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Composite materials parts manufacturing

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ABSTRACT

Composite materials parts manufacturing is based on the interactions of simultaneous as well as consecutive process steps. These influence the composite part properties and economical production. A wide range of possible composite materials and processing technologies necessitate a holistic view of the product life cycle to ensure the best possible economic and ecological outcome. Current studies on new manufacturing and machining processes aim for higher productivity and machinability, whereas new quality control approaches are enhancing the desired product quality. Furthermore, recent research addressing joining concepts and recycling methods has a huge impact on competitiveness and sustainability. Focusing on latest academic research approaches and current industrial application fields, this paper gives an overview of various process steps in the overall product life cycle of composite materials parts manufacturing.

1. Introduction

Growing demands on the efficiency of technical systems due to economical, ecological and social conditions require lightweight components, which are an integral part of today's product development. Fibre-reinforced polymers (FRPs) are therefore used in innumerable applications due to their superior light-weight potential. They are increasingly replacing conventional plastics and metals that cannot keep pace with the FRPs's performance. Apart from their high specific strength and stiffness, FRPs also benefit from properties such as low thermal expansion and corrosion resistance [312]. Another very important advantage, especially in vehicle construction, is the high energy absorption capacity in comparison to materials with similar density [38].

In general FRP belong to the group of composite materials and therefore consist of two or more basic components. The goal of creating composites is to achieve improved properties by exploiting the advantages of each component that cannot be achieved by one of the single components. Fibre reinforced composites (FRCs) involve fibrous materials which are applied especially in order to improve the strength, stiffness and thermo-mechanical behaviour of the built parts. Among other FRCs (e.g. metal matrix composites (MMC), or ceramic matrix composites (CMC)), FRPs constitute the most important and most popular composite material with respect to the manufacturing of lightweight structural parts, therefore only FRPs are covered in this paper [120].

Basically, FRPs consist of fibres embedded in polymer matrices. Mostly, short, long or continuous fibres are used, but also particles and whisker (fibrous mono-crystals) are exploited. A fibrous material has a much higher strength in fibre direction compared to the same material in other shapes [107]. The matrices are responsible for the shaping of the part, the load application and guidance of the loads between the fibres, as well as for the protection of the fibres. The interfaces of fibres and matrix are also essential for the performance. Multiple single endless fibres (filaments) can be assembled to rovings, uni-directional laminates or stacked multi-directional laminate structures, as well as woven or braided to fabrics. An impregnation of the fibre material with the matrix material is necessary. Processing of continuous fibres leads to high performance FRPs with a continuous and dedicated reinforcement. The characteristics of the manufactured part can be quasi-isotropic or anisotropic depending on the fibre orientation inside the composite. With short- and long-fibre reinforcements, quasi-isotropic semi-structural parts with lower performance can be realized by highly automated production processes. Here, the fibres are oriented stochastically [44].

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The matrix can be a thermoset or thermoplastic material as well as an elastomer. After chemical curing, no plastic formability remains for thermoset materials. Thermoplastic materials melt at higher temperatures and solidify when cooling down. By re-heating, a subsequent plastic deformation is possible. The Young's modulus and strength of the thermoplastic materials is lower compared to the thermoset material and creeping occurs caused by long-term loads. The processing temperatures of thermoplastic materials are higher than those of thermoset materials [280].

The mostly used fibre materials are glass-, carbon- and aramid-fibres. Typical glass fibres are E-glass (electrically isolating), S-glass (high breaking resistance and toughness), M-glass (high modulus) and R-glass (resistance). Carbon fibres can be high strength (HST), high modulus (HM), high tenacity (HT) and intermediate modulus (IM) fibres. Table 1 shows the range of the mechanical filament properties of fibres, typical for many lightweight applications. Fibre fabrics can be generated by weaving, draping, braiding, stitching, knitting and sewing. Fabrics are used as dry pre-forms or pre-impregnated for wet part manufacturing such as prepreg tape laying, wrapping or pultrusion [53].

Table 1
Mechanical filament properties of high performance fibres.

Filament	Density (g/cm^3)	Young's modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)	References
E-glass fibre	2.52–2.60	72–77	3400–3700	3.3–4.8	[23,40,324]
S-glass fibre	2.45–2.55	75–88	4300–4900	4.2–5.4	
M-glass fibre	2.89	87–115	4750–4900	4.0	
R-glass fibre	2.50–2.53	83–87	4400–4750	4.1–5.4	
HST carbon fibre	1.78–1.83	230–270	3900–7000	1.70–2.40	[20,70,88, 218,322]
HM carbon fibre	1.76–1.96	300–500	1750–3200	0.35–1.0	
HT carbon fibre	1.74–1.80	200–250	2700–3750	1.20–1.60	
IM carbon fibre	1.73–1.80	250–400	3400–5900	1.10–1.93	
Aramid fibre	1.39–1.47	58–186	2760–3620	1.9–4.4	[20,70,88, 218,323]

In order to implement an automated high volume production in the future, considerable challenges in production technology still need to be mastered [143].

Fig. 1 shows the product life cycle of FRPs beginning with fibres and polymers and ending with the recycling of the material. All steps of the product life cycle covered in this paper are highlighted.

The production of the materials is not covered in this paper, since it focusses on the major process steps. The following step "Part Generation" is topic of chapter two. An overview of all major current direct and indirect manufacturing processes and the current research in these processes is shown there. To conclude chapter two, a comparison among all discussed processes is given.

The "Machining and Post Treatment" in chapter three has its focus on various conventional and unconventional machining processes after describing fundamental issues of FRP composites machining, like chip formation, modelling and tool wear.

In chapter 4 "Joining" information about current applications and new research topics for the different classical joining techniques like mechanical, adhesive and thermal joining as well as hybrid joining concepts is given.

All mentioned process steps are subject to production metrology and quality control in order to produce high quality parts. Therefore the quality control is not a single process step, but part of each step in the production chain. Chapter five "Quality Control" covers different kind of defects of FRP production and how to measure those defects.

The next steps in the product life cycle of FRP "Utilization" and "Disassembly" are not covered in this paper, since the production has no big impact on these steps. However "Recycling", not a production technique itself, has a great impact on production processes, since the ecological footprint of a product often decides about its economic success. Different recycling processes for thermoset and thermoplastic glass- and carbon-FRPs are mentioned in chapter 6 along with the quality of recyclates and successfully implemented examples for recycling processes.

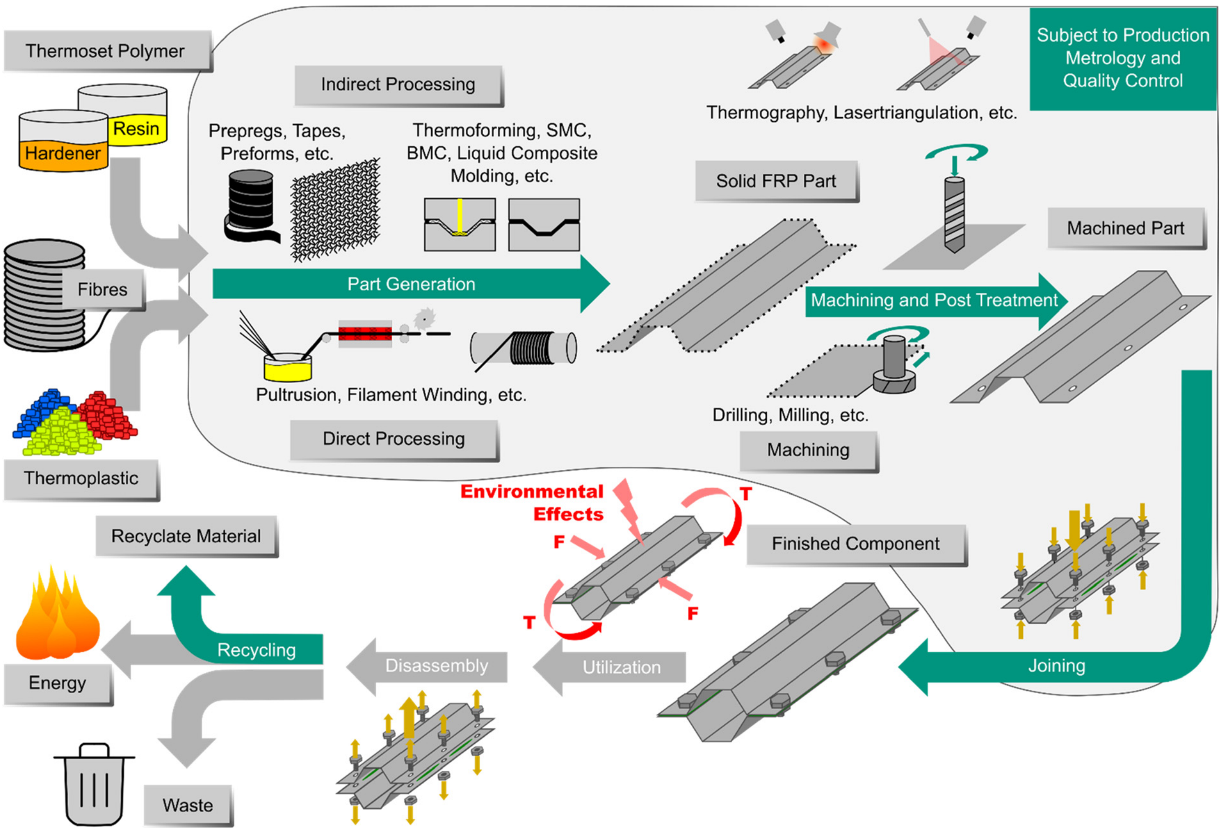

Fig. 1. Product life cycle for composite materials parts manufacturing.

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