

“REINFORCED COMPOSITE MATERIAL”

5 FIELD OF THE INVENTION

The present invention relates to reinforced composite materials, and in particular to fibre reinforced polymer composites. However, it will be appreciated that the invention is not limited to this particular field of use.

10 BACKGROUND OF THE INVENTION

Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of the common general knowledge in the field.

Fibre reinforced polymer composites are known in the art and are commonly
15 made by reacting a curable resin with a reactive diluent in the presence of a free radical initiator. Typically, the curable resin is an unsaturated polyester resin and the reactive diluent is a vinyl monomer. Reinforcing materials such as glass fibre are often included in the formulations to provide dimensional stability and toughness. Such reinforced composites are used in many key industrial applications, including: construction,
20 automotive, aerospace, marine and for corrosion resistant products.

For traditional glass fibre reinforced polymer composites, the fibre lengths typically range from about 12 mm up to tens of metres in the case of, for example, filament winding. In these glass fibre polymer composites the majority of fibres are held in position by mechanical friction and there is only relatively weak bonding of the fibres
25 to the resin matrix. Therefore, the performance of such polymer composites is largely due to the length of the fibres employed and in these composites there is a discontinuity/gap between the fibres and the resin. Cracks initiated in the resin matrix find it very difficult to jump gaps, therefore in these composites cracks initiated in the

resin are usually arrested at the resin boundary and do not reach the glass surface.

However, traditional glass fibre composites have a number of shortcomings. For example, it is difficult to “wet” the fibres with the resin prior to curing, and even dispersion of long fibres throughout the composite is difficult, especially for complex parts.

In addition, such traditional glass reinforced polymer composites are limited by their production techniques which generally require manual layering or are extremely limited in the shape and complexity of the moulds.

To overcome these shortcomings, very short glass fibres may be used. VSFPLCs or very short fibre polymerisable liquid composites can produce laminate with tensile strengths greater than 80 MPa flexural strength greater than 130 MPa. VSFPLCs are suspension of very short surface treated reinforcing fibres and polymerisable resins/thermoset such as UP resins vinyl functional resins, epoxy resins or polyurethane resins. The length of the fibres are kept very short so that they do not increase the viscosity of the liquid to where the resin fibre mixture is no longer sprayable or pumpable. VSFPLCs can be used to replace standard fibre glass layouts in open and closed moulding applications and also can be used as alternatives to thermoplastics in resin injection moulding and rotation moulding applications.

However, an improvement in the fibre-to-matrix bond is typically required since such very short glass fibres are too short to be mechanically “keyed” into the matrix.

Coating the reinforcing fibre with a coupling agent may provide an improvement in the fibre-to-matrix bond. For example, one commonly used coupling agent is Dow Corning Z-6030, which is a bifunctional silane containing a methacrylate reactive organic group and 3 methoxysilyl groups. Dow Corning Z-6030 reacts with organic thermoset resins as well as inorganic minerals such as the glass fibre. Whilst such coupling agents may

improve the fibre-to-matrix bond, the usefulness of the reinforced polymer composite is limited since they are prone to embrittlement over time. A product with greater flexibility and toughness is sometimes needed.

An attempt was made to address some of these shortcomings in PCT Patent Application No. PCT/AU01/01484 (International Publication No. WO 02/40577) where the coupling agent was pre-polymerised prior to coating the glass reinforcing fibre to “plasticise the interface”. The intention of the pre-polymerised coupling agent was to provide a rubbery interphase between the fibre and the bulk resin and thereby result in product having improved impact resistance and strength. However, long-term embrittlement is still an issue with the above PCT. In Very Short Fibre Polymerisable Liquid Composites there are no air gaps between the fibre and the resin. In VSFPLCs the resin is chemically bonded to the resin matrix and there are no gaps between the resin and the fibres. Cracks initiated in the resin matrix travel directly to the fibre surface. All the energy of the propagating crack is focused at a point on the glass fibre, and the energy is sufficient to rupture the fibre. Abundant evidence for this can be seen on the fracture surface of silane treated fibres. This is especially true for laminates with flexural strengths greater than 100 MPa.

It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the abovementioned prior art, or to provide a useful alternative.

DISCLOSURE OF THE INVENTION

According to a first aspect the present invention provides a method for producing a reinforced composite material, comprising: combining at least one curable resin and a plurality of reinforcing fibres; and curing the at least one curable resin, the cured resin adjacent the reinforcing fibres defining an interphase, wherein the reinforcing fibres are

treated such that the properties of the interphase are substantially equivalent to those of the bulk cured resin.

In a preferred embodiment the reinforcing fibres are glass fibres having a coupling agent coupled thereto. The glass fibres may be chosen from E-, S- or C-class
5 glass. The glass fibre length is typically between about 100 and 1000 microns and the fibres are preferably evenly dispersed through the resin. The coupling agent comprises a plurality of molecules, each having a first end adapted to bond to the glass fibre and a second end adapted to bond to the resin when cured. Preferably the coupling agent is Dow Corning Z-6030. However, other coupling agents may be used such as Dow
10 Corning Z-6032, and Z-6075. Similar coupling agents are available from De Gussa and Crompton Specialties.

The properties of the interphase which are substantially equivalent to those of the bulk resin may be mechanical properties selected from the group consisting of strength, toughness, and brittleness. Alternatively, or additionally, the properties may be physical
15 or chemical properties selected from the group consisting of density, cross-link density, molecular weight, chemical resistance and degree of crystallinity.

The curable resin(s) preferably includes a polymer and is chosen to have predetermined properties including from one or more of improved tear resistance, strength, toughness, and resistance to embrittlement. Preferably the resin is chosen such
20 that in its cured state it has a flexural toughness greater than 3 Joules according to a standard flexure test for a test piece having dimensions about 100 mm length, 15 mm width and 5mm depth. Ideally the cured resin having the polymer has a flexural toughness greater than 3 Joules up to 5 years following production.

In preferred embodiments the cured resin is resistant to crack propagation. A
25 preferred cured resin is able to supply fibrils in enough quantity and with enough

inherent tensile strength to stabilise the craze zone ahead of the crack, limiting or preventing the propagation of a crack. Ideally the polymer-modified curable resin arrests the crack before it can reach the surface of the glass fibre, or if the craze ahead of the crack reaches the glass it has insufficient energy to rupture the glass fibre surface.

5 Such toughened resins are ideally suited to very short fibre reinforced composites. In addition, such resins provide reduced embrittlement with age. NOTE: The very surface of the glass fibre is nowhere near the strength of the fibre itself due to vastly different cooling rates between the surface of the glass fibre and the body of the glass fibre. This surface is very easily ruptured. To illustrate this one has only to look at the process for
10 making "glue-chipped" decorative glass panels.

The treatment applied to the fibres is preferably a treatment that reduces catalysation of resin polymerisation in the interphase. In one embodiment the treatment applied to the reinforcing fibres is the application of a polymeric coating. Preferably the polymer of the polymeric coating is a monomer deficient (less than about 33% w/w
15 monomer) low activity unsaturated polyester resin having only a relatively moderate amount of unsaturation. Desirably the unsaturated polyester resin is formulated to be substantially hydrophilic.

In another embodiment, the treatment applied to the reinforcing fibres is the application of a hydrophilic surface coating. Reacting the coupling agent (coating the
20 glass fibre) with a hydrophilic agent provides the hydrophilic surface coating. In a preferred aspect the hydrophilic agent is provided by reacting Dow Corning Z-6030 with a tri-hydroxy compound, such as trimetholylpropane, or a tetra-hydroxy compound, such as pentaerythritol in the presence of a catalyst, such as tri-butyl tin. The glass
25 reinforcing fibre is sufficiently coated with the hydrophilic surface coating such that the modified fibre is substantially hydrophilic.

In a further aspect of the hydrophilic surface coating embodiment, the treated glass fibre is further treated with an emulsion. The treatment may simply be mixing, however compounding is preferred. The emulsion preferably comprises:

16.6 parts water;

5 100 parts acetone; and

200 parts polymer,

Optionally the emulsion comprises free radical inhibitors, which generally include hydroquinone (HQ) or hindered amines. The polymer may be a vinyl ester resin, however the polymers referred to above are preferred. In particular, the polymer is a
10 monomer deficient (less than about 33% w/w monomer) low activity unsaturated polyester resin having only a relatively moderate amount of unsaturation. Desirably the unsaturated polyester resin is formulated to be substantially hydrophilic.

In a further embodiment the treatment applied to the reinforcing fibres is the application of a coating of a free radical inhibitor, such as hydroquinone acetyl acetone,
15 hindered phenols or hindered amines. In yet a further embodiment the treatment applied to the reinforcing fibres is the reduction in the total surface area of the reinforcing fibres.

As discussed above, very short fibre polymerisable liquid composites typically require the use of coupling agents to improve the fibre-to-matrix bond since the fibres are too short to mechanically key into the matrix. The present applicants have found that
20 use of such coupling agents tends to cause embrittlement of the reinforced composite material over time. Others have attempted to mitigate such embrittlement by using a blend of resins whereby at least one of the resins is "rubbery". Other alternatives have been to modify the coupling agent to provide a "rubbery" phase surrounding the fibre, such as disclosed in WO 02/40577. The present invention takes an entirely different
25 approach.

Without wishing to be bound by theory, it is believed that prior art coupling agents coated to the glass fibre act to catalyse resin polymerisation in the interphase, ie the region directly adjacent the glass fibre, thereby forming a brittle interphase over time. The approach of the present invention is to chemically "passivate" the coupling agent coating, thereby attempting to mitigate any effects which the coupling agent may have on the fibre-resin interphase, and enabling the interphase to have substantially equivalent properties to those of the bulk cured resin. However, as the skilled person will appreciate, the degree of passivation should be sufficient to mitigate any effects which the coupling agent may have on the fibre-resin interphase whilst still achieving sufficient bonding of the fibre to the bulk resin.

The applicants have found that the present invention, which is entirely contradictory to the prior art, somewhat surprisingly provides a reinforced composite material which exhibits relatively reduced embrittlement as compared to prior art glass reinforced composite materials whilst retaining properties such as strength, toughness and heat distortion temperature. In particular, the long-term embrittlement issue of prior art composites employing coupled fibres is notably reduced.

According to a second aspect the present invention provides a reinforced composite material comprising: at least one cured resin having a plurality of reinforcing fibres, the cured resin adjacent the reinforcing fibres defining an interphase, the interphase having properties substantially equivalent to those of the bulk cured resin.

According to a third aspect the present invention provides a method for treating a reinforcing fibre for use in a composite material including a curable resin, the method comprising the step of applying one or more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor to the reinforcing fibre such that,

in use, the cured resin adjacent the reinforcing fibre defines an interphase, the interphase having properties substantially equivalent to those of the bulk cured resin.

According to a fourth aspect the present invention provides a reinforcing fibre for use in a composite material including a curable resin, the reinforcing fibre having one or
5 more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor applied thereto such that, in use, the cured resin adjacent the reinforcing fibre defines an interphase, the interphase having properties substantially equivalent to those of the bulk cured resin.

According to a fifth aspect the present invention provides a method for reducing
10 embrittlement in a composite material having a curable resin and a plurality of reinforcing fibres dispersed therethrough, the cured resin adjacent the reinforcing fibres defining an interphase, the method comprising the step of reducing the total surface area of the reinforcing fibres thereby providing a corresponding decrease in the quantity of the interphase.

15 According to a sixth aspect the present invention provides a moulded composite body according to the first aspect of the invention.

According to a seventh aspect the present invention provides a treated reinforcing fibre according to the third aspect of the invention.

According to a eighth aspect the present invention provides a method for
20 moulding a composite comprising the steps of providing a mixture of at least one curable resin and a plurality of reinforcing fibres according to the fourth aspect, applying the mixture to a mould and curing the at least one curable resin.

According to a ninth aspect the present invention provides a moulded composite material when produced by the method according to the eighth aspect.

According to a tenth aspect the present invention provides a liquid curable composite comprising at least one curable resin and a plurality of reinforcing fibres such that, in use, the cured resin adjacent said reinforcing fibres defines an interphase, wherein said reinforcing fibres are treated such that the properties of said interphase are

5 substantially equivalent to those of the bulk cured resin.

According to an eleventh aspect the present invention provides a liquid curable composite comprising at least one curable resin and a plurality of reinforcing fibres, said reinforcing fibres having one or more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor applied thereto such that, when cured, the

10 cured resin adjacent said reinforcing fibre defines an interphase, said interphase having properties substantially equivalent to those of the bulk cured resin.

Unless the context clearly requires otherwise, throughout the description and the claims, the words 'comprise', 'comprising', and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the

15 sense of "including, but not limited to".

Other than in the examples, or where otherwise indicated, all numbers expressing quantities of ingredients or reaction conditions used herein are to be understood as modified in all instances by the term "about". The examples are not intended to limit the scope of the invention. In what follows, or where otherwise indicated, "%" will mean

20 "weight %", "ratio" will mean "weight ratio" and "parts" will mean "weight parts".

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set out below. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments of the invention only and is not intended to be limiting.

Throughout this specification the terms “fibre” and “fibres” are to be taken to include platelet and platelets respectively. Glass fibres are the most suitable fibres for the invention. However other mineral fibres such as wollastonite and ceramic fibres may also be used without departing from the scope of the invention

5 Throughout this specification the terms “property” and “properties” are to be taken to include typical mechanical, physical and chemical properties of polymers and cured resins. For example, mechanical properties are those selected from the group consisting of flexural and/or tensile strength, toughness, elasticity, plasticity, ductility, brittleness and impact resistance. Chemical and physical properties are those selected
10 from the group consisting of density, hardness, cross-link density, molecular weight, chemical resistance and degree of crystallinity.

Throughout this specification the terms “catalyse” and “catalysation” are to be taken to be synonymous with the terms “initiate” and “initiation” in relation to free radical polymerization.

15 It will also be understood that the term “material” in the present application refers to liquid and solid forms of the fibre/resin mixture. The material itself can be provided in cured form, uncured liquid form or as a separate component e.g. reinforcing fibres and resin separately for mixing on site.

20 BEST MODE FOR CARRYING OUT THE INVENTION

The present invention provides a method for producing a reinforced composite material and the composite body produced by the method. The method comprises the steps of combining at least one curable resin with a plurality of reinforcing fibres such that the fibres are substantially evenly dispersed throughout the resin, and curing the
25 resin. Preferably the resin is a vinyl ester resin having about 40% of a reactive diluent,

such as styrene monomer. However, other monomers may also be used, such as mono- and di- and tri-functional acrylates and methacrylates. Alternatively, the resin may be chosen from unsaturated polyester resins, epoxy vinyl ester resins, vinyl function resins, tough vinyl functional urethane resins, tough vinyl functional acrylic resins, and non-
5 plasticised flexible polyester resins, and combinations thereof.

In preferred embodiments, the fibres are glass fibres chosen from E-, S- and C-class glass having a length of between about 100 and 1000 microns. However, fibres having lengths greater than 1000 microns can also be used. Preferably any sizing agent is removed from the glass fibre prior to its treatment with the coupling agent(s). The
10 preferred coupling agent is Dow Corning Z-6030. However, other coupling agents may be used such as Dow Corning Z-6032 and Z-6075.

The, at least one curable resin may include a polymer, is chosen or modified with such a polymer to have predetermined properties chosen from one or more of improved tear resistance, strength, toughness, and resistance to embrittlement. Preferably the
15 polymer-modified cured resin has a flexural toughness greater than 3 Joules for up to 5 years following production for a test piece having dimensions about 110 mm length, 15 mm width and 5 mm depth subjected to a standard flexure test.

In preferred embodiments the polymer-modified curable resin is resistant to crack propagation. Such polymer-modified resins provide reduced embrittlement with
20 age. Preferably the polymer is a monomer deficient (less than about 30% w/w monomer) low activity unsaturated polyester resin having only a relatively moderate amount of unsaturation. Examples of such polyesters are provided in the tables below. Desirably these polyesters are hydrophilic.

Once the resin is cured to provide the reinforced composite material, the cured
25 resin adjacent and substantially surrounding each of the glass reinforcing fibres defines

an interphase, and the reinforcing fibres are treated prior to their addition to the curable resin such that the properties of the interphase are substantially equivalent to those of the bulk cured resin. In one embodiment, the treatment applied to the fibres is a polymeric coating. The polymer of the polymeric coating is preferably the low activity unsaturated polyester resin described above.

As discussed above, without wishing to be bound by theory the applicant believes that a fibre treated with prior art coupling agents acts to catalyse resin polymerisation thereby forming an interphase having substantially different properties to the bulk cured resin. An interphase having highly cross-linked material will have properties vastly different to those of the bulk resin, thereby affecting the mechanical and physical properties of the final cured reinforced composite body. For example, an interphase having highly cross-linked material is inherently more brittle than the bulk resin. During fracture, a propagating crack will relatively easily rupture this brittle interphase and any crack-arresting properties of the resin in the interphase will substantially reduced. Further, as the skilled person will appreciate, the more fibre employed in the composite body the greater the total amount of brittle interphase will result, and the more brittle the composite body will become.

By treating the coupled glass fibre to reduce catalysation of free radical polymerisation, the applicants have been able to reduce the effect of the coupled glass fibre on the interphase such that the interphase has similar properties to the bulk cured resin. In other embodiments, the surface of the glass fibre is treated with a coating of one or more free radical inhibitors, such as hydroquinone or acetyl acetone, hindered phenols and hindered amines. The coating of free radical inhibitor(s) is associated with the surface of the glass fibre such that catalyzation of resin polymerisation in the interphase is reduced and the interphase has similar properties to the bulk cured resin.

In a further embodiment, the treatment is a reduction in the total surface area of the fibres. For example, this may be achieved by substituting the glass fibre with a glass fibre having a relatively larger diameter. To explain, glass fibres typically used in glass fibre reinforced composites have diameters between about 5-12 microns. However, the
5 applicants have discovered that use of glass fibres having diameters between about 15-24 microns provides significantly less embrittlement to the final properties of the reinforced composite body, since for a given weight of glass fibre the total surface area is inversely proportional to the increase in fibre diameter. Of course even larger diameter fibres can be used than 24 micron, however, there is a practical working limit
10 of the fibre properties.

In this embodiment, whilst the glass surface still may catalyse resin polymerisation to produce a brittle interphase, the total amount of brittle interphase material is relatively reduced. In addition, to provide a final cured polymer composite with similar mechanical properties, the length of relatively larger diameter glass fibre
15 used is preferably longer than that which would ordinarily be employed for the relatively smaller diameter fibre.

As the skilled person would be aware, combinations of the above-described embodiments may also be employed where appropriate. For example, it would be possible to use glass fibres having a relatively larger diameter and coat the fibre with a
20 free radical inhibitor, or coat the fibre with a polymer as described above.

In further embodiments, the treatment comprises a two-step process whereby the glass fibre is firstly coated with a first agent and then a second agent is reacted with the first agent to provide a substantially hydrophilic surface-modified glass fibre. Preferably the first agent is a coupling agent having a first end adapted to bond to the fibre, and a
25 second end adapted to bond either to the second agent or the resin when cured. In a

preferred embodiment, the coupling agent is methacryloxypropyltrimethoxysilane (Dow Corning Z-6030). The second agent comprises the reaction product between the first agent and a tri-hydroxy compound such as trimetholypropane. However, in alternative
5 embodiments the hydroxy compound is a tetra-hydroxy compound such as
pentaerythritol. The reaction of Z-6030 and trimetholypropane is conducted in the
presence of a tin catalyst, such as tri-butyl tin, under appropriate reaction conditions.

The method of treating the glass fibre according to the previous embodiment
further includes the step of mixing or compounding the coated reinforcing fibre with an
emulsion. The emulsion preferably comprises: 16.6 parts water, 100 parts acetone and
10 200 parts polymer, wherein the polymer is preferably the hydrophilic low activity
unsaturated polyester resin discussed above. The emulsion may also include a
hydrophilic free radical inhibitor such as HQ.

EXAMPLES

15 The present invention will now be described with reference to the following
examples which should be considered in all respects as illustrative and non-restrictive.

Treatment of a glass fibre with a hydrophilic surface coating

1. E-glass fibres were cut to an average fibre length of 3400 micron and then milled
to an average length of 700 micron.
- 20 2. The milled glass fibres were cleaned using boiling water, with a strong detergent
and with powerful agitation. The detergent was then rinsed from the fibres.
3. 1% w/w of methacryloxypropyltrimethoxysilane (Dow Z-6030) was
suspended in water at pH 4 and the fibres added to the suspension. The resulting
mixture was stirred vigorously at room temperature for 60 minutes.

4. The liquid was then drained from the glass fibres, leaving them still wet with the mixture.
5. The Z-6030-treated fibres were then redispersed in water at a pH of 7.
6. Separately, a solution of Z-6030 was reacted with trimetholypropane (TMP) in
5 the presence of a tin catalyst (eg tributyl tin) for 15-20 minutes at 110-120 °C to form a Z-6030-TMP adduct having a viscosity of about 1200-1500 cP. Methanol is evolved during the reaction.
7. The Z-6030 treated fibres were then reacted with the Z-6030-TMP adduct to provide a hydrophilic treated fibre. This was achieved by dispersing the Z-6030
10 treated fibres in water and adding the Z-6030-TMP adduct to the water at a concentration of about 2-3 wt% of fibres. The mixture was stirred together for approximately 10 minutes. The fibres were then separated and then centrifuged to remove excess water. The "wet" fibres were then dried, initially at 30 °C for 3-4 hours, and then heated to between 110 and 125 °C for 5-7 minutes.
- 15 8. Separately, an emulsion of polymer was prepared having 200 parts polymers, 100 parts acetone and 16.6 parts water. Preferably the polymer is a hydrophilic resin such as an unsaturated polyester.
9. The hydrophilic treated fibres were then compounded with the emulsified resin until evenly distributed in the rations of about 93 w/w% fibres and 7 w/w%
20 emulsion.
10. The compounded fibre-emulsion mixture was then added to the base resin at approximately 10-45% fibre-emulsion to 90-55% resin.

Table 1 provides flexural strength data for cured clear casts of the commercially available Derakane epoxy vinyl ester resin 411-350 (Ashland Chemicals). These test
25 panels were prepared according to the manufacturers specifications and the resulted in

flexural modulus averages about 3.1 GPa, the flexural stress at yield averages about 120 MPa, and the elongation at break averages between about 5 to 6%.

- Table 2 shows similar test panels to those of Table 1 but having been thermally aged. Panels are thermally aged by heat treatment at 108 °C for two hours followed by
- 5 controlled cooling to below 40 °C over about 2 hours. As can be seen, within experimental error, the flexural modulus and flexural stress are about the same post aging. However, the elongation at break has approximately halved, meaning that the panels have substantially embrittled with accelerated aging.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 1	2.98	112	4.9
Test Panel 2	3.12	119	5.7
Test Panel 3	3.11	123	5.6
Test Panel 4	3.28	132	6.0

Table 1: Flexural strength data for cured (un-aged) clear casts of Derakane 411-350

- 10 Epoxy Vinyl Ester Resin.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 5	3.30	117	3.0
Test Panel 6	3.40	121	3.1
Test Panel 7	3.10	131	4.1
Test Panel 8	3.20	123	3.6
Test Panel 9	3.20	127	4.2

Table 2: Flexural strength data for aged clear casts of Derakane 411-350 Epoxy Vinyl Ester Resin.

Table 3 provides flexural strength data for aged cured clear casts of Derakane epoxy vinyl ester resin with various polymer additions (discussed below). As can be seen, the resulting flexural modulus averages about 3.3 GPa, the flexural stress at yield averages about 135 MPa, and the elongation at break averages between about 5 to 7%.

- 5 Comparing the elongation data between Tables 2 and 3 it can be seen that the various polymer additions have substantially reduced aged embrittlement.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 10 + polymer 1	3.20	132	6.7
Test Panel 11 + polymer 2	3.20	131	4.9
Test Panel 12 + polymer 3	3.30	136	5.7
Test Panel 13 + polymer 4	3.50	140	6.0
Test Panel 14 + polymer 5	3.60	146	6.6

Table 3: Flexural strength data for aged clear casts of Derakane 411-350 Epoxy Vinyl Ester Resin having 12-15 wt% of a polymer additive.

- 10 The polymers provided in the tables are the condensation products of a polyol and a diacid. The polyol's and diacid's comprising each polymer are provided in Table 4. These polyesters are generally prepared by heating approximately equimolar amounts of diol and acid at temperatures in excess of about 200 °C for periods of about 4 to about 12 hours. Most of the unsaturation is present as fumarate diester groups. These
- 15 polyesters have acid numbers in the range of from about 15 to about 25. (The acid number is the milligrams of potassium hydroxide needed to neutralize one gram of sample).

A 3-liter, round-bottomed flask equipped with a paddle stirrer, thermometer, an inert gas inlet and outlet and an electric heating mantle. The esterification reactions were conducted in 2 stages. The first stage was reacting the saturated acids in excess glycol, and the second stage was carried out with the addition of the unsaturated acids and remaining glycols. The reactor vessel was weighed between the stages and glycols were added if needed to compensate for any losses. The mixture was heated to between 150 and 170 °C such that water was liberated and the condenser inlet temperature was greater than 95 °C.

During the next 2-3 hours the temperature of the mixture was raised to 240 °C. The mixture was then cooled to 105 °C and blended with inhibited styrene. The final polyester resin contained 80 percent by weight of the unsaturated polyester and 20 percent styrene.

Polymer	polyol	diacid	ratio of saturated to unsaturated acids
Polymer 1	propylene glycol 4 moles, MP-diol 1.5 moles	terephthalic acid 2 moles, isophthalic acid 1 mole, fumaric acid 2 moles	3:2
Polymer 2	diethylene glycol 5.5 moles	terephthalic acid 3 moles, fumaric acid 2 moles	3:2. Also, a 0.5M excess glycol was maintained at the commencement of the second stage
Polymer 3	diethylene glycol 6 moles, MP-diol 1.5 moles	1,4-cyclohexane diacid, fumaric acid	4:3
Polymers 4 and 7	Nuplex 316 / Terephth 50/50 blend		
Polymer 5	neopentyl glycol 6.25 moles, propylene glycol 2 moles	1,4-cyclohexane diacid 4.5 moles, fumaric acid 3 moles	3:2
Polymer 6	diethylene glycol	1,4-cyclohexane diacid 3 moles, fumaric acid 2 moles	3:2
Polymer 8	neopentyl glycol 6.25 moles, propylene glycol 1 mole	1,4-cyclohexane diacid 4 moles, fumaric acid 3 moles	4:3

Table 4: Polyesters used to modify the Derakane base resin in Tables 3 and 5.

Table 5 provides flexural strength data for Derakane epoxy vinyl ester resin having the stated ratios of resin to glass fibre (in brackets) wherein the glass fibre is treated only with the Z-6030 coupling agent.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 15 (2.3:1)	6.20	124	0.87
Test Panel 16 (2:1)	6.70	129	0.70
Test Panel 17 (1.9:1)	7.50	135	0.63
Test Panel 18 (1.7:1)	8.10	142	0.60
Test Panel 19 (1.6:1)	9.00	149	0.58

Table 5: Flexural strength data for aged Z-6030 treated glass fibres in Derakane 411-350

5 epoxy vinyl ester resin.

Table 6 shows flexural strength data for aged test panels of Derakane epoxy vinyl ester resin having about 12-15 weight % of a polymer additive as described above and 45-50 weight % of a treated glass fibre according to the present invention.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 20 + polymer 5	6.10	136	2.6
Test Panel 21 + polymer 6	6.20	133	2.2
Test Panel 22 + polymer 6	5.90	129	2.9
Test Panel 23 + polymer 7	6.00	134	3.1
Test Panel 24 + polymer 8	6.20	135	3.4

Table 6: Flexural strength data for aged Derakane 411-350 epoxy vinyl ester

10 resin having 12-15 wt% of a polymer additive and 47 wt% of treated glass fibre

according to the present invention, wherein the treatment comprises the hydrophilic surface coating and the emulsified polymer.

In the comparison of the flexural data provided in Table 5 and Table 6, it can be seen that the test panels 20-24 according to the present invention have significantly improved the elongation at break for aged panels, providing a reduction in aged embrittlement.

Table 7 provides flexural strength data for aged test panels of Derakane epoxy vinyl ester resin having the stated ratios of resin to glass fibre (in brackets) wherein the glass fibre is treated with a monomer deficient resin. Test panel 25 is uncoated and panels 26 to 28 are coated. Panels having the coated glass fibre show significantly improved toughness.

Composite	Flexural Modulus (GPa)	Flexural Stress at Yield (MPa)	Elongation at Break (%)
Test Panel 25 (2.3:1)	6.20	124	0.87
Test Panel 26 (5:1)	3.80	120	4.0
Test Panel 27 (5:1)	3.50	115	4.0
Test Panel 28 (5:1)	3.60	118	4.0

Table 7: Flexural strength data for aged test panels of Derakane 411-350 epoxy vinyl ester resin having a polymer treated glass wherein the polymer is a monomer deficient resin.

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INDUSTRIAL APPLICABILITY

The present invention is useful in a wide variety of industries, including: construction, automotive, aerospace, marine and for corrosion resistant products. The reinforced composite material of the invention provides improved long-term mechanical properties compared to traditional glass fibre reinforced materials.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

CLAIMS:

1. A method for producing a reinforced composite material, comprising: combining at least one curable resin and a plurality of reinforcing fibres; and curing said at least one curable resin, the cured resin adjacent said reinforcing fibres defining an interphase,
5 wherein said reinforcing fibres are treated such that the properties of said interphase are substantially equivalent to those of the bulk cured resin.
2. A method for treating a reinforcing fibre for use in a composite material including a curable resin, said method comprising the step of applying one or more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor
10 to said reinforcing fibre such that, in use, the cured resin adjacent said reinforcing fibre defines an interphase, said interphase having properties substantially equivalent to those of the bulk cured resin.
3. A method according to claim 1 or claim 2 including the step of coupling a coupling agent to said reinforcing fibre.
- 15 4. A method according to claim 3 wherein said coupling agent is a vinyl functional silane.
5. A method according claims 4 wherein said coupling agent is selected from the group consisting of Dow Corning Z-6030, Z-6032, and Z-6075.
6. A method according to any one of the preceding claims wherein said reinforcing
20 fibre is glass fibre.
7. A method according to claim 6 wherein the length of said glass fibre is between about 100 and 1000 microns.
8. A method according to any one of the preceding claims wherein said properties comprise mechanical properties selected from the group consisting of strength,
25 toughness, and brittleness or a combination thereof.

9. A method according to any one of the preceding claims wherein said properties comprise physical or chemical properties selected from the group consisting of density, cross-link density, chemical resistance, molecular weight and degree of crystallinity or a combination thereof.
- 5 10. A method according to any one of the preceding claims including the step of combining a polymer with said at least one curable resin to produce a polymer-modified resin.
11. A method according to claim 10 wherein said polymer is combined with said at least one curable resin at between about 5 to 50 % w/w.
- 10 12. A method according to claim 10 or claim 11 wherein said curable resin is chosen or modified with said polymer to have predetermined properties.
13. A method according to claim 12 wherein said properties are chosen from one or more of tear resistance, strength, toughness and resistance to embrittlement.
14. A method according to any one of claims 10 to 13 wherein the cured resin has
- 15 flexural toughness greater than about 3 Joules when tested in a standard flexure test, the test piece having dimensions about 100 mm in length, 15 mm in width and 5 mm in thickness.
15. A method according to claim 14 wherein the cured composite material has flexural toughness greater than 3 Joules for up to 5 years.
- 20 16. A method according to any one of claims 10 to 15 wherein said polymer is a monomer deficient low activity unsaturated polyester resin.
17. A method according to claim 16 wherein said monomer content of said polymer is between about 5 to 30 % w/w.
18. A method according to claim 16 or claim 17 wherein said unsaturated polyester
- 25 resin is provided by reacting a polyol with an acid, said polyol being chosen from the

groups consisting of propylene glycol, methyl propanediol, neopentyl glycol and diethyleneglycol, and wherein said acid is chosen from the group consisting of terephthalic acid, isophthalic acid, fumaric acid, and 1,4-cyclohexane diacid, said unsaturated polyester resin comprising a saturated to unsaturated acid ratio of between
5 about 1.2:1 to 2:1.

19. A method according to any one of the preceding claims wherein said treatment is a polymeric coating applied to said reinforcing fibres.

20. A method according to claim 19 wherein said polymer of the polymeric coating is a monomer deficient low activity unsaturated polyester resin.

10 21. A method according to any one of claims 1 to 18 wherein said treatment is a hydrophilic surface coating applied to said reinforcing fibres.

22. A method according to claim 21 wherein said hydrophilic surface coating is prepared by reacting methacryloxypropyltrimethoxysilane with trimetholypropane.

23. A method according to claim 21 or claim 22 wherein said hydrophilic surface
15 coating further includes treatment with an emulsion.

24. A method according to claim 23 wherein said emulsion comprises about 16.6 parts water, 100 parts acetone and 200 parts polymer.

25. A method according to claim 23 or claim 24 wherein said emulsion comprises free radical inhibitors.

20 26. A method according to claim 25 wherein said free radical inhibitor is hydroquinone, a hindered amine, acetyl acetone, hindered phenols, or combinations thereof.

27. A method according to any one of claims 1 to 18 wherein said treatment is a coating of a free radical inhibitor applied to said reinforcing fibres.

28. A method according to any one of claims 10 to 27 wherein the same polymer is chosen to:

- a. modify the curable resin; and/or
- b. coat the fibres; and/or

5 c. used in the preparation of the emulsion.

29. A method according to any one of claims 1 to 18 wherein said treatment is a reduction in the total surface area of said reinforcing fibres.

30. A method according to claim 29 wherein said reduction of said surface area is provided by altering the dimensions of said reinforcing fibres.

10 31. A method according to claim 30 wherein said dimensions are altered by increasing the diameter of said reinforcing fibres and/or reducing the length of said reinforcing fibres.

32. A method according to claim 31 wherein the diameter of said fibres is between about 15 to 24 microns.

15 33. A method according to any one of the preceding claims wherein the flexural modulus of the cured composite material is greater than about 3.5 GPa.

34. A method according to any one of the preceding claims wherein the flexural stress of the cured composite material is greater than about 120 MPa.

20 35. A method according to any one of the preceding claims wherein the elongation at break of the cured composite material is greater than about 2%.

36. A method according to any one of the preceding claims wherein said treatment reduces catalysation of resin polymerisation in the interphase when compared to a fibre not treated according to the present invention.

37. A method according to any one of the preceding claims wherein said treatment reduces embrittlement of said interphase when compared to a fibre not treated according to the present invention.

38. A method according to any one of the preceding claims wherein said fibre is
5 sufficiently coupled to said resin to reinforce said resin.

39. A reinforced composite material comprising: at least one cured resin having a plurality of reinforcing fibres, the cured resin adjacent said reinforcing fibres defining an interphase, said interphase having properties substantially equivalent to those of the bulk cured resin.

10 40. A reinforcing fibre for use in a composite material including a curable resin, said reinforcing fibre having one or more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor applied thereto such that, in use, the cured resin adjacent said reinforcing fibre defines an interphase, said interphase having properties substantially equivalent to those of the bulk cured resin.

15 41. A reinforced composite material according to claim 39 or a reinforcing fibre according to claim 40 wherein said reinforcing fibre has a coupling agent coupled thereto.

42. A reinforced composite material according to claim 41 or a reinforcing fibre according to claim 41 wherein said coupling agent is a vinyl functional silane.

20 43. A reinforced composite material according to claim 42 or a reinforcing fibre according to claim 42 wherein said coupling agent is selected from the group consisting of Dow Corning Z-6030, Z-6032, and Z-6075.

44. A reinforced composite material according to any one of claims 39 to 43 or a reinforcing fibre according to any one of claims 40 to 43 wherein said reinforcing fibre
25 is glass fibre.

45. A reinforced composite material according to claim 44 or a reinforcing fibre according to claim 44 wherein the length of said glass fibre is between about 100 and 1000 microns.

46. A reinforced composite material according to any one of claims 39 to 45 or a
5 reinforcing fibre according to any one of claims 40 to 45 wherein said properties comprise mechanical properties selected from the group consisting of strength, toughness, and brittleness or a combination thereof.

47. A reinforced composite material according to any one of claims 39 to 46 or a
10 reinforcing fibre according to any one of claims 40 to 46 wherein said properties further comprise physical or chemical properties selected from the group consisting of density, cross-link density, chemical resistance, molecular weight and degree of crystallinity or a combination thereof.

48. A reinforced composite material according to any one of claims 39 to 47 or a
15 reinforcing fibre according to any one of claims 40 to 47 wherein said at least one curable resin includes a polymer to produce a polymer-modified resin.

49. A reinforced composite material according to claim 48 or a reinforcing fibre according to claim 48 wherein said polymer is included at between about 5 to 50 % w/w.

50. A reinforced composite material according to claim 48 or claim 49 or a
20 reinforcing fibre according to claim 48 or claim 49 wherein said curable resin is chosen or modified with said polymer to have predetermined properties.

51. A reinforced composite material according to claim 50 or a reinforcing fibre according to claim 50 wherein said properties are chosen from one or more of tear resistance, strength, toughness and resistance to embrittlement.

52. A reinforced composite material according to any one of claims 48 to 51 or a
25 reinforcing fibre according to any one of claims 48 to 51 wherein the cured resin has

flexural toughness greater than about 3 Joules when tested in a standard flexure test, the test piece having dimensions about 100 mm in length, 15 mm in width and 5 mm in thickness.

53. A reinforced composite material according to claim 52 or a reinforcing fibre
5 according to claim 52 wherein the cured composite material has flexural toughness greater than 3 Joules for up to 5 years.

54. A reinforced composite material according to any one of claims 48 to 53 or a reinforcing fibre according to any one of claims 48 to 53 wherein said polymer is a monomer deficient low activity unsaturated polyester resin.

10 55. A reinforced composite material according to claim 54 or a reinforcing fibre according to claim 54 wherein said monomer content of said polymer is between about 5 to 30 % w/w.

56. A reinforced composite material according to claim 54 or claim 55 or a reinforcing fibre according to claim 54 or claim 55 wherein said unsaturated polyester
15 resin is provided by reacting a polyol with an acid, said polyol being chosen from the groups consisting of propylene glycol, methyl propanediol, neopentyl glycol and diethyleneglycol, and wherein said acid is chosen from the group consisting of terephthalic acid, isophthalic acid, fumaric acid, and 1,4-cyclohexane diacid, said unsaturated polyester resin comprising a saturated to unsaturated acid ratio of between
20 about 1.2:1 to 2:1.

57. A reinforced composite material according to any one of claims 39 to 56 or a reinforcing fibre according to any one of claims 40 to 56 wherein said treatment is a polymeric coating applied to said reinforcing fibres.

58. A reinforced composite material according to claim 57 or a reinforcing fibre according to claim 57 wherein said polymer of the polymeric coating is a monomer deficient low activity unsaturated polyester resin.

59. A reinforced composite material according to any one of claims 39 to 58 or a
5 reinforcing fibre according to any one of claims 40 to 58 wherein said treatment is a hydrophilic surface coating applied to said reinforcing fibres.

60. A reinforced composite material according to claim 59 or a reinforcing fibre according to claim 59 wherein said hydrophilic surface coating is prepared by reacting methacryloxypropyltrimethoxysilane with trimetholypropane.

10 61. A reinforced composite material according to claim 59 or claim 60 or a reinforcing fibre according to claim 59 or claim 60 wherein said hydrophilic surface coating further includes treatment with an emulsion.

62. A reinforced composite material according to claim 61 or a reinforcing fibre according to claim 61 wherein said emulsion comprises about 16.6 parts water, 100 parts
15 acetone and 200 parts polymer.

63. A reinforced composite material according to claim 61 or claim 62 or a reinforcing fibre according to claim 61 or claim 62 wherein said emulsion comprises free radical inhibitors.

64. A reinforced composite material according to claim 63 or a reinforcing fibre
20 according to claim 63 wherein said free radical inhibitor is hydroquinone, a hindered amine, acetyl acetone, hindered phenols or combinations thereof.

65. A reinforced composite material according to any one of claims 39 to 56 or a reinforcing fibre according to any one of claims 40 to 56 wherein said treatment is a coating of a free radical inhibitor applied to said reinforcing fibres.

66. A reinforced composite material according to any one of claims 48 to 65 or a reinforcing fibre according to any one of claims 48 to 65 wherein the same polymer is chosen to:

- a. modify the curable resin; and/or
- b. coat the fibres; and/or
- c. used in the preparation of the emulsion.

67. A reinforced composite material according to any one of claims 39 to 58 or a reinforcing fibre according to any one of claims 40 to 58 wherein said treatment is a reduction in the total surface area of said reinforcing fibres.

68. A reinforced composite material according to claim 67 or a reinforcing fibre according to claim 67 wherein said reduction of said surface area is provided by altering the dimensions of said reinforcing fibres.

69. A reinforced composite material according to claim 68 or a reinforcing fibre according to claim 68 wherein said dimensions are altered by increasing the diameter of said reinforcing fibres and/or reducing the length of said reinforcing fibres.

70. A reinforced composite material according to claim 69 or a reinforcing fibre according to claim 69 wherein the diameter of said fibres is between about 15 to 24 microns.

71. A reinforced composite material according to any one of claims 39 to 70 or a reinforcing fibre according to any one of claims 40 to 70 wherein the flexural modulus of the cured composite material is greater than about 3.5 GPa.

72. A reinforced composite material according to any one of claims 39 to 71 or a reinforcing fibre according to any one of claims 40 to 71 wherein the flexural stress of the cured composite material is greater than about 120 MPa.

73. A reinforced composite material according to any one of claims 39 to 72 or a reinforcing fibre according to any one of claims 40 to 72 wherein the elongation at break of the cured composite material is greater than about 2%.

74. A reinforced composite material according to any one of claims 39 to 73 or a reinforcing fibre according to any one of claims 40 to 73 wherein said treatment reduces catalysation of resin polymerisation in the interphase when compared to a fibre not treated according to the present invention.

75. A reinforced composite material according to any one of claims 39 to 74 or a reinforcing fibre according to any one of claims 40 to 74 wherein said treatment reduces embrittlement of said interphase when compared to a fibre not treated according to the present invention.

76. A reinforced composite material according to any one of claims 39 to 75 or a reinforcing fibre according to any one of claims 40 to 75 wherein between about 5 to 50% w/w of treated fibres are added to said resin.

77. A reinforced composite material according to any one of claims 39 to 76 or a reinforcing fibre according to any one of claims 40 to 76 wherein said fibre is sufficiently coupled to said resin to reinforce said resin.

78. A method for reducing embrittlement in a composite material having a curable resin and a plurality of reinforcing fibres dispersed therethrough, the cured resin adjacent said reinforcing fibres defining an interphase, said method comprising the step of reducing the total surface area of said reinforcing fibres thereby providing a corresponding decrease in said quantity of said interphase.

79. A method according to claim 78 wherein said reduction of said surface area is provided by altering the dimensions of said reinforcing fibres.

80. A method according to claim 79 wherein said dimensions are altered by increasing the diameter of said reinforcing fibres and/or reducing the length of said reinforcing fibres.

81. A method according to claim 80 wherein the diameter of said fibres is between
5 about 15 to 24 microns.

82. A method according to any one of claims 78 to 81 wherein said reduction in the total surface area of said reinforcing fibres reduces the total amount of catalysation of resin polymerisation in the interphase thereby relatively reducing the embrittlement of said interphase.

10 83. A method for moulding a composite material comprising the steps of providing a mixture of at least one curable resin and a plurality of reinforcing fibres produced by the method according to any one of claims 2-38, applying the mixture to a mould and curing the at least one curable resin.

84. A moulded composite material when produced by the method according to claim
15 83.

85. A liquid curable composite comprising at least one curable resin and a plurality of reinforcing fibres such that, in use, the cured resin adjacent said reinforcing fibres defines an interphase, wherein said reinforcing fibres are treated such that the properties of said interphase are substantially equivalent to those of the bulk cured resin.

20 86. A liquid curable composite comprising at least one curable resin and a plurality of reinforcing fibres, said reinforcing fibres having one or more of a polymeric coating, a hydrophilic surface coating, or a coating of a free radical inhibitor applied thereto such that, when cured, the cured resin adjacent said reinforcing fibre defines an interphase, said interphase having properties substantially equivalent to those of the bulk cured
25 resin.