table 6. Testing Results of Lift Test Rail Fastening Systems of the Bridge Railway Sleepers

Item	Weight	Specimen Type I	Specimen Type II
Load measured at separation (P)	kg	850.00	1031.25
heavy railway sleepers	kg	126.90	126.90
heavy framework	kg	22.24	22.24
load test (Pt)	kg	999.14	1180.39
1.5 Pt	kg	1498.71	1770.59

The Bridge Railway Sleepers burdened with a load of 1.5 Pt. For the test specimen type I load magnitude 1.5 Pt amounted to 1498.71 kg while for the test object of type II of 1770.59 kg. From visual observation after b the Bridge Railway Sleepers burdened with a load of 1.5 Pt for each specimen, it can be seen that: no component of the fastening system is broken, cracked or collapsed (good conditioned), rail cannot be separated, no loose or torn inserts. From the results of this test it can be concluded that the bearing under test meets the requirements of the test lift rail fastening systems.

Rail fastening system endurance test against longitudinal load

Test specimen rail fastening system is set up complete with a rail. Longitudinal load given in stages and each increment load recorded magnitude of displacement in the longitudinal direction. At the load of 10.9 kN shift in the longitudinal direction shall not exceed 5 mm. Testing of rail fastening system resistance to longitudinal loads, said that a shift by 5.5 mm, occurred at the time of the rail burdened with a load of 677.5 kg (6.65 kN). From this test it can be seen that the specimen (rail fastening apparatus / fastening) does not meet the requirements specified longitudinal strength. This may be due to rail clip used is not suitable.

4. Conclusions

Conclusions from preliminary study are the highest tensile strength test results achieved on code SB of 3324 kg/cm^2, the highest flexural strength test results achieved in code WR200 of 3227 kgf/cm^2, The highest compressive strength test achieve on code WR200 of 3208 kg/cm^2 and the highest hardness achieved on WR400 and WR600 of 118 HRr. From this research obtained information that Wr 200 will provide high tensile strength properties and provide a smooth surface material, while Stitch Bonded will give flexural strength properties and high compressive strength. Therefore, the manufacture of products Railway Bridge sleepers WR200 and SB use of glass fiber and epoxy resin. The mechanical properties of coconut fiberboard have an higher the mechanical properties of bagasse fiberboard

The better results of mechanical testing of the Railway Bridge sleepers all variations meet the technical specifications of end user, just look at the techno economic factors and wear time. The mechanical properties of the Railway Bridge sleepers using coconut fiberboard higher than using bagasse fiberboard as sandwich filler

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