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ULTRAVIOLET RADIATION CURED BIO-FIBRE COMPOSITES FROM OIL PALM EMPTY FRUIT BUNCH

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Abstract

In this study, development of ultra-violet (UV) cured biofibre composites is reported. The composites were based on the pulp made from empty fruit bunch (EFB) as the reinforcing agent and unsaturated polyester as the matrix. The EFB fibres were treated with different concentrations of sodium hydroxide (NaOH) solutions. The results showed that the Kappa number of the EFB decreased as the NaOH concentration was increased. The composites were produced from EFB fibres, which were treated with 22% and 28% NaOH solutions. The flexural, tensile and impact strength of the composites made from 22% NaOH treated EFB showed an increasing trend as the % of EFB was increased. However, those with 28% NaOH treated EFB decreased as the % of EFB was increased. Generally, the results showed that composites with EFB fibres treated with 22% NaOH displayed higher flexural, tensile and impact strength. However, no significant difference was observed for both types of composite with respect to flexural modulus. The study revealed the influence of two important factors, (a) the decrease of the light absorptivity (as a result of the removal of lignin) (b) the degradation of fibre strength as a result of higher concentration of NaOH treatment.

Introduction

The thermoset fibre reinforced polymer matrix composites are currently produced from unsaturated polyester resins by thermally induced initiators. Examples are polyester pre-pregs, sheet moulding compounds, bulk-moulding compounds etc [1]. The production of these composites involves use of high temperatures and requires expensive moulds and hydraulic presses. Room temperature curing of such systems takes a long time.

Ultra-violet (UV) radiation are widely used in Malaysia in surface coatings especially in wood industry [2] and followed by printing, electronic and adhesive industry [3]. In recent times photo-curing process has been adopted for making composites that may prove superior to the thermal curing systems. This process employs ultraviolet radiation to cure the composites. The success of the photo-fabrication of polymer matrix composites by the use of UV radiation stimulated our interest to apply the radiation curing technology for the production of biofibre-composites and been a subject of study in our laboratory and a patent for the process is being filed on this [4].

Literature Review

The use of natural fibre reinforcement in synthetic polymer bonded composites has gained significant importance in recent times [5]. Natural fibre biomass can be renewed in perpetuity and hence can be used exclusively or in part in fibre reinforced composites. Biofibres can replace glass and other high cost fibres to make composites, which are considerably cheaper, less abrasive so that the tools for moulding will not be damaged. Oil Palm industry in Malaysia generated large quantity of biomass. Recent investigations show various products from oil palm tree produce such as oil palm component-plastic composite, oil palm component-rubber composite, sheet moulding compound, composites, pulp and paper [6]. Besides strong economic incentive, natural fibers in composites have lower in specific gravity, higher specific tensile strength, biodegradable, and less energy intensive to process, so they are well suited to these type of technologies [7]. The UV curable systems are well known in the field of surface coating and have distinct advantages of being solvent free, environmentally friendly and energy saving [8]. The entire process of curing occurs at room temperature and hence does not require expensive high temperature equipment to cause the cure [9]. Further there is no fire hazard. In view of the above advantages attempts have been made to make polymer matrix composites by employing UV radiation for affecting the cure.

Materials and Methods:

Materials

Unsaturated polyesters P9728 was purchased from Euro Chemo Pharma Sdn. Bhd.. Empty fruit bunch (EFB) was obtained from Sabutek Sdn. Bhd. Photointiator IRGACURE 1800 was supplied by Ciba Speciality (Singapore) Pte. Ltd.

Preparation of Composites.

EFB was pulped at four different concentrations of sodium hydroxide (NaOH); 8%, 15%, 22% and 28% under the following conditions: fiber:liqour ratio (1:10, vol/vol), Temperature: 170°C and time of pulping: 2 hours. Fibers were formed into mat (20cm x 20cm) in a deckle box by the procedure reported earlier[4] and dried in oven at 80°C-100°C for 4 hours. After that, mats were pressed using hot press Gotech Testing Machine Inc model GT-7014-100 (2 minutes, 500 kg/cm^2, 100°C) and the thickness of the mats were controlled to ±1 mm. Three percent of photo-initiator IRGACURE 1800 was mixed with unsaturated polyester and poured onto EFB mat. The mat was impregnated with resin and the air bubbles if any were removed by means of a hand roller. After impregnation, mats were passed through 1ST UV machine for twenty passes at conveyor speed of 10m/min[10].

Testing.

The sheets produced into three type of test samples; i.e flexural, tensile and impact tests. Tensile tests were carried out on sample with dimension 10cm x 1.5cm x 0.1cm, using Universal Testing Machine model STM-10 at a crosshead speed of 1mm/min, according to ASTM D3039. Flexural tests were conducted according to ASTM D790, i.e a three – point bending, using Universal Testing machine model STM-10. The samples, with dimension 8cm x 1.2cm x 0.1cm were tested at a crosshead speed of 1.0 mm/min. The izod impact tests were carried out on unnotched samples with dimension 6.5cm x 1.2cm x 0.1cm, using an Impact Pendulum Tester (Zwick) model 5101 according to ASTM D252. A minimum of eight samples was tested in each case. Kappa number test were used to determine delignification process according to TAPPI 236 cm-85. Percentage of curing was determined through the Gel Content test and according to ASTM D2765.
The fractured surfaces of the composites from the tensile test were investigated with a Leica Cambridge S-360 Scanning Electron Microscope. All fracture surfaces were sputter coated with gold to avoid electrostatic charging and poor image resolution.

Results and Discussion:

1. Effect of Kappa number of the pulp on the degree of cure of the matrix of the composite

Fig. 1 shows how the degree of cure of the matrix material influenced by the kappa number of the pulp for different percentages of EFB pulp. Two important facts can be observed from this figure.

1. Influence of EFB pulp content in the composite
2. Influence of kappa number of the pulp

As the EFB pulp content in the composite increases, the gel content or the degree of cure of the matrix material decreases. This is due to the absorption of UV radiation by lignin present in the pulp. As the pulp content increases, the UV radiation is absorbed by the lignin present in the pulp and hence the depth of penetration decreases. The submerged layers of the composite do not receive sufficient light energy for cure. In other words, the submerged layers of the matrix material are in the shadow regions caused by the strong absorption of lignin present in the pulp.

Another interesting observation that can be made from the figure is that the gel content increases as the kappa number decreases. This is due to lesser quantities of lignin being present in the pulp and the light can penetrate more deeply into the matrix materials uninfluenced by unfavourable absorption of UV light by the top layers.

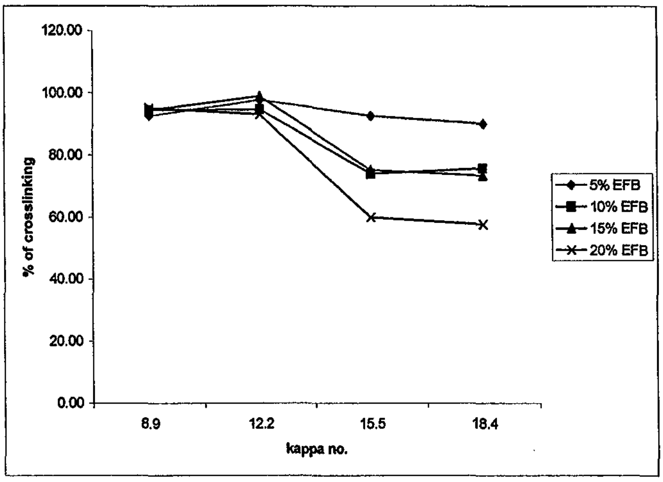

Fig. 1: Effect of Kappa number of the pulp on the degree of cure of the matrix of the composite

Effect of Sodium Hydroxide concentration on Kappa Number

From Fig. 2 it is obvious that the kappa number decreases as the percent of NaOH used in the pulping process increases. Hence use of higher concentration of NaOH for pulping is thus favourable for producing pulp with lesser amounts of lignin. This is a desirable condition for ensuring the complete cure of the matrix material in the composite. As reported in the previous paragraph this is true with respect to degree of cure. It should however be examined whether pulping under such high alkali concentrations is conducive to produce composites with mechanical strengths unimpaired. Hence, experiments were conducted to determine the effect of alkali concentration on flexural strength, flexural modulus, tensile strength, tensile modulus, and impact strength

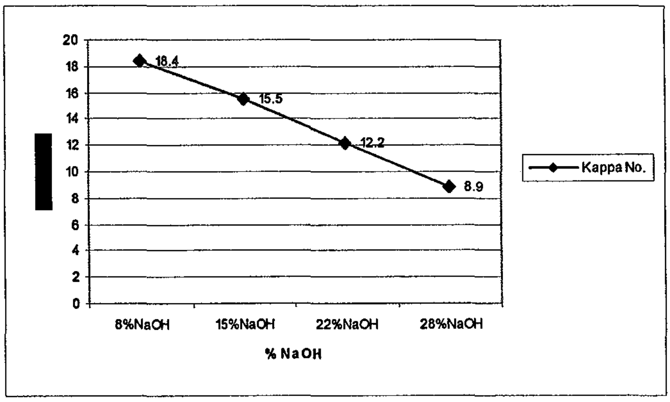

Fig. 2: Effect of Sodium Hydroxide concentration on Kappa Number

Effect of % NaOH in the pulp cooking liquor and EFB pulp percentage in composite on the flexural strength

Fig. 3 shows how the concentration of sodium hydroxide employed in pulping affects the flexural strength. The figure depicts the influence of percent of EFB pulp cooked with 22% NaOH and 28% NaOH on the flexural strength. In the case of EFB pulped with 22% NaOH the flexural strength increases up to above 56 MPa at 15% EFB and thereafter reduces to about 54 MPa at 20%. Although removal of lignin is conducive to a general increase in the light penetration and satisfactory cure, it is noticed that higher percent of fibre in the composite may still absorb light and prevent deeper penetration. It can further be noticed that pulp made with 28% NaOH produces composites with lesser flexural strength than the pulp made with 22% NaOH. It is evident that fibre damage occurs at higher alkali concentration, which could be the cause for reduced flexural strength.

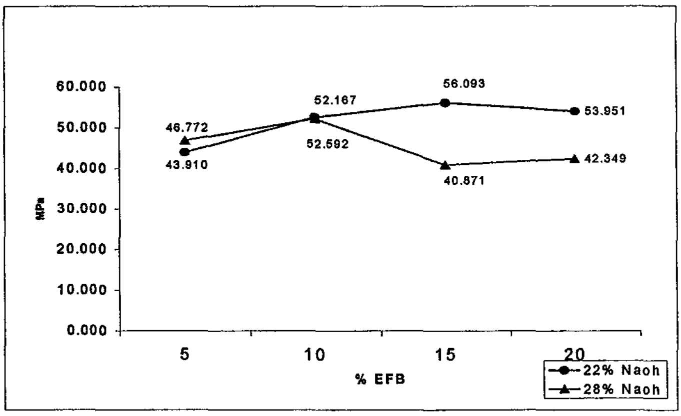

Fig. 3: Effect of percent of NaOH in the pulp cooking liquor and EFB pulp percentage in composite on the flexural strength

Effect of % NaOH in the pulp cooking liquor and EFB % in composite on the tensile strength

Fig. 5 gives the effect of percent of EFB pulp cooked under two different alkali concentrations in the cooking liquor on the tensile strength. It can be noticed that as the EFB fibre content increases the tensile strength increases. But the fibres cooked at 28% NaOH produced composites with lower tensile strength than the fibres cooked at 22% NaOH. This may be due to the loss in strength of fibres due to increased alkali concentrate.

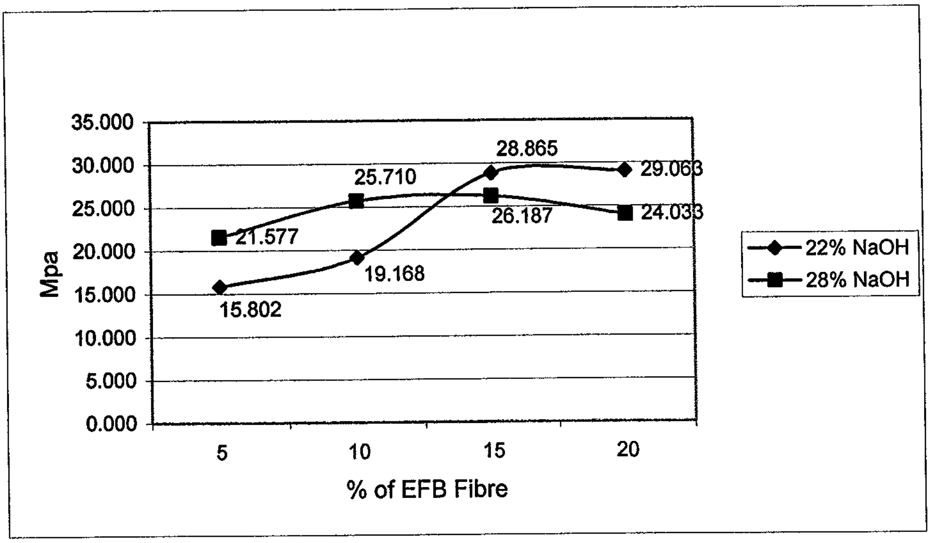

Fig. 5: Effect of % NaOH in the pulp cooking liquor and EFB % in composite on the tensile strength

Effect of % NaOH in the pulp cooking liquor and EFB % in composite on the impact strength

As the EFB% increases the impact strength increases up to 10% fibres and thereafter decrease. Pulp cooked in the liquor of 28% alkali concentration produces composites with lower impact strength than the pulp made at 22% alkali concentration. Light penetration as well as the fibre damage caused by increased alkali concentration in the pulping liquor appears to be the contributory factors in this case as well.

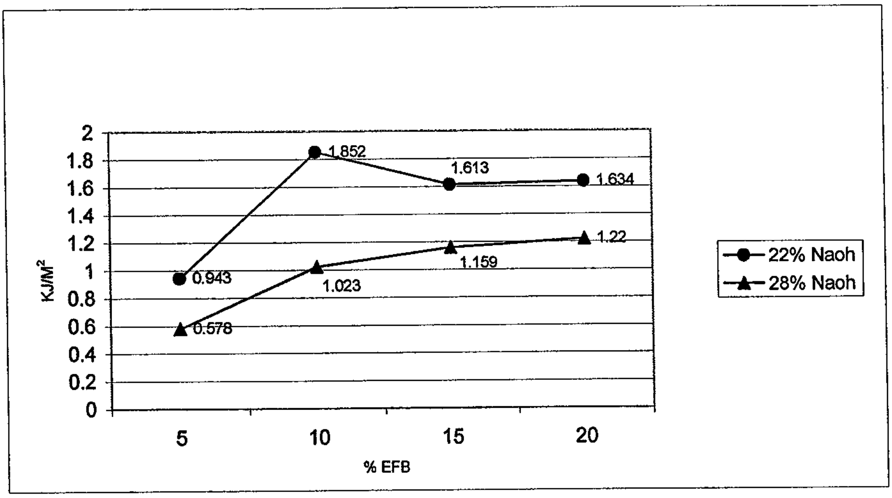

Fig. 6: Effect of % NaOH in the pulp cooking liquor and EFB % in composite on the impact strength

Conclusion:

The UV curable biofibre based polymer matrix composites can be produced by employing EFB pulp as the reinforcing fibre and unsaturated polyester resin as the polymer matrix. The degree of cure and the mechanical properties are related to the lignin content since lignin absorbs the UV light strongly and hence control the penetration depth and the degree of cure in the submerged layers of the composite. Although higher percentages of sodium hydroxide in the cooking liquor can produce pulp with low kappa numbers, which is desirable condition for promoting better penetration of light, there is a concurrent damage caused to the fibres due to higher alkali cooking.

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BIO-FIBRE COMPOSITES

1. FIELD OF THE INVENTION

This invention relates to a matrix composites and, more particularly, to a bio-fibre polymer matrix composites.

2. BACKGROUND OF THE INVENTION

It is an environmentally friendly, energy, time and space saving process meant to utilize large quantities of bio-fibres as partial or complete substitute for glass and other synthetic reinforcing fibres for producing composite materials. In this respect it is unsurpassed by any other competitive processes currently being employed for making similar products.

Glass or bio-fibre polymer matrix composites are generally made traditionally using thermoplastic or thermosetting resins such as unsaturated polyester, polypropylene, polyethylene etc. These composites are currently processed by application of heat in a compression, transfer moulding presses or injection moulding machines. These processes are both energy and capital intensive necessitating costly equipment of the type mentioned above. Even though room temperature curing is also possible in some of the conventional operations, these processes are time consuming and difficult to control to obtain consistent and reliable product.

3. SUMMARY OF THE INVENTION

It is therefore the object of the present invention to provide an efficient method of producing bio-fibre composites.

It is another object of the present invention to provide an environmentally friendly method of producing the biofibre composite.

It is yet another object of the present invention to produce material having improved quality.

These and other objects of the present invention are accomplished by providing

A method of producing bio-fibre matrix composite comprising the steps of (a) Preparing bio-fibre mat by wet or dry pr
(b) Impregnating

C (a) sandwiching treated bio-fibre mat between two layers of polyester films; and

impregnated

(d) (b) iridiating the sandwiched ~~treated~~ bio-fibre mat for

substantially few minutes.

Preferably the treated bio-fibre mat is made by pouring matrix resin onto substantially dry bio-fibre mat.

Further providing a method of producing bio-fibre mat comprising the steps of

(a) dicing fibres into appropriate lengths; said fibres comprising natural fibres and/or inorganic fibres and/or organic fibres and/or synthetic fibres;

(b) mixing said fibres uniformly into fibre blend;

(c) dispensing said fibre blend into water and stirring well fibre mixture; (d) Pouring the dispersion in a mat forming device such as deckle bo

(d) drying fibre mixture.

4. BRIEF DESCRIPTION OF THE DRAWINGS

The embodiment of the invention will now be described, by way of example only, with reference to the accompanying figure in which:

FIG. 1 shows a flowchart on the method of producing biofibre matrix composite according to the preferred embodiment of the present invention.

5. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Bio-fibres in the raw or delignified, or de-fibrated form (by thermo-mechanical or chemical defibration process) can be used as reinforcing fibres. The bio-fibres are treated chemically to enhance the the matrix - fibre adhesion. Glass and other synthetic fibres can also be incorporated for optimum final strength of the composite. A wide range of products from such bio-fibre composite is ~~vast;~~ possible / for ~~an~~ example may include products having high fire resistance. In short, process for producing the bio-fibre composites would be held entirely at room temperature thus expensive hydraulic hot presses are not required. In addition, due to its ultra quick curing of matrix resins, productivity of the composites is high with consistent quality and with less wastage of 'in process' resinous materials. For a better understanding of the present invention, Fig. 1 shows a flowchart on the method of producing bio-fibre matrix composites. An outstanding feature of the process is in fabricating the bio-fibre composite / using radiation where it was found that photo-fabrication of bio-fibre matrix based composites by employing ultraviolet radiation / or Solar radiation for curing the matrix is ultrafast and efficient due to the appropriate (ing

choice of UV lamp and photo-initiator combinations ensures a uniform and consistent through-cure. The UV curing process eliminates the use of peroxides as employed in conventional curing systems. The UV process employs single pack resin system (resin containing photo-initiators) which have a very long shelf life and the viscosity of the resin does not change during impregnation process. This ensures consistency in the quality of the product, a feature non-existent in the currently used process using peroxide curing agents. Since the curing reaction goes to near completion, the residual styrene emission is absent, a desirable characteristic not achievable in peroxide based curing systems.

There have been a disclosure of photofabrication of glass fibre composites recently but of bio-fibres have not been utilized so far anywhere. A wide range of composite and sandwich products can be made in single operation. Surface appearance and strength enhancement of wood composites such as plywood, particleboard, MDF can be achieved through this technology thereby making available a wide variety of final products to meet the requirements of different end users such as the building industry for structural and non-structural applications, ceilings, wall paneling, transluscent roofs and such like; the transportation industry for interior trims, lamp housings, door skins and such like; the electrical industry for insulation panels, housings for regulators, switches and such like; the chemical industry for fabrication of chemical storage tanks, chemical resistant floorings and such like; and many other industries.

Raw materials for the preparation of the bio-fibre composites is fibres made up of natural fibres preferably palm fibre, rubberwood and such like; inorganic fibres; organic fibres; and synthetic fibres. The first stage in the preparation of the bio-fibre composites is to make bio-fibre/hybrid fibre mat. Three methods have been adopted for the production of the bio-fibre according to the present invention.

Bio-fibres are reinforcing fibres which can be found in the form of firstly, raw without defibration; and secondly, defibrated fibres. For making bio-fibre mat from raw bio-fibre without defibration, there are two options namely, first, a wet process and second, a dry process.

(a) Wet process

In the wet process bio-fibres for example, palm fibres are cut or diced

into approximately 2.25cm (1 inch) length. Hybrid composites such as glass fibre, nylon or other synthetic fibres are cut to the same size. The composition of each fibre in the mixture can be varied from weight fraction 0 to 1. For the present invention the variations were made in accordance with the statistical experimental procedure called "Mixture Design". The actual compositions were computer generated. Once the compositions are fixed, the blended fibres are dispersed in water. Approximately 3-4 percent consistency is suitable for the formation of the reinforcing mat. Fibre mixture or slurry is stirred well to ensure a uniform distribution. The slurry is then poured into a " deckle box". The deckle box consists of a vertical rectangular vessel made of Perspex where at the bottom of the vessel is positioned a sieve made of nylon. A wooden frame surrounds the sieve and keeps the sieve in position. After the slurry is poured into the deckle box, water flows through the sieve leaving a layer of wet fibre mat on the sieve. The wet mat is then carefully removed from the sieve and transferred to a tray. The tray is kept in an oven which is maintained at about 110 deg. C. The wet mat is thus dried until its moisture content is about 3 percent.

(b) Dry Process

On a commercial scale dry fibre mats can be made by employing machines meant to produce non-woven fabrics. In the absence of such a machine, in the laboratory, a simple method was adopted to make the dry mat by hand. The bio-fibres, glass or other synthetic fibres of composition mentioned earlier are spread out uniformly by hand taking care that the fibre distribution is as uniform as possible.

(c) Defibration Process for Making the Fibre Mat

For making bio-fibre mat from defibrated fibres where bio-fibres in the raw state are bulky, said bio-fibres are made to go through a defibration process and in this instance a Kraft Pulping Method process is employed in order to achieve a certain degree of compactness. This process can also remove lignin which is a strong absorber of UV radiation which can compete with the photo-initiator for the UV light. Removal of lignin can be carried out by employing paper pulping technique.

The following preferable conditions were used for pulping in that amount of active alkali is between 13 to 21 % ; sulfidity is between 16 to 34 %;

at temperature between 160° C to 178° C and reaction time between 94 to 135 minutes.

Preparation of matrix resin

In the meanwhile matrix resin is prepared separately as follows: To about 125 g of unsaturated polyester (or vinyl ester) is added 0.5% - 4 % of photo-initiator selected from the following types comprises of benzoin ether, benzyl ketals, hydroxy alkyl phenones, amino alkyl phenone or bis acylphosphine oxide or a mixture of these compounds and mixed well.

Process of producing bio-fibre matrix composite

The dry bio-fibre mat as prepared by the procedure outlined above (from the wet process, the dry process or defibration process) is impregnated with the 'matrix resin' by placing the dry bio-fibre or hybrid fibre mat on a polyester film. The matrix resin is carefully poured onto the surface of the mat such that entire area of the mat is covered by the resin. Another polyethylene film is placed over the resin soaked mat or in other words reinforced mat, thus said reinforcing mat is sandwiched between two layers of polyester films. To further enforce the penetration of the resin within the bio-fibre mat, carefully apply a uniform pressure onto the bio-fibre mat using a steel roller to remove air bubbles from said mat. The reinforced mat together with the polyester films is placed into a metal frame or enclosure and securely kept in position. The enclosure is then placed on a conveyor belt and made to passed through UV irradiator. The reinforced or impregnated mat is thus exposed to the UV/Solar radiation where the matrix resin undergoes polymerization under these conditions and is transformed into a thermosetting plastic. It requires about ten to fifteen passes (about 1 to 2 minutes) for a complete cure of the composite. After the cure, the enclosure is removed from the conveyor belt and cured bio-fibre matrix composite is removed from the metal enclosure and the polyester films are then removed from the cured composite. The process flow chart is given in Fig 1.

The physical and mechanical properties of the composites made from the bio-fibres and bio-fibre synthetic fibre composites are given in Table 1 (Experimental Data on HYBRID COMPOSITES) and those made from defibrated rubber wood are given in Table 2 (Mechanical and Physical Properties of Defibrated Rubber Wood Fibre Composites) and effect of mechanical and physical properties of defibrated rubber wood fibre composites on % photoinitiator are given in Table 3 (Effect of Mechanical and Physical Properties of Defibrated Rubber Wood Fibre Composites on % Photoinitiator).

Investigation were carried out to develop composites based on bio-fibres and hybrid combination with other synthetic fibres making use of ultra violet radiation. Composite boards of size 20 cm x 20 cm and thickness of approximately 2 mm were made. Mixture experiment namely Simplex-lattice Design were conducted in order to establish the functional relationship between the compositional variables (glass fiber %, biofiber % and nylon fiber %) and mechanical properties of composites made thereof. From this experiment, the effect of the individual fibers on the properties could be evaluated. The basic phenomena influencing the process of making the composites and the role of individual fibres in controlling these properties were identified. Optimization of the composites for obtaining composites with a compromise of overall properties was determined. Several possible selections were obtained from which to choose the desire of the hybrid reinforcements to produce composites with the most desirable combinations properties.

It should be understood that various changes, adaptations and modification may be made thereto without departing from the spirit of the invention and the scope of the claim. It should be understood, therefore, that the invention is not limited to details of the illustrated innovation shown in the figures and that it may include variations as will be apparent to one skilled in the art.

What is claimed is:

1. A method of producing bio-fibre composite comprising the steps of
   - (a) sandwiching reinforced bio-fibre mat between two layers of polyester films;
   - (b) irradiating said reinforced bio-fibre mat for substantially few minutes.

2. A method of producing bio-fibre composite as claimed in claim 1 in

that pressure is preferably being applied onto the sandwiched reinforced bio-fibre mat to remove air bubbles within said reinforced bio-fibre mat.

Solar radiation)

3. A method of producing bio-fibre composite as claimed in claim 1 in that sources of iridiation includes UV radiation, gamma radiation and such like.

4. A method of producing bio-fibre composite as claimed in claim 1 in that the treated bio-fibre mat is made by soaking said bio-fibre mat with matrix resin.

5. A method of producing bio-fibre mat as claimed in claim 2 comprising the steps of
   (a) dicing appropriate lengths of fibres, said fibres includes natural fibre and/or inorganic fibre and/or organic fibre and/or synthetic fibre;
   (b) mixing uniformly into fibre blend;
   (c) dispensing fibre blend into water and stirring well forming fibre mixture;
   (d) spreading evenly fibre mixture into mat form;
   (e) sieving said mat formed fibre mixture;
   (f) drying said fibre mat to substantially 3% moisture content.

6. A method of producing bio-fibre mat as claimed in claim 2 comprising the steps of
   (a) dicing appropriate lengths of fibres, said fibres includes natural fibre and/or inorganic fibre and/or organic fibre and/or synthetic fibre;
   (b) mixing uniformly into fibre blend;
   (c) dispensing fibre blend into water and stirring well forming fibre mixture;
   (d) spreading evenly fibre mixture into mat form;
   (e) drying said fibre mat to substantially 3% moisture content.

7. A method of producing bio-fibre mat as claimed in claim 2 by Kraft Pulping Method where lengths of natural fibre mixed with amount of substantially 13% to 21 % of active alkali substantially 16% to 34% sulfidity at temperature substantially 160 deg C to 178 deg C for a duration of substantially 94 to 135 minutes.

8. **A method of producing matrix resin as claimed in claim 4 by mixing substantially 0.5% to 4% of photo-initiator with substantially 125 g of** unsaturated polyester (or vinyl ester), said photo-initiator selected from either one of benzoin ether, benzyl ketals, hydroxy alkyl phenones, amino alkyl or bis acylphosphine oxide or a mixture of these compounds.

9. A natural fibre as claimed in claim 5 or claim 6 or claim 7 is palm fibres.

10. A natural fibre as claimed in claim 5 or claim 6 or claim 7 is rubberwood.

11. A bio-fibre matrix composite product being made by a method as claimed in claim 1.

Abstract

BIO-FIBRE COMPOSITES

There is disclosed a novel process of producing a bio-fibre composite by a method of iridiation where bio-fibre soaked in resin being iridiated with UV radiation.

(The most illustrative figure is Fig. 1)

Table 1

Run	Factor A:OPEFB	Factor B:GLASS	Factor C: NYLON	DENSITY g/cm³	WATER ABSORPTN %	IMPACT STRENGTH kJ/m²	TENSILE STRENGTH N/mm²	M.O.R N/mm²	GEL CONTENT %
1.	0.00	0.00	1.00	1.09	1.36	11.21	27.3	60.62	100
2.	1.00	0.00	0.00	1.15	2.36	4.4	38.42	47.15	100
3.	0.00	0.00	1.00	1.08	1.50	13.3	22.2	63.4	99
4.	0.00	0.67	0.33	1.18	1.09	17.1	48.3	70.9	100
5.	0.67	0.33	0.00	1.12	2.49	8.7	29.7	42.85	97
6.	0.00	1.00	0.00	1.24	4.95	18.14	37.83	100.95	100
7.	0.33	0.33	0.33	1.19	2.05	13.4	25.8	55	96
8.	0.67	0.17	0.17	1.12	2.62	12.2	21.25	62.37	95
9.	0.67	0.00	0.33	1.14	2.43	7.8	13.73	46.47	99
10.	0.33	0.00	0.67	1.13	1.77	17.54	24.2	58.41	97
11.	0.17	0.17	0.67	1.16	1.54	15.77	25.81	63.14	97.8
12	0.33	0.33	0.33	1.15	1.82	9.82	25.74	57.93	97.56
13.	0.00	1.00	0.00	1.24	1.11	17.97	53.8	104.5	100
14.	1.00	0.00	0.00	1.16	2.58	5.83	17.51	47.19	98
15.	0.17	0.67	0.17	1.2	1.51	14.4	35.3	88.5	97.6
16.	0.33	0.67	0.00	1.21	1.73	8.15	38.83	73.47	100
17.	0.00	0.33	0.67	1.14	1.31	12.82	30.4	74.65	99

Table 2:

No	% Active alkali	% sulfidity	Temp °C	Time min	Kappa No.	Density g/cm³	Impact Strength kJ/m²	Tensile Strength MPa	Flexural Strength MPa	Water Absorptn %
1	15.5	30.0	175	135	25.00	1.18	6.17	33.9	104.41	0.98
2	20.5	20.0	165	135	21.9	1.19	5.58	56.9	98.66	0.83
3	15.5	30.0	165	135	37.4	1.20	5.38	28.9	100.08	0.99
4	15.5	20.0	165	105	36.0	1.17	4.97	21.7	52.13	0.99
5	18.0	25.0	170.0	120	22.5	1.18	4.21	23.9	53.04	0.99

Table 3

No.	% Photoinitiator	Density, g/cm³	Impact Strenght, kJ/m²	Tensile Strength, MPa	Flexural Strength, MPa	Water Absorption, %
1	1.5	1.19	3.87	43.8	97.00	0.92
2	2.0	1.18	4.27	45.6	105.39	0.98
3	2.5	1.19	5.33	46.4	112.01	0.97
4	3.0	1.19	5.58	56.9	98.66	0.93
5	3.5	1.18	4.93	49.6	94.72	0.92
6	4.0	1.38	6.10	47.0	104.09	0.97

FIG. 1