Section 2

Inspection and Testing of Fibre Composite Materials

A. Requirements

1. General

1.1 In accordance with the Rules and Guidelines of Germanischer Lloyd (GL), the materials used for manufacturing components made of FRP under the supervision of GL shall be approved by GL. Approvals are granted for the following materials:

– gelcoat and/or laminating resins

– reinforcing materials

– prepregs

– core materials

– adhesives

1.2 Applications for approval by Germanischer Lloyd Head Office GL-HO shall be made by the material manufacturer or an agent. Together with the application, the following shall be submitted to GL-HO:

– a declaration in writing by the applicant that the tested materials comply with those for which the approval is requested, and that the sample is manufactured in accordance with the Rules and Guidelines of Germanischer Lloyd

– product description

– safety data sheet

– storage and processing instructions

– copy of the test certificate of a recognized testing body, i.e. an accredited testing laboratory or a notified testing body.

1.3 The tests shall be carried out in accordance with the standards mentioned in this rule. However, comparable standards of other countries are also acceptable after agreement with GL-HO in each individual case.

1.4 The minimum properties required by GL for the tests shall be fulfilled by all specimens.

1.5 In the case of inadequate test results of individual specimens, attention shall be paid to the following (for a basic number of 6 tests):

– If one or two specimens yield inadequate results, the tests shall be repeated with twice as many specimens.

– If the test results are inadequate for three or more specimens, the test can be repeated on newly produced specimens, provided that GL agrees to this.

– If even one sample yields inadequate results while repeat-testing, then approval is not possible.

1.6 If the material fulfils the GL requirements, then a statement of material approval is issued by GL-HO. This is generally valid for four years, whereby extensions are possible.

1.7 GL-HO shall be notified immediately of all modifications or other changes to the material. Decisions regarding the further validity of the material approval is made on an individual basis.

1.8 A constant material quality shall be provided by the manufacturer through suitable QM measures. If this is not ensured, GL reserves the right to suspend, or withdraw, the approval.

1.9 GL reserves the right to demand and/or carry out spot tests of the material properties during the period required for material approval. If, in doing so, there is no adequate comparison with the required values, the material approval can be suspended or withdrawn by GL.

1.10 The approval refers only to the approved material. The applicability of this material in connection with other approved materials shall be demonstrated independently by the manufacturer, or the user, in a suitable manner. In cases of doubt, GL reserves the right to require a check of the properties of the material combination.

2. Thermosetting resins

2.1 General

2.1.1 The basic requirements listed under 1. apply for material approval.

2.1.2 A general description of the thermosetting resin, its processing conditions as well as the properties of resin in the processing state shall be submitted. The basic properties of the cured thermosetting resin shall be verified by the test certificate of a recognized testing body. These values shall fulfil specified minimum requirements.

2.1.3 Cold-setting unsaturated polyester (UP) resins and cold-setting epoxy (EP) resins are specifically described below. Other types of resins can also be approved after consultation with GL-HO, whereby the required minimum properties are specified by GL-HO on an individual basis. However, they shall at least comply with those of UP resins.

2.2 Description

2.2.1 A description of the thermosetting resin shall be submitted in order to allow an unequivocal identification:

- resin type and state
- purpose
- manufacturer
- trade name

2.2.2 In addition, the following shall be indicated:

- storage conditions
- environmental conditions for processing
- type and proportion of allowed additives
- curing conditions, tempering

2.3 Properties in the processing state and during curing

The properties shall be determined in accordance with the following standards:

- density (DIN EN ISO 1675)
- viscosity (DIN 53015 - DIN EN ISO 2555)
- reactivity:

  UP resins: acid number
  (DIN EN ISO 2114)

  EP resins: epoxy equivalent
  (DIN EN ISO 3001)
- WP resins: Monomer proportion
  (DIN EN ISO 3251)
- gel time (temperature increase)
  (DIN 16945, Section 6.2, 6.3 - DIN EN ISO 2535)
- curing shrinkage (DIN 16945, Section 6.5)

2.4 Properties in the cured state

2.4.1 The following properties shall be submitted for all thermosetting resins in the cured state:

- density
- water absorption
- strength, modulus of elasticity in tension, and tensile fracture strain
- strength and modulus of elasticity in bending
- dimensional stability under heat

2.4.2 For gelcoat and topcoat resins, the following additional information shall be submitted:

- abrasion resistance
  (DIN 53754 - ISO 9352) 3 samples
- resistance against seawater, fuels, hydraulic oil, weak acids and alkalis (DIN EN ISO 175)

2.4.3 With regard to the properties, the following shall be verified by the test certificate of a recognized testing body. For this purpose, specimens shall be used which are produced in accordance with the submitted processing guidelines. The specimens shall be cured and tempered for 16 h at 40 °C (polyester resins) or 16 h at 50 °C (epoxy resins). For gelcoat and topcoat resins, only the first four properties shall be verified:

- density (DIN EN ISO 1183, method A),
  3 specimens
- water absorption (following DIN EN ISO 175, Specimen 50 mm × 50 mm × 4), 3 specimens
- dimensional stability under heat
  (DIN EN ISO 75-2, method A), 3 specimens
- tensile strength, fracture strain, modulus of elasticity in tension (DIN EN ISO 527-2, test piece 1 B), 6 specimens
- bending strength
  (DIN EN ISO 178), 6 specimens
- modulus of elasticity in bending
  (DIN EN ISO 178), 3 specimens

2.4.4 The mechanical properties are normally determined at standard climate 23/50 (23 °C / 50 % relative humidity). If the intended operating temperature range of the resin is not between – 20 °C and + 50 °C, further testing temperatures shall be agreed on with GL-HO.

2.4.5 The testing speed in the case of tensile and bending tests shall be selected in such a way that a specimen or edge-fibre strain of about 1 % / min is ensured. This shall be documented in the test report. The modulus of elasticity shall be determined as a secant modulus between 0,05 % and 0,25 % strain. The water absorption shall be specifically determined at 23 °C after 24 ± 1 h and 168 ± 2 h.

2.5 Minimum properties

2.5.1 For resin products consisting of UP resins, the following minimum properties are specified for use as laminating resins (values for gelcoat resins in brackets):

tensile strength:	40	MPa	(—)
fracture strain:	2,0	%	(3,0 %)
modulus of elasticity: (tension)	2700	MPa	(—)

bending strength:	80	MPa	(—)
dimensional stability under heat:	60	°C	(60 °C)

The water absorption after 168 h shall not exceed 70 mg for laminating resins and 60 mg for gelcoat resins.

2.5.2 The following minimum properties apply to resin products consisting of EP resins:

tensile strength:	55	MPa	(—)
fracture strain:	2,5	%	(3,5 %)
modulus of elasticity: (tension)	2700	Mpa	(—)
bending strength:	100	Mpa	(—)
dimensional stability under heat:	70	°C	(70 °C)

The water absorption after 168 h for laminating and gelcoat resins shall not exceed 50 mg.

2.5.3 The abrasion resistance properties and the resistance properties to extraneous media in the case of gelcoat resins may be determined by the applicant.

– The abrasion resistance determined in the test (sliding abrasion rate) shall be adequate.

– The properties stipulated in DIN ISO 175 shall be determined after 24 h and 168 h at 23 °C. Taking these properties into account and following agreement between GL-HO and the applicant, the following classification is made:

  – Resistant

  – Conditionally resistant

  – Not resistant

3. Reinforcing materials

3.1 General

3.1.1 The basic requirements listed under 1. apply for material approval.

3.1.2 A general description of the reinforcing material and of the filament shall be provided. Basic properties of laminate specimens taken from the reinforcing material shall be verified by the test certificate of a recognized testing body. These values shall fulfil specified minimum requirements.

3.1.3 The following applies to fibre reinforcements made of glass and carbon. Products with other reinforcing fibres, e.g. aramide, can also be approved, following agreement with GL-HO, whereby the minimum properties are then specified on an individual basis.

3.1.4 Due to the great number of the fibre reinforcing products on the market, only the most common ones can be listed. Products not covered (e.g. complexes, hybrids), can also be approved, following agreement with GL-HO.

3.2 Description

3.2.1 A description is necessary which allows an unequivocal identification of the reinforcing material:

– fibre material

– reinforcement type (mat, fabric etc.)

– manufacturer

– trade name

3.2.2 In addition, the following is required:

– form of supply

– storage conditions

– processing instructions

3.2.3 The filament and its treatment/sizing shall be submitted:

– filament diameter (DIN 53811 - ISO R 137)

– coupling agreed or sizing

– resin compatibility

In the case of glass fibre products, the average filament diameter shall be at maximum 19 µm.

3.2.4 In the case of reinforcing products consisting of a combination of different fibre materials and/or filaments, all fibre types shall be indicated.

3.2.5 If, in the case of textile glass reinforcing products, no E-glass or R-glass is used in accordance with DIN 1259-1, then an alkali oxide content (DIN ISO 719) of less than 1 % shall be verified by means of a test certificate from a recognized testing body.

3.3 Properties of the reinforcing products

3.3.1 Rovings

– number of the filaments in the roving

– roving fineness (ISO 4602)

When rovings are used as gun rovings (DIN 52316 - ISO 3375), the stiffness shall be additionally verified by the certificate of a recognized testing body.

3.3.2 Mats (continuous and chopped-strand mats)

– fibre length (for chopped-strand mats)

– linear density of the fibre (ISO 1889)

– weight per unit area (ISO 3374)

– layer thickness (ISO 3616)

– binder (see 3.3.5)

3.3.3 Fabric

- linear density of the fibres, warpwise and weftwise (ISO 1889)
- count, warpwise and weftwise (EN 1049-2)
- weight per unit area (ISO 4605)
- fabric thickness (ISO 4603)
- weave (DIN 61101-T2)

3.3.4 Non-woven fabric

- lay up
- weight per unit area of the individual layers and of the non-woven fabric (ISO 4605)
- non-woven fabric thickness (ISO 4603)
- binder (see 3.3.5)

In addition if a non-woven fabric contains mat or fabric layers, then the linear density and, where appropriate, the fibre length shall be indicated.

3.3.5 A difference shall be made between chemical and mechanical bond types. In the case of chemical bond types, the binder, the percentage weight (glass ISO 1887, carbon DIN 29965) and its solubility (DIN 52332) shall be indicated. In the case of mechanical bond types, the type of weave shall be indicated.

3.3.6 In the case of reinforcing products with different fibre materials, the percentages of materials used in the respective reinforcing directions shall be indicated.

3.4 Laminate properties of the reinforcing products

3.4.1 For laminate production, it is strongly recommended that GL-approved cold-setting UP resins are to be used. After curing, the specimens shall be tempered for 16 h at 40 °C. If, for special reasons, other (also warm-setting) thermosetting resins are to be used, then this shall be agreed in advance by GL-HO.

3.4.2 For rovings, tensile test specimens shall be prepared for all fibre materials in accordance with DIN 29965, Section 4.1.3.5. The test certificate of a recognized testing body shall be submitted to verify the tensile strength, the fracture strain and the modulus of elasticity as the mean values from six tests carried out in accordance with DIN 65382. Furthermore, the tensile strength and the modulus of elasticity shall be determined in accordance with DIN 65469 on flat specimens prepared for testing under tension.

3.4.3 For all other reinforcing products, laminate test panels shall be prepared in accordance with DIN EN 2374, Section 5.3 (Method C). In doing so, the reinforcing products shall be arranged in identical alignment. Depending on number of the reinforcing directions, the laminates shall have approximately the following thicknesses: unidirectional laminates 2 mm, bi-directional laminates 4 mm and multi-directional laminates 5 mm.

3.4.4 Appropriate test panels shall be prepared by fibre resin spraying for the use of gun rovings. The length of the gun rovings in this case shall be 35 mm.

3.4.5 The gun prescribed number of specimens shall be cut out of the test panels for each test. In doing so, specimens shall be taken from each reinforcing direction of the laminate in order to test the mechanical properties. For products with randomly distributed reinforcing directions, specimens shall be taken from any two directions, but at right angles to each other.

3.4.6 The specimens shall be tested in accordance with DIN EN ISO 291 after at least 16 h under standard climate conditions.

3.4.7 The following properties shall be verified by the test certificate of a recognized testing body:

- fibre content (DIN ISO 1887, carbon DIN EN 2564), 3 specimens
- tensile strength, fracture strain, modulus of elasticity in tension (DIN EN ISO 527-4, test piece III), 6 specimens
- bending strength, modulus of elasticity in bending (DIN EN ISO 14125, Method A), 6 specimens

Deviating from the standard the modulus of elasticity in tension shall be determined as a secant modulus between 10 % and 50 % of the fracture strain.

In addition, for carbon fibres, the compressive strength and the modulus of elasticity in compression shall be demonstrated (carbon, Draft DIN EN 2850, test piece A1 with gauge length 8 mm).

3.4.8 The testing speeds shall be selected in such a way to ensure a strain rate of 1 % / min in the test piece or the edge fibre. The testing speed shall be indicated.

3.4.9 Testing shall be carried out in a standard climate 23/50 (23 °C / 50 % relative humidity). If the operating temperatures of the fibres are not between – 20 °C and + 50 °C, then additional testing temperatures shall be agreed on with GL-HO.

3.5 Minimum properties

3.5.1 For approval, fibre reinforced products shall fulfil specified minimum values for the mechanical properties. The influence of the fibre volume content on the properties has been taken into account when specifying the values. The values refer to the 0° direction in the case of a uniform lay up. If necessary, a correction to the actual lay up shall be done.

3.5.2 The minimum values of all mechanical properties to be verified are determined by means of the following equation together with the values given in Table.2.1:

$$X_{min} = \alpha \left[X_{ref} \left(\frac{\varphi}{0,4} \right) \right]$$

X_{min} = minimum required value

X_{ref} = reference value for fibre volume content $\varphi = 0,4$

α = factor for lay-up

φ = fibre volume content $0,2 \leq \varphi \leq 0,6$

Deviations from the above specification are allowed for laminates with glass mats or gun rovings; in these cases, the minimum values for a percentage fibre weight content of $0,25 \leq \psi \leq 0,35$: are:

– tensile strength :

$$R_Z = 1278\psi^2 - 510\psi + 123 \quad [MPa]$$

– Young's modulus (tension) :

$$E = (37\psi - 4,75) \cdot 10^3 \quad [MPa]$$

– bending strength :

$$R_B = 502\psi^2 + 106,8 \quad [MPa]$$

3.5.3 In the case of multidirectional lay up of the reinforcing products, the values shall be proved at least for one direction (preferably 0°).

3.5.4 For reinforcing products with different fibre materials in one direction, the values of the material with the lower minimum properties shall be fulfilled.

3.5.5 The minimum values for fabric are 95 % of the specified values for 0° / 90° lay up.

3.5.6 The stiffness of the gun rovings to be verified in accordance with DIN 52316 shall not be below 130 mm.

3.5.7 The linear relationship between the property and fibre volume content assumed when specifying minimum values does not apply for all properties, and shall therefore not be used to extrapolate measured values.

4. Prepregs

4.1 General

4.1.1 The basic requirements listed under 1. shall apply for material approval.

4.1.2 Since prepregs are based on resin systems which cure under heat, consultation with GL-HO concerning the curing process of the resins is required.

4.1.3 The testing of cured prepreg laminates is identical with the laminate testing of fibre reinforced products. Taking into account the resin system, the minimum characteristic values shall be agreed on with GL-HO.

4.1.4 Unidirectional non-woven prepregs and woven prepregs are considered within the framework of these Rules. Other prepregs can also be approved, following agreement with GL-HO.

Table 2.1 Coefficients for the determination of the minimum properties

Fibre	Propert	X_{ref} [MPa]	α			
			0°	0° / 90°	0° / ± 45°	0° / 90° / ± 45°
Glass	Tensile strength	500	1,00	0,55	0,50	0,45
	Young's Modulus of elasticity	26.000	1,00	0,67	0,57	0,55
	Bending strength	650	1,00	0,55	0,45	0,40
Carbon	Tensile strength	900	1,00	0,55	0,50	0,45
	Modulus of elasticity	80.000	1,00	0,55	0,45	0,42
	Bending strength	725	1,00	0,55	0,45	0,40
	Compressive strength	600	1,00	0,55	0,50	0,45
	Modulus of elasticity compression	70.000	1,00	0,55	0,50	0,45

4.2 Prepreg properties

4.2.1 A description is necessary which allows an unequivocal identification of the prepreg:

– fibre material

– resin system

– reinforcement type

– trade name

– manufacturer

– storage conditions, processing guidelines

4.2.2 The following properties shall be submitted for the non-cured prepreg material:

– mass per unit area (DIN 53854)

– resin percentage by weight (DIN 29971, Section 5.1.1.4)

– layer thickness (DIN 53855-1)

– resin flux percentage by weight (DIN 65090, Section 5.1.1)

4.2.3 The following are necessary for the reinforcing material:

– filament diameter (DIN 53811 - ISO 137)

– count (EN 1049-2)

– bond type (only woven prepregs)

5. Core materials

5.1 General

5.1.1 The basic requirements listed under 1. shall apply for material approval.

5.1.2 A general description of the core material shall be submitted. The basic properties shall be verified by the test certificate of a recognized testing body.

5.1.3 Rigid foam materials and cross-grained balsa are considered specifically as a core material within the framework of these Rules. Cores made of other materials can also be approved, following agreement with GL-HO.

5.2 Rigid foams

5.2.1 The following information is necessary for a general description:

– basic material and additives

– trade name

– manufacturer

– resin systems suitable for bonding/coating

– storage conditions

5.2.2 The manufacturer shall provide details of the maximum permissible processing temperatures and the operating temperature limits. The long-term operating temperature shall at least cover the range –20 °C to +50 °C.

5.2.3 The test certificate of a recognized testing body verifying the following properties shall be submitted:

– apparent density (ISO 845); sample thickness ≥ 25 mm, 3 specimens

– water absorption (ISO 2896), 3 specimens

– compressive strength (ISO 844), 6 specimens, vertical to the plane of the test panel

– modulus of elasticity (compression) (ISO 844), 3 specimens, test piece III, vertical to the plate plane of the panel

– shear strength (DIN 53294), 6 specimens

– shear modulus (DIN 53294), 6 specimens

5.2.4 The specimens shall be tested without foam skin. The testing shall take place in a standard climate 23/50 (23 °C/50 % relative humidity). Testing procedures are given mainly for rigid foams, whereas in the case of tough foams GL-HO shall be consulted if there is any doubt.

5.2.5 The following minimum properties are specified for an apparent density of 60 kg/m^3 and 200 kg/m^3:

	60 kg/m^3	**200 kg/m^3**
Compressive strength [MPa]	0,6	3,5
Modulus of elasticity (compression) [MPa]	40	200
Shear strength [MPa]	0,5	2,6
Shear modulus [MPa]	15	65
Water absorption [vol.-%] (after 28 Days)	2	2

5.2.6 In the case of other apparent densities, linear interpolation of the densities shall be used to determine strengths and moduli.

5.3 Cross-grained balsa wood

5.3.1 The requirements for cross-grained balsa wood are specified in Chapter 2 – Wood, Section 2.

5.3.2 Adhesion of balsa wood shall not be impaired by impregnation.

6. Adhesives

6.1 General

6.1.1 The basic requirements listed under 1. shall apply for material approval.

6.1.2 A general description of the adhesive shall be provided. Basic properties of the cured adhesive shall be verified by the test certificate of a recognized testing body.

6.1.3 The following specifically considers cold-setting and hot-setting thermosetting adhesives as well as hot-melt adhesives. Other adhesives, provided that they can be used for processing of FRP (e.g. expansion adhesives) can also be used, following agreement with GL-HO.

6.2 Description

6.2.1 A description of the adhesive shall be submitted in order to allow an unequivocal identification of the adhesive:

– type of adhesive
– manufacturer
– trade name
– storage conditions
– processing and curing guidelines
– volume shrinkage after exceeding the gel point
– glass transition temperature (ISO 11357/2)

6.2.2 In the case of adhesive films with backing, the backing material shall be specified.

6.3 Properties of the adhesive

6.3.1 In the processing state, the following information shall be provided:

– density (DIN EN ISO 1675)
– viscosity (DIN 53019)

6.3.2 In the case of two-component thermosetting resins which cure at room temperatures, the pot life (DIN 16945, Section 6.3) shall also be indicated.

6.4 Properties in the cured state

6.4.1 The following mechanical properties shall be verified by the certificate of a recognized testing body (on 6 specimens respectively):

– tensile lap-shear strength (DIN EN 1465)
– peeling resistance (ISO 11339)
– dimensional stability under heat (DIN EN ISO 75-2, Method A)

In addition, a long-duration shear tension test (based on EN 1465) shall be carried out. In doing so, the sample is subject to loads in a standard climate 23 °C / 50 % relative humidity at 60 % of the mean tensile lap-shear strength for 192 ± 2 h.

6.4.2 The testing shall be carried out for two different conditioning states of the specimens:

– 24 ± 1 h after curing at 23 °C and storage at 50 % relative humidity
– 1000 ± 12 h storage in distilled water at 23 °C

6.4.3 For each test and conditioning state, specimens with adhesive layer thicknesses of 0,5 mm and 3 mm shall be used.

6.4.4 All tests shall all be carried out in a standard climate 23 °C / 50 % relative humidity. In addition, the tensile lap-shear strength shall be verified at 50 °C.

6.5 Minimum properties

6.5.1 The following properties shall be achieved for directly tested specimens as well as specimens tested after wet storage:

– tensile lap-shear strength: 12 MPa
– peeling resistance: 2 N/mm
– dimensional stability under heat: 65 °C

6.5.2 Strain in creep shall be below 0,18 mm in the long-duration shear tension test for an adhesive layer thickness of 0,5 mm and below 1 mm for an adhesive layer thickness of 3 mm.