

Annex B

Requirements for FRP Materials and Production

A. Definitions

1. Fibre reinforced plastics (FRP)

Heterogeneous materials, consisting of a thermosetting resin as the matrix and an embedded reinforcing material.

2. Thermosetting resin

Two-component mixture consisting of resin and hardener as well as possible additives.

3. Reinforcing materials

Materials generally in the form of fibre products which are embedded in a matrix in order to improve certain properties. In doing so, fibres of different materials displaying isotropic or anisotropic properties are processed in the form of semi-finished textile products (mats, rovings, fabrics, non-wovens). For special requirements, mixtures of different fibre materials are also used (hybrids).

4. Prepreg

Reinforcing material which is pre-impregnated with a thermosetting resin which can be processed without any further addition of resin or hardener.

5. Laminate

A moulded part which is manufactured by placing layers of reinforcing material on top of each other together with the thermosetting resin.

6. Sandwich laminate

Two laminate layers connected together by means of an intermediate core of a lighter material.

B. Materials

1. Thermosetting resin

Depending on the purpose, and consequently the requirement, a distinction is made between laminating resin and coating resin. Compatibility shall be demonstrated for the combination of gelcoat and laminating resin if the basic formulation of the resins are not the same.

1.1 Gelcoat and Topcoat resin

Gelcoat and topcoat resins shall protect the surface of the laminate from mechanical damage and environmental influences. Therefore, in a cured stage, the resin is to have a high resistance to existing media (e.g. fuel, river and sea water), to maritime and industrial environments), and to abrasion, in addition to low water absorption capabilities. Thixotropic agents and colouring pigments are the only permitted additives for gelcoat resins. In topcoat resins, additives for low styrene evaporation are also permitted.

1.2 Laminating resin

Laminating resins shall have good impregnation characteristics when being processed. In a cured stage, they shall be resistant to fuels, river and sea water, and shall exhibit a high resistance to ageing. Furthermore, adequate resistance to hydrolysis shall be ensured when used with permissible additives and filling materials. When using unsaturated polyesters (UP) as the resin, the resistance to hydrolysis shall be significantly higher than that of standard UP resin (for example through the use of a resin with an isophthalic acid basis).

1.3 Additives

1.3.1 All additives (catalysts, accelerators, filling materials, colouring pigments etc.) shall be suitable for the thermosetting resin and shall be compatible with it as well as the other additives, such that a complete curing of the resin can be ensured. The additives shall be dispersed carefully throughout the resin, in accordance with the guidelines of the manufacturer.

1.3.2 Catalysts, which initiate the hardening process, and accelerators, which control the working time (pot life, gel-time) and the cure time, shall be used in accordance with the processing guidelines provided by the manufacturer. For cold-setting systems, catalysts shall be proportioned in such a way that complete curing is ensured between temperatures of 16 °C and 25 °C. Cold-setting systems that are to cure at temperatures outside of this range, as well as warm-curing systems, may be used after consultation with GL Head Office (GL-HO).

1.3.3 Filling materials shall not significantly impair the properties of the cured resin. The type and quantity of the filling materials shall be approved by GL-HO and shall not lead to non-compliance with the mini-

imum properties of the resin. In general, the proportion of filling materials in the laminating resin compound shall not exceed 12 % by weight (including a maximum of 1,5 % by weight of the thixotropic agent). If a smaller value is specified by the manufacturer, this value shall apply. The proportion of thixotropic agent in the gelcoat resin compound shall not exceed 3 % by weight. Laminates used for fuel and water tanks shall not contain filling materials.

1.3.4 Colouring pigments shall be climate-proof and consist of inorganic or non-fading organic dyes. The maximum permissible proportion shall not exceed the value specified by the manufacturer; if no value is specified, then it shall not exceed 5 % by weight.

2. Reinforcing materials

2.1 Various types of reinforcing materials with filaments of glass, carbon and aramide are available:

Roving: A large number of parallel filaments placed together with or without twisting.

Mat: Irregular layering of continuous filaments (fleeces), or chopped rovings (minimum 50 mm long) which are joined together by means of a binder.

Fabric: Rovings woven together by means of the weaving techniques used in the textile industry, such as binding cloth, satin, body, atlas etc. Different materials and/or filament thicknesses are possible for warp and weft.

Non-woven fabric: Unidirectional layers of fibres which are laid on each other in an arbitrary manner. The layers are fixed by thin fibre strands, either together or on mats. Different materials and/or filament thicknesses are possible in the individual layers.

2.2 Fibre surface treatment with sizing, coupling agents or finish shall be matched to the thermosetting resin, in order to ensure adequate material properties, also under the influence of media.

2.3 Only low-alkaline aluminium boron silicate glass may be used for glass fibres (alkali oxide content $\leq 1\%$), e.g. E-glass in accordance with VDE 0334/Part 1, 9.72, Section 4.

3. Core materials for sandwich construction

3.1 It shall be demonstrated that the core materials used are suitable for the intended purpose. They shall not impair the curing of the laminating resin.

3.2 The joining surfaces of local reinforcements made of metallic materials (e.g. inlets, connections) shall be cleaned in the same manner as for a gluing process, in order to ensure optimal bonding (cf. DIN 53281, Part 1).

3.3 Core materials other than those listed below may be used, provided that they are suitable for the intended purpose and that this is accepted by GL-HO by beforehand.

3.4 Rigid foam materials

Rigid foam materials which are used as core material for sandwich laminates, or as shear webs, shall be of a closed-cell type and have high resistance against the laminating resin or the adhesive, as well as against ageing, fuels, river and sea water. A low water absorption capability is required, together with a minimum apparent density of 60 kg/m³.

It shall be ensured that the allowable temperature of foam material is not exceeded during the curing reaction (exothermic reaction).

3.5 End-grained balsa wood

End-grained balsa wood used as core material for sandwich laminates shall fulfil the following requirements. It shall

- have immediately been treated after felling against attack by fungi and insects,
- be sterilized and homogenized,
- be kiln-dried within 10 days after felling, and
- have an average moisture content of maximum 12 %.

4. Prepregs

Fibre reinforcements pre-impregnated with laminating resin shall satisfy the requirements placed on their components. In addition, a minimum resin volumen content of 35 % by volume shall be ensured, as well as adequate tack at the processing temperature.

5. Adhesives

5.1 When bonding fibre-reinforced plastics together, or with other materials, only solvent-free adhesives shall be used. Preference shall be given to two-component reaction adhesives, if possible with the same basis as the laminating resin.

5.2 Laminates shall only be bonded in the cured state. Hot-setting adhesives generally attain a higher strength; however, the maximum allowable temperature of the materials to be bonded shall not be exceeded. This applies especially when using single-component hot-melt adhesive.

5.3 The adhesives shall be used in accordance with the processing guidelines issued by the manufacturer. They shall not affect the materials to be bonded and shall exhibit a high resistance to humidity and ageing. The influence of the operating temperature on the adhesive strength shall be small.

5.4 Adhesives shall be usable within a minimum temperature range of -20° to $+60^{\circ}$ °C.

C. Approval of Materials

1. All materials to be used during production of components from FRP shall first be assessed and approved by GL. Approval by other organizations can be recognized following agreement by GL, provided that the tests required for approval are in accordance with GL requirements.

2. The manufacturer and/or supplier of the material shall apply to GL-HO for approval.

3. Approval is granted if the material fulfils the requirements of GL. For this purpose, specific tests are necessary, and they shall either be carried out under supervision of GL or the results shall be documented in the report of a recognized testing institute.

4. Before production starts, the required material approvals shall be submitted to GL-HO and/or the responsible GL inspection office. If no approvals, or not all required approvals have been obtained, then as an exception and following agreement with GL-HO, proof of the properties of the basic material can be demonstrated as part of material testing of the component laminate.

5. The packaging or wrapping material shall bear a reference to the approval.

D. Requirements Regarding Manufacturing Equipment

1. General

1.1 All manufacturing facilities, store-rooms and their operational equipment shall fulfil the requirements of the responsible safety authorities and professional employers liability insurance associations. The

manufacturer is exclusively responsible for compliance with these requirements.

1.2 The danger of contamination of laminating materials shall be minimized through separation of production facilities from store-rooms.

1.3 During laminating and bonding in the laminating shop, no dust-generating machinery shall be operated nor any painting or spraying operations carried out. As a matter of principle, such work shall take place in separate rooms.

2. Laminating workshops

2.1 Laminating workshops shall be closed spaces capable of being heated and having supply and exhaust ventilation. During laminating and curing, a room temperature of between 16° °C and 25° °C and a maximum relative humidity of 70 % shall be maintained, provided that the manufacturer of the laminating resin compound does not specify otherwise.

2.2 In order to control the climatic conditions, thermographs and hydrographs shall be provided. The equipment shall be set up following agreement with GL, their number and arrangement depending on operational conditions. The equipment shall be calibrated in accordance with statutory regulations. The recordings shall be kept for at least 10 years and submitted to GL on request.

2.3 Ventilation facilities shall be arranged in such a manner that no inadmissible amounts of solvents are removed from the laminate, and also that no inadmissible workplace concentrations (MAK values) occur.

2.4 The workplaces shall be illuminated adequately and suitably, but at the same time precautionary measures shall be taken to ensure that the controlled curing of the laminating resin compound is neither impaired through sunlight nor lighting equipment.

3. Storage-rooms

3.1 Laminating resins shall be stored in accordance with the manufacturer's instructions. If no such instructions are provided, then they shall be stored in dark, dry rooms at a temperature between 10° °C and 18° °C. The temperature of the storage-rooms shall be recorded continuously by means of thermographs.

3.2 Prepregs shall be stored in special cold-storage rooms in accordance with the manufacturer's instructions. The temperature in general shall not exceed -22° °C.

3.3 Hardeners, catalysts and accelerators shall be stored separately in well-ventilated rooms in accordance with the manufacturer's instructions. If no instructions are provided, they shall be stored in dark, dry rooms at temperatures between 10 °C and 18 °C.

3.4 Reinforcing materials, fillers and additives shall be stored in closed containers, in dry and dust-free conditions.

3.5 Storage shall be arranged in such a way that the identification of the materials, their storage conditions and maximum period of storage (expiry date) as prescribed by the manufacturer are clearly visible. Materials whose duration of storage exceeds the expiry date shall be removed immediately from the stores.

3.6 Quantities of materials due to be processed shall be brought to the production shops as early as possible to ensure complete adjustment to the processing temperature ($\Delta T \leq 2^\circ \text{C}$), with the containers remaining closed.

3.7 Materials taken from the stores and partially used shall only be replaced in the stores in special cases (e.g. hot-curing prepregs) and with the consent of GL.

E. Regulations for Processing

1. General

1.1 As a matter of principle, only materials approved by GL shall be used. In addition to the choice of suitable and approved materials, special care shall be taken when working with them because of the great influence on the properties of the product.

1.2 For the preparation and processing of the resin compounds and reinforcing material, these Rules, the instructions issued by the material manufacturers and the regulations of the local authorities shall also be observed.

1.3 Resin, hardener and resin additives shall be mixed in such a way as to ensure a uniform distribution and to minimize the amount of air introduced into the mixture as far as possible. A degassing of the resin compound may be necessary in individual cases.

1.4 During lamination, the processing time of the prepared resin compound specified by the manufacturer shall not be exceeded. If such a time is not specified, the pot-life shall be determined by means of a preliminary test and the processing time then established in consultation with GL.

1.5 It is not possible to cover all types of moulds and processing methods in detail. Deviations are therefore possible for special cases with the consent of GL.

2. Requirements for moulds

2.1 The moulds shall be made of a suitable material that, on the one hand, has adequate stiffness to prevent inadmissible deformations while laminating or curing, and on the other hand has no influence on the curing of the laminate. Moulds made of FRP may be used only after complete curing and subsequent tempering.

2.2 In the case of moulds for products which are made using vacuum bags, absolute air tightness of the mould shall additionally be ensured.

2.3 The surface of the moulds shall be as smooth as possible and shall have no sharp edges. The mould shall be designed in such a way as to permit flawless removal of the product from the mould.

2.4 Before commencing with the laminating, the surface of the components shall be treated with a sufficient quantity of a suitable release agent and brought up to the temperature required for lamination. The surfaces shall be dry and free of dust. It is not permissible to use release agents with a silicon base.

3. Building up the laminate

3.1 If the surface protection is to be achieved by providing a gelcoat, then the gelcoat resin compound shall be applied with a uniform thickness of between 0,4 and 0,6 mm, using a suitable process.

3.2 The first laminate layer shall be applied as soon as possible after application of the gelcoat. A fibre mat or fabric with low weight per unit area and a high resin content shall be used (e.g. for glass fibres: a maximum of 450 g/m² and a maximum of 30 % glass by weight).

3.3 The laminate shall be built up in accordance with the approved technical documentation, whereby GL shall be consulted about the method. Air shall be adequately removed from the reinforcing layers and these layers shall be compacted in such a manner to ensure that the required proportion of resin is achieved. Resin enrichment shall be avoided.

3.4 The maximum thickness of the material that can be cured at one time is determined by the maximum permissible heat development. In the case of vacuum bagging, as a rule, the decisive factor is the maximum number of layers from which air can still be totally removed.

3.5 If a laminating process is interrupted for a period causing the base laminate resin to exceed the point of gelation, a test is to be performed to verify adhesion between the base laminate and the top laminate. For each resin system, under the given processing conditions, the permissible period of interruption of the laminating process is to be determined. In the event of this period being exceeded, the laminate shall be thoroughly ground in order to provide a surface exhibiting adequate adhesion properties after removal of the dust. For UP resins on an orthophthalic acid and standard glycol basis not containing any skin-forming agents a 48 h interruption on the laminating process may, without any further proof being furnished, be considered uncritical with respect to lamination.

3.6 When grinding laminates containing resins with low styrene evaporation as the matrix system, the surface shall be removed down to the mat layer. In order to ensure that no skin-forming agent elements (e.g. paraffins) will be left on the surface, the surface shall finally be polished using new abrasive paper. The same procedure shall also be applied when treating the surfaces of materials to be bonded (see E.6.2.3).

3.7 Transitions between different thicknesses of laminate shall be made gradually. A minimum value (for glass fabric in the fibre direction) of 25 mm per 600 g/m² reinforcing material can be used. In the transition region from a sandwich construction to a solid laminate, the core material shall be tapered with a gradient of not more than 1 : 2.

3.8 If cutting of reinforcing layers is unavoidable in the case of complicated mouldings, then the cut edges shall overlap, or reinforcement strips shall be provided. In the butt or seam region of laminates, every reinforcing layer shall overlap by at least 25 mm per 600 g/m².

3.9 Different components may be laminated together only while they are not fully cured. Special attention shall be paid to crossings of laminates.

3.10 Parallel or insert linings shall be free of all moisture and pollution (dirt). Their bonding surfaces with the laminate shall be prepared in a suitable manner (roughening, coupling agent or similar).

4. Glass-fibre resin spraying

Glass-fibre resin spraying, a partly mechanical method of lamination by hand, requires fulfilment of the following specific requirements:

4.1 The equipment to be used shall be demonstrated before use and its suitability proven.

4.2 The qualification of the fibre-resin sprayer, and where appropriate his assistant, shall be demonstrated to GL by means of procedure test.

4.3 The equipment shall be calibrated in accordance with the guidelines of the manufacturer. Calibration shall be checked regularly before fibre-resin spraying, but the very least at the beginning of every production day.

4.4 The length of a roving cut shall be between 25 mm and 50 mm.

4.5 A powder-bound textile glass mat of maximum 450 g/m² shall be used for the first laminate layer. The glass part of this layer (to be applied manually) shall be less than 30 % by weight.

4.6 The glass weight per unit area of the spray laminate layer of a combined laminate shall not exceed 1150 g/m².

4.7 After a maximum of 1150 g/m² of fibres have been sprayed, air shall be removed and the composite shall be compacted.

4.8 Tests shall be performed on a regular basis to check whether a uniform laying up of the reinforced layers as well as a uniform distribution of percentage glass weight has been achieved. GL reserve the right to demand test pieces to check the resulting mechanical properties.

5. Curing and tempering

5.1 Completed components may only be taken from the moulds after adequate curing of the thermosetting resin compounds. The required cure time generally depends on the manufacturer's instructions. Otherwise, a minimum cure time of 12 hours shall be observed for cold-setting systems.

5.2 Resin systems which cure under pressure, UV radiation and/or increased temperature shall be treated in accordance with the manufacturer's instructions.

5.3 Immediately after curing, the components should receive post-treatment at increased temperature (tempering). The tempering time depends on the resin in question and the temperature attained within the component during tempering, whereby this shall be below the temperature for dimensional stability under heat and shall be agreed on with GL. Cold-setting systems which are not subsequently tempered shall be stored for 30 days at a temperature of 16 °C, and for correspondingly shorter periods at temperatures up to 25 °C. This period can be shortened with the consent of GL, provided the relevant manufacturer's specifications regarding post-curing are available, or post-curing values exist which are supported by experimen-

tal results. If such values are not available, then in general the following tempering conditions can be used (polyester/epoxy resin):

at least 16 h at 40 °C / 50 °C or

at least 9 h at 50 °C / 60 °C

6. Bonding

6.1 General

6.1.1 Bonded joints for load-bearing parts shall in general be verified using a procedure test to be agreed on for each individual case. The scope of the required tests shall be determined in agreement with GL.

6.1.2 For bonding of composite fibre materials, only adhesives approved by GL shall be used.

6.1.3 The adhesives shall not have any negative effects on the materials to be bonded.

6.1.4 The application limits for the adhesive, as specified by the manufacturer, shall be adhered to. A bonding-suitable design which as far as possible avoids peeling moments and forces shall be used, and the thickness of the adhesive layer shall be kept as thin as possible.

The joining surfaces shall be kept as large as possible, and forces shall be applied over a large area.

6.2 Surface pre-treatment

6.2.1 The different surface pre-treatments are listed in VDI (Association of German Engineers) guidelines 2229 and 3821.

6.2.2 The surfaces of the materials to be bonded shall be dry and free of grease, dust and solvents. Particularly when degreasing, attention shall be paid to compatibility of the solvent with the materials.

6.2.3 In the case of smooth surfaces, they shall be roughened e.g. mechanically by grinding or sand blasting, or chemically through pickling. This is absolutely necessary when there are coatings on the surfaces of the materials to be bonded which impair adhesion (e.g. skin-forming agents in polyester resins; see E.3.6).

6.2.4 In most cases, an increase of the adhesive strength is achieved by the application of specially matched primers, in particular, the use of primers recommended for bonding which is subsequently subjected to negative environmental influences.

6.3 Processing

6.3.1 The adhesive shall be used in accordance with the instructions issued by the manufacturer,

whereby the proportion of filling materials shall not exceed the permissible value.

6.3.2 The adhesive shall be applied uniformly, free of voids and not too thickly onto the materials to be bonded.

6.3.3 If, for special reasons, gluing joints of 5 mm or more cannot be avoided, then the materials to be bonded shall be first provided with a thin coating of pure adhesive resin.

6.3.4 It is not permissible to apply loads to the gluing before complete curing of the adhesive.

6.3.5 In the case of cold-setting thermosetting resin adhesives, a subsequent tempering of the gluing is recommended.

6.3.6 The edges of the area treated with adhesives shall be protected by means of suitable measures against penetration of extraneous media (e.g. humidity).

7. Sealing

7.1 Laminate surfaces without surface protection shall be sealed after curing or tempering, using suitable agents. In particular, edges of cut-outs and bondings shall be protected carefully against the penetration of extraneous media (moisture).

7.2 The sealing materials used shall not impair the properties of the laminate or of the bonding. Furthermore, they shall be appropriate for the purpose of the component.

F. Manufacturing Surveillance

1. General

1.1 For components made of FRP, manufacturing surveillance consists of the quality control of the basic materials, production surveillance and the quality inspection of the finished components.

1.2 In the case of manufacturing surveillance, a distinction is made between internal and third-party (external) surveillance. In the sense of these rules, third-party surveillance means periodic and random checks by GL of the internal surveillance as well as of the component quality.

1.3 GL reserve the right to carry out inspections in the production facilities without giving prior notice. The manufacturer shall grant inspectors access to all areas used for production, storage and testing and shall present all documentation concerning records and tests carried out.

1.4 The scope of third-party surveillance can be reduced in the case of production facilities that have a certified quality management system.

2. Incoming inspection

2.1 Characteristic values and mechanical properties specified in the material approval shall be confirmed by the manufacturer, at least by a test report (DIN EN 10204-2.2). On arrival of the product, a check shall be carried out to ascertain whether it corresponds to the requirements. Material properties shall be checked by random sampling.

2.2 The products shall be listed in the inventory file and shall be stored in accordance with the requirements of these rules.

3. Production surveillance

3.1 Details of production shall be stipulated by means of check lists and routing cards which accompany each stage of the production and are signed by the employees in charge.

3.2 Production surveillance shall be carried out constantly by the internal quality department. The scope shall be stipulated in an inspection and test plan and signed by the employees in charge.

3.3 Employees involved in production shall be suitably trained and shall work under professionally qualified supervision.

3.4 The materials used in the production shall be documented in a clear and comprehensive manner. Parameters relevant for the quality (temperature, humidity etc.) shall also be recorded in the production documentation.

3.5 Details (including the direction) of reinforcing layers in the laminate shall be checked off immediately during the production process.

3.6 A sample shall be taken from each batch of thermosetting resin compound that is mixed, and this shall be labelled, cured and stored. These samples shall be subjected to random testing of the degree of their curing and the results shall be documented.

3.7 During production, laminate samples shall be prepared and shall be used for checking the characteristic values and the mechanical properties. The material strength values shall conform with the specified values. If no adequately-sized laminate samples can be obtained from cuttings or sections, then reference laminates produced in parallel with dimensions of approximately $50 \times 50 \text{ cm}^2$ shall be prepared. Their quantity depends either on the number of the components, or the number of production days (the lower number can be chosen).

4. Structural tests

4.1 During production and on completion of production, the component shall be subjected to visual inspections. In particular, attention shall be paid to voids, delamination, warping, discoloration, damage etc. In addition, the general quality, e. g. surface finish, shall be assessed.

4.2 By means of suitable testing procedures, the quality of the components shall be determined, if possible during production, and at the latest on completion of production. Special attention shall be paid to the bonding and to the degree of curing of the component.

4.3 Following agreement with GL, individual or random tests shall be carried out on finished components under static and/or dynamic loads.

4.4 GL shall be informed about repairs of any faults relevant to the strength of the component, and the procedure used to carry out the repair shall be in accordance with the Rules for Classification and Construction, [II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 1 – Fibre Reinforced Plastics and Bonding, Section 3](#).