Fire retardant fiber-reinforced components according to DIN SPEC 91326

Isotropic or quasi-isotropic load-optimized components produced using the vacuum infusion process meet the requirements of DIN EN 45545

- Jörg Bünker -

Fig. 1: Resin impregnation during the vacuum infusion process

The vacuum infusion process (see Fig. 1) allows fiber-reinforced components to be produced in the form of highly integrated structures. Unlike classic differential construction, components that are made this way exhibit the highest potential for lightweight construction. Their material parameters have now been standardized in a DIN specification. Thanks to new technologies, these components also meet the stringent requirements of the European fire safety standard for the first time.

Despite the technological added value, reduced personnel expenses during production as well as the lower material usage ratio mean that price neutrality of the finished component can be expected.

Fiber-reinforced plastics in rail vehicles

Fiber-reinforced plastics (FRPs) are used in a wide variety of areas in rail vehicles. Qualification of the components in accordance with the European fire standard DIN EN 45545 [1] is required for this application.

Besides the low weight of the components, the high degree of forming flexibility is a particular focus of the FRP designs.

In the past, textile-glass-reinforced laminates with filled fire-retardant resins based on unsaturated polyester resins have been used. The current transition from the nationally applicable fire standards to DIN EN 45545, which is valid throughout Europe, also results in dramatic tightening of the fire safety requirements for FRP in some cases. This also has a direct influence on the raw materials that can be used.

At present, a wide range of different types of resin and fire protection systems is available on the market. Depending on the provider or the resin formulation, various levels of fire-retardant fillers are used in the resin. It is common practice for manufacturers of FRP to mix the resin systems used in the components themselves during production or to purchase pre-filled resin systems. Due to the fillers, the quality of the components is subject to high variation since this manual method of production has only low reproducibility and the fluctuating filler content has a significant impact on the mechanical properties and flammability characteristics of FRP.

Due to the large number of different suppliers and the manual mixing of resins that takes place to a degree, component designers do not have a uniform overview of the material performance and the properties of the materials or combinations of materials that are used. This is now exacerbated by the new fire protection standard because the amounts to be used in fire-retardant fillers sometimes need to be increased or combined with other flame retardants to meet the increased demands in terms of fire protection according to DIN EN 45545. This in turn decreases the mechanical performance of the resin and the overall performance of the FRP.

Alternatively, it is possible to completely dispense with the use of fire-retardant fillers in the resin and to produce FRPs using a closed vacuum infusion process; at the same time, these FRPs meet the high requirements of DIN EN 45545.

Infusion technology makes it possible to produce pre-definable components with lightweight construction characteristics for the railway market in quantities never before possible. This results in FRPs with a very high specific strength and low weight, combined with high resistance to fire.

DIN SPEC 91326 [2] has been developed to standardize and establish these properties. The objective is to specify a FRP which has defined mechanical properties and verified, reproducible flammability characteristics that, for the first time, allow the designer to reliably design and dimension components with reproducible quality.

DIN SPEC 91326 has been developed using the PAS method, where the DIN institute carries out controls and ensures that the DIN SPEC does not contradict existing standards. The DIN institute then publishes the standard – internationally too.

The focus of the DIN SPEC is the specification of an isotropic and a quasi-isotropic fiber-reinforced material which describes a combination of materials with previously known and reliable properties. This data therefore represents a generally applicable state-of-the-art that can be used both by designers and component manufacturers.

General characteristics of fiber-reinforced components

A fiber-reinforced component is a multiphase or mixed material that is generally made from two main components (a bedding matrix plus reinforcing fibers). Due to mutual interaction between the two components, this material acquires properties of higher quality than either of the components individually.

Since the fibers can be aligned depending on the stresses and because their density (number per unit area) can be adapted, customized components are the result. In order to influence the rigidity in different directions, non-crimp fabrics are used instead of individual fibers. This means that the fibers may be present in various defined angles and are produced prior to contact with the matrix.

The superior characteristics of an FRP component are only achieved through the interplay of both components.

Regarding the flammability characteristics of FRP, it can be stated that the fiber is usually made of inorganic E-Glass, and thus represents a non-combustible phase. The surrounding matrix usually consists of organic resin, which (with a few exceptions) is flammable. Thus, a high content of inorganic fiber is desirable, also in terms of the requirements of DIN EN 45545.

Not all combinations of fiber and matrix materials lead to an increase in the rigidity and stiffness of the composite. Three conditions must be satisfied so that a reinforcing effect occurs in parallel with the fiber direction:

1. $E_{fiber,\ longitudinal} > E_{matrix}$
   The modulus of elasticity of the fiber in the longitudinal direction must be greater than the modulus of elasticity of the matrix material.
2. $\varepsilon_{break,\ matrix} > \varepsilon_{break,\ fiber}$
   The elongation at break of the matrix material must be greater than the elongation at break of the fiber.
3. $R_{fiber,\ longitudinal} > R_{matrix}$
   The breaking strength of the fibers must be greater than the breaking strength of the matrix material.

Special properties of fiber-reinforced plastics

In order to standardize such a fiber-reinforced plastic with a good reinforcing effect so that it is suitable for use in the rail vehicle market while taking DIN EN 45545 into consideration, the properties of such a plastic according to DIN SPEC 91326 are described below.

Production of fiber-reinforced components

To produce an FRP with the highest specific lightweight values, it is important to not only use the right raw materials, but also to select the appropriate manufacturing process.

State-of-the-art

In the past, components for the rail vehicle market made using filled resin systems have been produced using the hand lay-up procedure. With this manual method, a lamination roll is used to coat the filled resin system onto a textile glass mat that was previously placed in the mold; then the mat is impregnated. This process is repeated until the required component thickness is achieved. Usually the textile glass mats consist of non-directional short glass fiber snippets, so-called chopped strand mats (CSM). The use of CSM results in isotropic FRPs; however, these have only a low material performance with regard to the non-directional structure of the reinforcing material.

In addition, the combination of highly filled resin systems with CSM mats and processing using the hand lay-up method results in FRP components with a low content of reinforcing material, which in turn decreases the performance.

Due to the manual lay-up process, it is also difficult to achieve uniform component quality. Firstly, the applied resin system often contains air bubbles that must be removed during the process because they reduce the quality of the components. This is often difficult, and achieving uniformity is rarely possible. Furthermore, as a result of their manufacturing process, the CSM mats that are used are subject to large variations in glass content. Thus, it is also difficult to adjust the desired glass content in a reproducible manner.

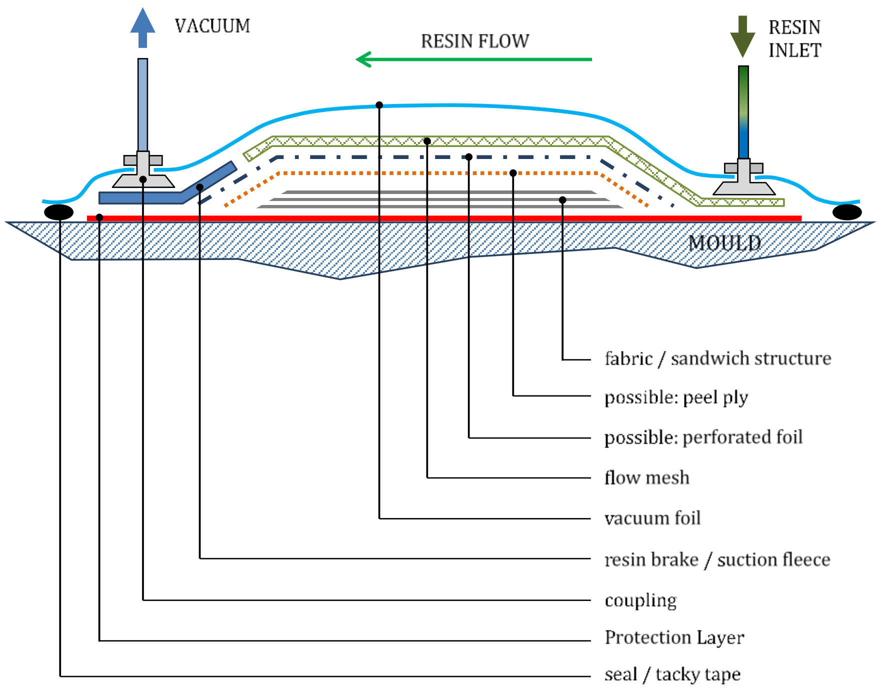

Fig. 2: Layer structure of an infusion component

Fig. 3: Cross-section of a LEO component with a sandwich core

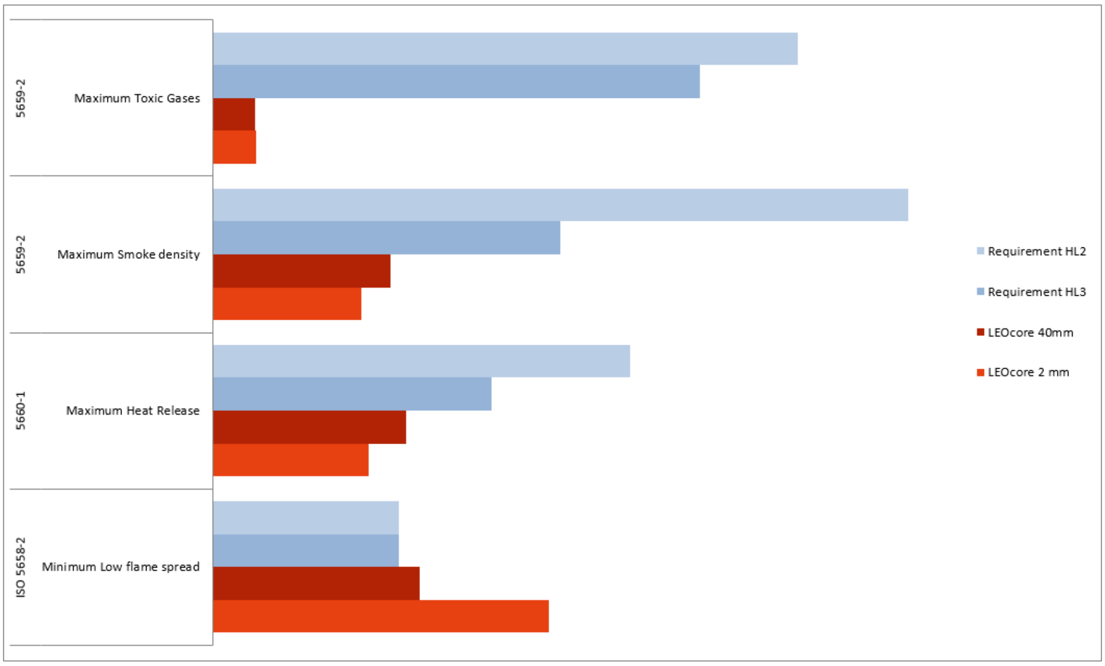

Fig. 4: Flammability results for a sandwich component with different thicknesses

Production using the infusion method

The production of FRPs in a closed process, such as infusion technology, has become established in many areas of the composites industry. These areas include, among others, the production of rotor blades for wind turbines, ships and fast ferries in the marine and offshore industry and the production of structural components in the automotive industry.

Previously, infusion technology was used only to a limited extent in the rail vehicle market. Using the LEO system from SAERTEX GmbH & Co. KG, it is now possible for the first time to manufacture FRPs using infusion technology (see Fig. 2) according to DIN SPEC 91236 with certified flammability characteristics that satisfy DIN EN 45545.

The main elements of the LEO system are multiaxial non-crimp fabrics that have been modified in terms of their fire protection properties, an unfilled low-viscosity infusion resin – based on a vinyl ester resin – that has been modified in terms of its fire protection properties, as well as a protection layer that not only acts as a covering layer, but also has high fire protection properties (see Fig. 3).

These three system components are chemically matched to one another so that they develop synergies in the event of a fire and meet the highest requirements of DIN EN 45545. It goes without saying that there are no halogens, and other toxic ingredients have been eliminated.

Due to the coordinated system components, which now also fulfill the fire protection requirements, infusion technology can also be used more widely in the rail vehicle market.

Currently, mainly large structures and primary components are produced using infusion technology. Here, the pre-calculated structure of dry non-crimp fabrics that has been selected according to the structural requirements of the component is placed in the mold. The non-crimp fabrics can differ in terms of their angular positions, the weight per unit area or the number of individual layers. In addition, not only components that are constructed purely of (monolithic) glass non-crimp fabrics, but also components with an integrated foam core (sandwich components, Fig. 3) can be produced. Unlike the traditional hand lay-up method, the impregnation of the structure does not take place layer-by-layer, but in a single step.

For this purpose, the entire layer structure is covered with a film and the infusion resin is drawn into the component using negative pressure (see Fig. 2). As a result, even sandwich components can be produced in a single step. Due to the defined amount of resin and the adjustable vacuum, high-quality components with definable properties can thus be produced. Because of the differences in pressure during infusion, the non-crimp fabrics are strongly compacted and pressed against the mold surface, resulting in a high glass content and high mechanical properties.

To provide designers and component manufacturers with the data necessary for calculating and simulating FRP components, DIN SPEC 91326 lists all the required laminate characteristics.

In addition to the mechanical properties, such as rigidity values, and modules of a unidirectional individual layer that serve as a design template for new composite structures, all FRP parameters – such as the individual layer thickness, the fiber content and the material density – are described. With this information, a complete FEM analysis of a component can be prepared.

In order to make proposals for existing FRP structures to manufacturers of FRP components, DIN SPEC 91326 also describes examples of various monolithic and sandwich constructions. In addition to isotropic structures, quasi-isotropic constructions with various thicknesses are described, so that an example of direct lamination is given for each application; this can be adopted by the user. This creates the possibility of a modular system in which the appropriate components can be selected for each project.

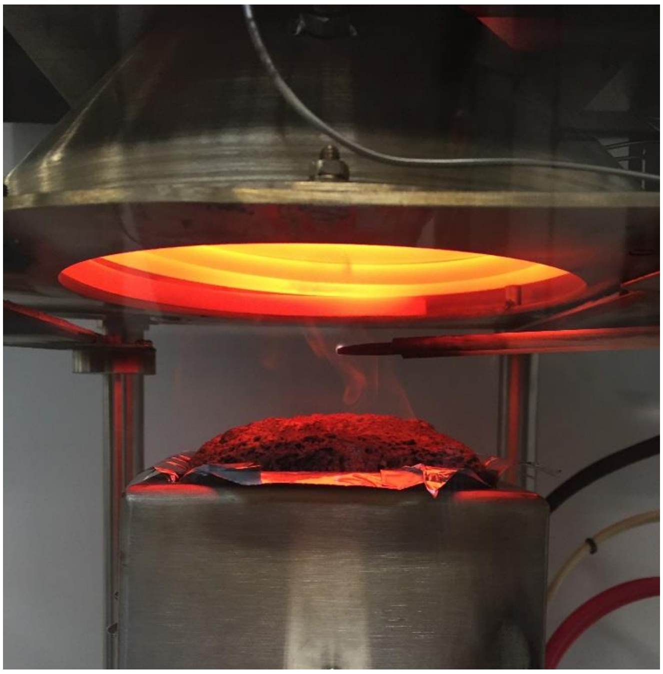

Fig. 5: Cone calorimeter test according to fire protection standard ISO 5660-1

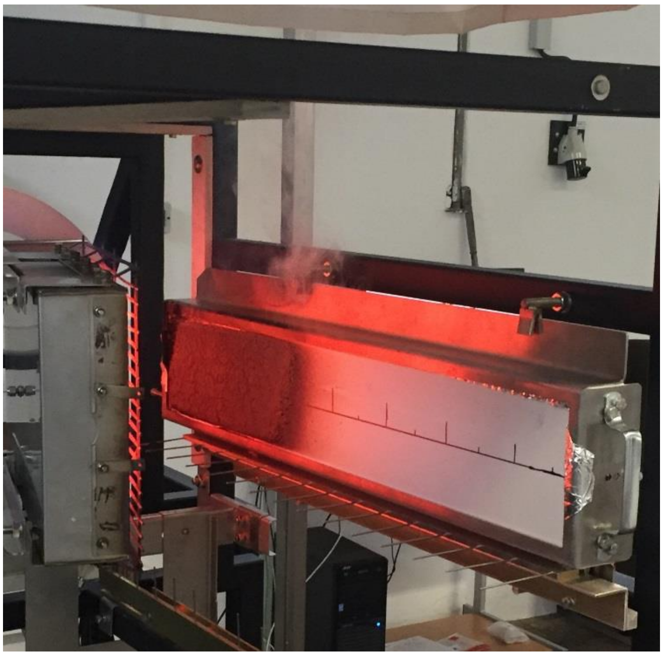

Fig. 6: Cone calorimeter test according to fire protection standard ISO 5660-1

Certified fire protection

All the listed laminate examples meet the fire safety requirements of DIN EN 45545. With regard to the fire standard specifications, laminates are classified as either HL2 or HL3.

To provide users with a range of laminate structures that is as broad as possible, sample monolithic laminates in thicknesses of 2.5 mm - 8.0 mm were tested with an appropriate protection layer for HL2 according to R1 [3]. According to the fire protection standard, all intermediate thicknesses are thus considered to have been tested, giving the user a wide range of possibilities for using monolithic laminates.

In order to also demonstrate the possibilities of using sandwich structures in the LEO system, fire tests were performed on different structures (see Fig. 4). Here, the LEOcore sandwich cores had thicknesses ranging between 2 mm and 40 mm. The thickness of the glass laminates also varied between 0.6 and 3.2 mm [4], [5].

The flammability tests show the highest classification of HL3 for R1, R7, and R17, regardless of whether the thickest or the thinnest sandwich element was examined. The system thus fulfills all fire safety requirements according to DIN EN 45545 for the tested sets R1, R7 or R17, regardless of the number or thickness of the layers.

The results of the individual tests for smoke and toxins, as well as the maximum heat release and the low flame propagation, significantly exceed the requirements of the standard. This is an intended result of the system because the tested FRP parts were tested without additional coating and because different coating systems can sometimes significantly affect the fire-protection properties of FRP components.

References:

[1] DIN EN 45545-2 Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behavior of materials and components
[2] DIN SPEC 91326: Fire retardant, multiaxial reinforced composite parts, manufactured in vacuum process technologies for railway vehicle applications; Beuth Verlag GmbH, March 2016
[3] Test report No. 2015-1668, Exova Warringtonfire, Frankfurt, 15.07.2015
[4] Test report No. 2016-1019: Brandhaus Rhein-Main, Frankfurt am Main, Mar. 23, 2016
[5] Test report No. 2016-1021: Brandhaus Rhein-Main, Frankfurt am Main, Mar. 23, 2016

Summary:

Using examples, DIN SPEC 91326 describes various FRP structures with tested fire-protection properties according to DIN EN 45545 and known mechanical properties. In addition to isotropic structures, quasi-isotropic structures with various thicknesses are described, so that an example of direct lamination is given for each application; this can be adopted by the user. This creates the possibility of a modular system in which the appropriate components can be selected for each project. The advantages provided by vacuum infusion result in reproducible, highly integrative FRP components with a high potential for lightweight construction – for the first time with tested fire-protection properties.

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Fig. 6: Spread of flame test according to fire protection standard ISO 5658-2 (source: Brandhaus Rhein-Main GmbH)

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