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The specialties of fiber-reinforced plastics in terms of product lifecycle management

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Abstract: Since the use of fibre reinforced plastics and computer based data management systems increased over the last decades, the need to define and organize the material-specific data of FRP in those data management systems is demanding. Because of the differences in material characteristics of metals and reinforced plastics, most data management systems have to be adjusted. The user has to be aware of all the specialties of FRP to decide about the use of those complex materials. There are differences between metals and FRP in almost every phase of the product life cycle, like the material construction in the definition phase, like more process parameter in the realization phase, like the challenging service in the usage phase and the often expensive disposal in the recycling phase.

Keywords: PLM, FRP, Data management, Composites

1. INTRODUCTION

The development and application of plastics and in particular of fiber-reinforced plastics has shifted in the last decades more and more into the mass market [2]. According to Flemming et. al. [1] the automotive and airplane industries are the development leaders. Additionally motorcycle helmets, sailing yachts and most sporting equipment contain fiber-reinforced plastics (FRP). Because of the guaranty laws and and for safety reasons most of those products have extreme high standards in quality and durability.

To launch an optimized product usually the manufacturer has to:

1. Reduce material and /or use the needed material more effectively. This leads to smaller material costs, a higher payload, smaller design space and a better handling.
2. Optimize production processes. As a result the waste is minimized, production cycles are shorter and changes and adjustments of products are easier possible.
3. Guarantee support and user knowledge by an extensive and meaningful documentation and thus make a fast and simple treatment of warranty claims possible. The disposal and recycle ability must be sufficient for the social requirements.

There are material-specific characteristics in the Product Lifecycle Management (PLM) at all three gists when using fiber-reinforced plastics and without the use of an efficient computer based PLM-system the high potentials of FRP can not be used.

2. DIFFERENCES BETWEEN FRP AND METALS

Today, as light weight constructions are getting more and more important because of increasing transportation costs and payload reasons, metals as steel or similar materials are often replaced by fiber-reinforced plastics. The FRP-material is developed and manufactured during the production of the product by joining two components. The material corresponds directly to the product geometry since a finishing and a rework would damage the material (fibers) and that leads to a degradation of the mechanical characteristics of the product. FRP draw in principle by a high specific strength and stiffness, sufficient flexibility, high elastic module, good structural stability, acceptable price, good fatigue behavior and low thermal expansion [4]. Naturally depending on the used components a compromise is always entered, since no material has all these qualities. Nevertheless a composite material often offers itself and can replace metals within many ranges. In a composite the fibers serve as main load carrier, it determine in the composite considerably the mechanical characteristics such as strength and stiffness. The matrix, into which the fibers is embedded, serves the force application, protects the fiber and ensures a certain pressure strength of the construction. Thermosetting polymers, usually epoxy or polyester resins, have the largest application spreading today. In polymer high-tech composite materials aramid, carbon and/or glass fibers are used. Common semi-finished materials are rovings, mats and fabrics, or pre-impregnated fibers such as prepregs and molding compounds. The application of FRP is most common in the aircraft construction, in the military range and in the sports area. Besides there are applications in the yacht and automotive building. Interesting examples are a corvette of the HDW (53m long) from carbon fiber-reinforced plastic sandwich and the wings (47m long) of wind power plants from glass fiber-reinforced plastic [5]. The simultaneous production of the component and the material brings a wide range of material characteristics and component geometry. Based on this flexibility FRP are extraordinary suited for the integral construction [2]. Due to their anisotropy and non linear behavior alphanumerics analysis are very fastidious. Additionally experimental investigations are often necessary to validate the theoretical results.

3. FRP in PLM

In certain product life phases FRP differ from common metallic materials. As a result of the close relationship of material, component geometry and production technology characteristics arise, which must settle in the Product Lifecycle Management.

3.1. Product development phase

As a result of the design aim to orient as many fibres as possible in the main load directions, a complex dimensioning arises because of the anisotropic material. This consciously brought in anisotropy forces usually non-linear numerical analyses and additional experiments. The designer has to be aware of that he is not working with a well-known standardized metal, but he works with a designed material. Lighter products with smaller material employment and high integration can be developed by using the high specific stiffness and strength of most FRP. Products with small wall thickness's and complicated forms such as undercuts can be manufactured in one piece. All possibilities provided by FRP must be considered when developing products. Also the good resistance against environmental influences such as seawater, acids and variations in temperature extend the area of application of FRP. During the embedding of FRP into a PLM system instances must be created, to represent the time-consuming construction phase with the points:

- evaluation of material properties by experiments
- production of layout plans, fibre orientations, lengths and types
- definition of all production process parameters.

The data management system, including time tables and process planning, has to handle all additional data, like anisotropic material properties, laminate plans and results of fatigue and ageing experiments. During the realization phase the necessary informations, like layout plans, material components, curing pressures and temperatures, cooling times, etc. have to be available to the production process (because it is not only material-processing but also material-producing). For the product usage phase service-schedules with consideration of failure criteria and material-specific workshop manuals must be provided. Finally the technical designer has to create a disassembly and a disposal plan for the product.

3.2. Production phase

Due to at least two components, which are combined in a chemical reaction to one material, the production is accordingly complex. Additionally complicated tools and forms, which are necessary for the high standard of an integral construction, are needed. All process information has to be available in the data system for the machine operators and production managers. For quality control the true process parameters must be illustrated in the PDM system. The components, mixing proportion, processing temperatures, air humidity, hardening times, processing pressures, etc. are crucial for the structural and optical quality of the product. A further challenge represents the industrial safety. The resins and hardeners used for producing the FRP are chemically reactive and impair the health. Therefore material instruction cards have to be saved in the data management system to be considered by every worker in the production phase. During the rework (sawing, grinding...) dust collectors are unavoidable and filter exchange intervals and tool services have to be present in the production plan. By the embedding of all process data into the PDM system the purchasing department can buy the necessary components just-in-time, the selling department can set delivery dates and possible lot sizes. An efficient quality control is also given by comparing the ideal and the real process parameters.

3.3. Usage phase

The product must be maintained over the entire life span and examined according to the failure criteria defined by the designer. In case of FRP, embedded sensor technology can be used in the material. A visual inspection seizes only macro damage and non destructive material investigations on FRP are very complex. Therefore the designer and the customer service bureau has to define exact damage criteria, which entail a repair or an exchange of the construction unit. Failures are often marked by matrix discolourations and large errors, such as delaminationens, can be seen with the naked eye. Irreversible ageing arises because of intermolecular changes in all polymer materials. Those changes lead to microscopic damages and combine to macroscopic changes of the material properties. Therefore polymer ageing has to be embedded in the PLM systems via maintenance plans, service schedules, exact damage and repair logging and repair instructions [1]. These informations are enormously important for potential secondary users and disassembler, since repairs of FRP, contrary to metals, can be made with most diverse materials and procedures. The results are very different material combinations.

3.4. Disposal phase

The integral construction of most FRP-parts avoids joins and connections which are usually weak spots of a design. On the other hand an integral construction is no assembly and damaged parts can not be exchanged. On exposed parts an exact maintenance of the surface coating (lacquer) limits the polymer-typical ageing and thus a structural weakening. Accidents, intensive use or reaching of the maximum life span stress a FRP-material and the construction has to be disassembled and recycled. Compared with metals FRP-constructions can hardly be dismantled and recycled, because of adhesive joining and the common use of material mixing constructions like sandwich or aluminium core [1]. A further disadvantage is the partial unknown ageing [3] of polymer materials. Material and ageing experiments can be investigated on prototypes, but simulating all possible environmental influences is hardly possible. UV-light, heat, humidity, mechanical and chemical loads have different effects in dependence of their simultaneous occurrence. That is why the definition of the correct decommissioning time is very difficult and has to be based on failure criteria (see product usage phase). Current attempts in recycling FRP are burning, granulating (thermoplastics) or depositing. Thermosetting polymers and carbon fibres can only be burned in contrary to thermoplastics that can be melded and reused. Therefore the appropriate disposal has to be defined and all chemical components (also from repairs) have to be explicitly designated in the PLM system.

4. CONCLUSION

When employing FRP the product must be suitable for this type of material. Positive characteristics of the composite, like high specific stiffness and strength and small thermal expansion, have to subside the higher costs and a limited recycling ability. Additionally a more complex construction and the difficult guarantee of security and function over the entire life span have to be justified when substituting metal by FRP.

In terms of the PLM special measures must be introduced when using FRP in comparison to designing with metals. Not only the stronger weighting of the product planning and the documentation and manufacturing process control have to be considered, but also the fulfilment of industrial safety requirements, the need to provide failure criteria and the planning of the usually difficult disposal. On one hand FRP offer the special chance to use the assigned material optimally, on the other hand FRP employ a complex production technology and the disposal is comparatively expensive.

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