TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

ANNI LAHTI

THE CREATING OF A DESIGN HANDBOOK: A CASE STUDY OF COMPOSITE MATERIALS

Master of Science Thesis

Examiners:
Assistant Professor Mikko Kanerva
& Postdoctoral Researcher Ulla
Saari

Examiners and topic approved on
1 November 2017

ABSTRACT

ANNI LAHTI: The creating of a design handbook: A case study of composite materials
Tampere University of technology
Master of Science Thesis, 85 pages, 4 Appendix pages
January 2018
Master's Degree Program in Materials Engineering
Major: Polymers and biomaterials
Examiners: Assistant Professor Mikko Kanerva & Postdoctoral Researcher Ulla Saari

Keywords: handbook, composites, design, marketing

In this thesis, the objective was to understand the influence of handbooks in the field of composite materials. The thesis consists of three different parts: background study, methodology and a case study provided by Excel Composites Plc.

For the background study, were reviewed composites in general and their applications as well as the most common types of handbooks and manuals that are used in the business environment and overview their content and usability. The basic strategies for successful marketing were briefly reviewed to build the bridge between marketing theory and the business of composites. In addition to the background study, it was also studied how the structure and contents of different engineering design guides and material handbooks together with technical writing guides form a common baseline. The information obtained from the background study was used for the creating of the design handbook of composites.

At the second part of the thesis, it was first presented and illustrated how the methodology of creating the design handbook of composites can be analyzed. The research for this part was done by studying different composite, design, and sizing handbooks. Also, a general survey was performed by interviewing people working in the field of composites and with the aid of the personnel of Exel Composites Plc. By the interview, the usefulness of handbooks and the basis of what kind of requirements the possible readers could have for the case study handbook's content.

The case study itself was conducted for Exel Composites Plc, a Finnish company specializing in pultruded composite materials. The company wanted to update the outdated design handbook to meet today's requirements. The content of the handbook is based on the previous studies of theoretical background and analyze of methodology.

The thesis gave a lot of detailed information of various publications used in the industry, basics of marketing and composites.

TIIVISTELMÄ

ANNI LAHTI: Suunnittelukäsikirjan luominen: Tapaustutkimus komposiittimateriaaleista
Tampereen teknillinen yliopisto
Diplomityö, 85 sivua, 4 liitesivua
Tammikuu 2018
Materiaalitekniikan diplomi-insinöörin tutkinto-ohjelma
Pääaine: Polymeerit ja biomateriaalit
Tarkastaja: TkT Mikko Kanerva & tutkijatohtori Ulla Saari

Avainsanat: käsikirja, komposiittimateriaalit, suunnittelu, markkinointi

Tämä diplomityö taviotteena oli ymmärtää käsikirjojen merkitys komposiittiteollisuudessa. Työ koostuu kolmesta eri osuudesta: taustatutkimuksesta, menetelmäosuudesta ja Exel Composites Oyj:n antamasta tapaustutkimuksesta.

Työn taustatutkimuksessa perehdyttiin komposiittimateriaaleihin ja niiden applikaatiohini sekä tyypillisimpiin teollisuudessa käytettäviin käsikirjoihin. Työssä perehdyttiin myös markkinoinnin perusteisiin, jotta saatiin luotua yhteys komposiittien ja markkinointi teorian välille. Aiempien lisäksi, taustatutkimuksessa tutustuttiin erilaisiin suunnittelu ja materiaalikäsikirjoihin sekä teknisen kirjottamisen oppaisiin. Taustatutkimuksen tieto hyödynnettiin itse komposiittimateriaalien suunnittelu käsikirjassa.

Menetelmäosuudessa esiteltiin menetelmät komposiittimateriaalien suunnittelukäsikirjan tekoon. Tämän osion tutkimus tehtiin eri komposiittimateriaali-, suunnittelu- ja mitoituskäsikirjojen sekä Excel Composites Oyj:n avulla. Lisäksi haastateltiin suunnittelukäsikirjan mahdollisia käyttäjiä. Haastattelun tarkoituksena oli selvittää käsikirjojen käytettävyyttä yleisesti sekä millaisia vaatimuksia lukijoilla on komposiittimateriaalien suunnittelukäsikirjalle.

Tapaustutkimus tehtiin Exel Composites Oyj:lle, joka on suomalainen yritys erikoisalanaan pultruutatut komposiittimateriaalit. Yritys halusi päivittää vanhentuneen suunnittelukäsikirjan vastaamaan nykypäivän vaatimuksia. Käsikirjan sisältö perustuu taustatutkimus ja menetelmät osioista saatuihin tietoihin.

Diplomityön teko antoi paljon syventävää tietoa erilaisista teollisuudessa käytettävistä julkaisuista, markkinoinnin perusteista ja komposiittien maailmasta.

PREFACE

I would like to thank Exel Composites Plc. for the interesting case study and especially Market development manager Mikko Lassila, Design manager Jari Ristola and Development chemist Jani Sippola for their help. I would also like to thank Professor Mikko Kanerva and Ulla Saari for being my examiners, and for their advices and guidance during my work.

Lastly, I would like to express my greatest gratitude for my parents of their encouraging words and support during my studies.

Tampere, 20.12.2017

Anni Lahti

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

B2B	Business-to-business
B2C	Business-to-consumer
CMC	Ceramic Matrix Composite
CAGR	Compound Annual Growth Rate
EP	Epoxy
FVF	Fiber Volume Fraction
ILSS	Interlaminar Shear Strength
ISO	International Organization for Standardization
MMC	Metal Matrix Composite
OHSAS	Occupational Health and Safety Assessment Specification
PA	Polyamide
PAN	Polyacrylonitrile –treatment for carbon
PE	Polyethylene
PMC	Polymer Matrix Composite
PP	Polypropylene
PU	Polyurethane
PVD	Physical Vapor Deposition
RIM	Reaction Injection Molding
RTM	Reaction Transfer Molding
UD	Unidireccional
UPE	Polyester
VE	Vinyl Ester
UV	Ultra Violet
VI	Vacuum Injection

1. INTRODUCTION

Handbooks and manuals are the most common form of documentation in the business and engineering environment. Usually the documentation is stored in electronic forms in companies' intranets and publisher's webpages or as e-books, but printed manuals and handbooks are still used as well. The main purpose of these documentations in business environment is to serve information and guide employees and customers about the company's policies and their products and processes. In general, provide better communication between individuals. In engineering environment handbooks are used, for instance, to support calculations and material selections during design processes. It can be considered, that without these documentations, their users would lose valuable reference source, companies would suffer untrained workers and, in worst case, lose valuable customers. [1]

1.1 Background of the study

The background of the study is based on the need for a design handbook of a composite, which is created for Exel Composites Plc. The company wishes to update their old design handbook to serve better information of composites and emphasize the communication with their customers during design processes.

1.2 Exel Composites Plc

Exel Composites Plc is a leading composite technology company that designs, manufactures and markets composite products and solutions for demanding applications. Their head office is located in Vantaa, Finland and production plants are located in seven different countries (Figure 1): Finland, United Kingdom, Belgium, Germany, Austria, China and Australia. The company provides solution for various customer segments (Figure 2) such as industrial applications, construction and infrastructure, and many other applications. [2]

Figure 1. *Production plant locations of Exel Composite Plc. [2]*

Figure 2. *Customer segments of Exel Composites Plc.*

Originally, the company's name was derived from the words Explosive Electronics. It was founded on 1960 by three chemists that were specialized in the production of electronic detonator caps. Officially, composite production started at 70’s and today Exel is the largest manufacturer of pultruded composite products in the world. [2]

Company’s most common manufacturing methods are pultrusion, pull-winding and co-winding and others including continuous lamination and extrusion. They have developed most of the pultrusion technologies of which benefits are possibility of continuous production, to vary the product structure and the controllability of fiber structure during the different stages of the process. [2]

Exel Composites' share is listed in the Small Cap segment of the NASDAQ Helsinki Ltd. in the Industrials sector. On 2017, their half-year revenue were 43.4 million euros. [2]

Figure 3. *Exel Composites Plc's logo. [3]*

Figure 4. *Exel’s carbon fiber reinforced (on left) and hybrid tubes.*

1.3 Objective of the study

The objective of the study is to create a design handbook of composites that meets the requirements that are set from Exel Composites Plc. At the beginning of the thesis will be studied composites and most common handbooks and manuals that are used in the business environment. The objective of the theoretical background is to overview what are these publications, where are they used, and what kind of information they offer. There will be also studied the basic of marketing and the role of sales materials as part of marketing.

Secondly, in this thesis will be illustrated and explained the methodology of creating a design handbook of composites. The objective of this part is to understand which tasks and information the creation process will require and how a design handbook is build. For the background of the creating process will be used the theoretical background studied and interviews of the persons working in the field of composites. As a result of the creating process of a design handbook, there will be introduced a case study of the created design handbook of composites for Exel Composites Plc.

1.4 Thesis structure

The thesis structure is divided into three parts as can be seen from the table 1. At the first part there will be studied the theoretical background for the thesis. This part is shared under three different chapters: composites, basics of marketing and definition of handbooks. At the second part, methodology, will be presented the methods used for building the design handbook. At third part of the thesis, case study, will be presented content of the created design handbook of composites and explained how the structure solutions are done.

Thesis structure

Part number	Name of the part	Content of the part
I	Theoretical background	Composites Basics of marketing Definition of handbooks
II	Methodology	Definition of the case Methods for creating a design handbook
III	Case study	Introduction to the case study Design handbook of composites

Table 1. *Thesis structure.*

1.5 Thesis work structure

The thesis work structure is presented at Figure 5. The thesis work is started by a meeting with Exel Composites. At the meeting there will be discussed about the company's desires and requirements for the design handbook, the scope and target of the handbook and the key information and how it should be presented.

After the meeting, there will be studied the theoretical background for the thesis, which involves basics of marketing and different types of handbooks used in business environment. For closer study there will be selected handbooks of materials and engineering design together with technical writing guides. Based on the study in the theoretical background there will be more understanding about the handbook's structure design and how the handbook's content should be expressed.

The study of theoretical background will be followed by interviewing possible users of the design handbook. The objective for the interview is to survey how useful the design handbooks are seen and do the possible users have any requirements for the content. The answers are then evaluated and the suggestions implemented into the design handbook.

With all the information obtained before will be then used for designing the handbook's structure. This structure design is then revised with Exel Composites before it is finalized. The visual lay-out of the book will be created by external advertising agency and therefore it will not be presented in the thesis and it does not require verification from the company. Final step of the thesis work will be binding the thesis.

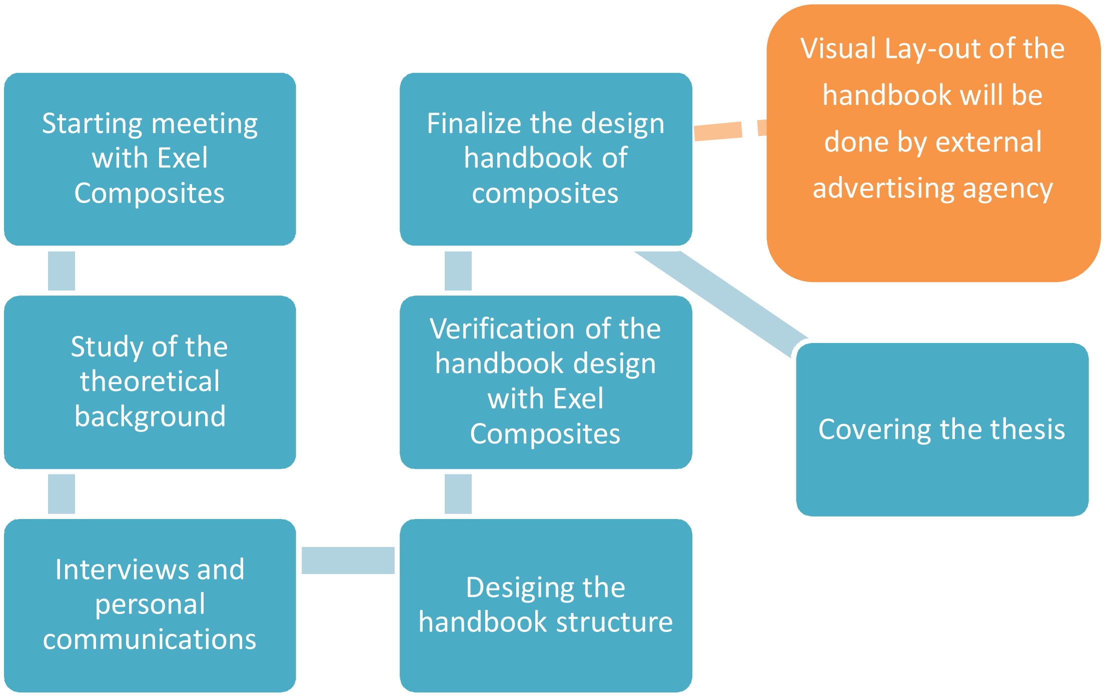


Figure 5. *The schematic of the thesis work structure.*

PART I: THEORETICAL BACKGROUND

2. COMPOSITES

Composite is a material that combines two or more materials, reinforcement and matrix (Figure 6). The matrix, resin system, is the continuous phase that binds reinforcements together and protects them from the imposed forces. The matrix also gives the shape for the product and transfer the imposed forces to reinforcements. Reinforcements provide strength, stiffness, and other mechanical properties to the composite. In most cases, the reinforcement is harder, stronger and stiffer than the matrix. In general, composites vary from other materials, such as metals, in the way that they are anisotropic materials while metals are isotropic. This means that they provide different material properties in all different directions. [4] [5]

Composites can be divided into three groups based on their matrix material. These groups are: Polymer matrix composites (PMC), ceramic matrix composites (CMC) and metal matrix composites (MMC). In this thesis, the term composite is used to refer to a polymer matrix composites. [5]

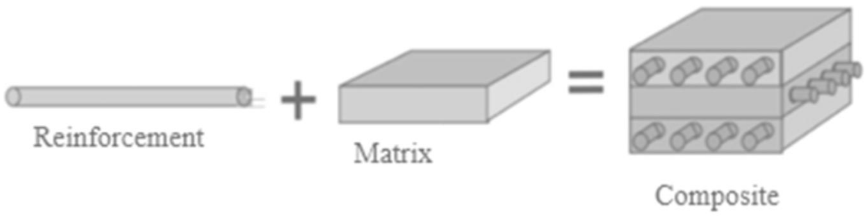


Figure 6. *Simplified composition of a composite. [6]*

2.1 Matrix materials

Polymer matrix materials can be divided into two groups, thermoplastics and thermosets, based on their mouldability. Thermoplastics consist of long polymer chains that do not have any chemical bonds between the chains. The forces between the polymer chains weaken when the plastic is heated and get stronger when cooled. Therefore thermoplastic materials are re-moldable with the aid of pressure and heat. Most common thermoplastic matrix materials (Figure 7) are polyethylene (PE), polypropylenes (PP) and polyamides (PA). [5, p. 18]

Figure 7. *Most common thermoplastic matrix materials. [7] [8] [9]*

The most common matrix material for PMC's are thermosets. Thermosets are fabricated from resins that are chemically cured. In the curing reaction the polymer chains of the resin are cross-linked into a reticulated structure. Once the cross-linking between the polymer chains has occurred, the structure cannot be re-molded. [5, pp. 18-19]

Some of the resins can be cured just with the aid of a heat but many of the resins requires to be mixed with a hardener to establish the curing reaction. The curing reaction is an exothermic reaction, where will be released heat. During the reaction there can occur a shrinkage in volume of the resin, but it can be avoided with shrinkage agent. [5, pp. 18-19]

At the beginning, the curing reaction (Figure 8) advances slowly, which allows shaping of the product. The time that is required for the shaping is called gel-time. After gel-time the reaction advances fast and the temperature of the laminate arises. The highest temperature during the curing reaction is called the peak exotherm. [5, pp. 18-19]

Most common thermoset matrix materials are polyesters, epoxies and vinyl esters from where epoxies are the most expensive ones and polyesters the cheapest.

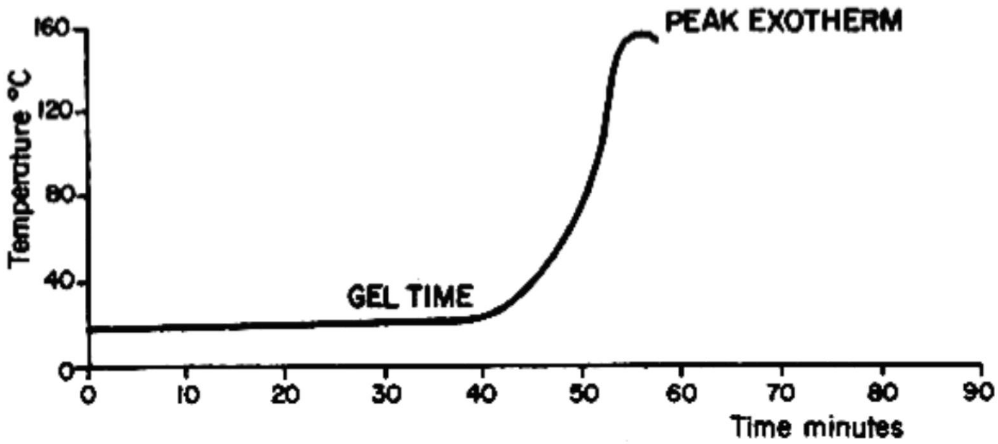


Figure 8. *Curing reaction of a thermosets.*

2.1.1 Additives

Additives are fine minerals, pulverized glass or metal particles that are mixed with resins. They are used to reduce the raw-material costs, improve processability of the resin and enhance the thermal- and electrical conductivity of the final product. [5, p. 20]

2.2 Reinforcement materials

Composites are made by reinforcing the matrices with fibers. Most common reinforcement fibers are made of glass, carbon or aramid fibers (Figure 9) from where carbon fibers are the most expensive ones and aramid the cheapest. Some natural fibers such as jute, hemp and flax are used as well. [5, p. 20]

One fiber has a thickness of a micron, therefore for processing they are gathered together into strands or twisted yarns. Commonly, threadless glass fiber strand is called roving and carbon fibers tows. [5, p. 20]

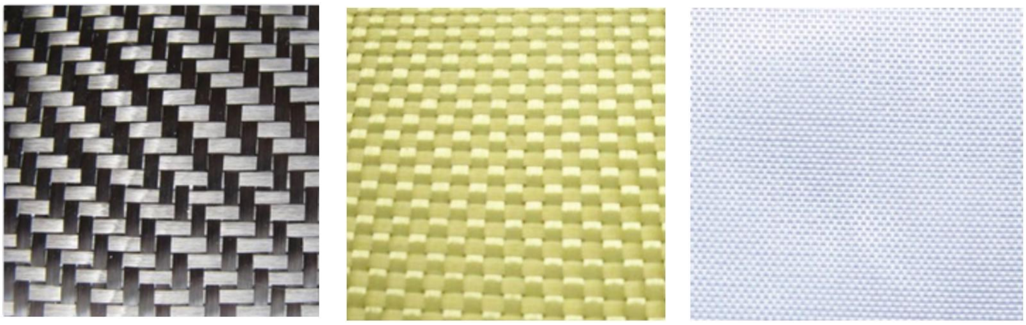


Figure 9. *Carbon, aramid and glass fiber fabrics. [10]*

2.3 Reinforcements preforms

In composites, reinforcement fibers can be used in different forms such as continuous and discontinuous fibers or in further processed forms as non-woven fabrics (mats), woven fabrics (Figure 10) or braids. In same product, there can be combined more than two types of reinforcements preform from where the most common combos are weaves or strands with mats.

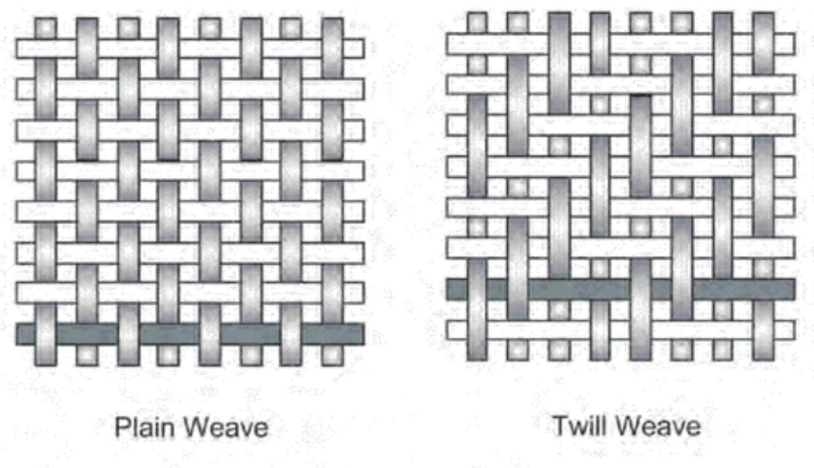


Figure 10. *Different woven fabric types used in composites. [4]*

In same product there can be used more than one different reinforcement, when it is called hybrid reinforcing. This hybrid reinforcing can be made with preforms made out with two or more different materials (Figure 11), or from two or more separate preforms of different materials. The aim with hybrid reinforcing, is use the typical properties of each reinforcement in the best and most cost-effective way.

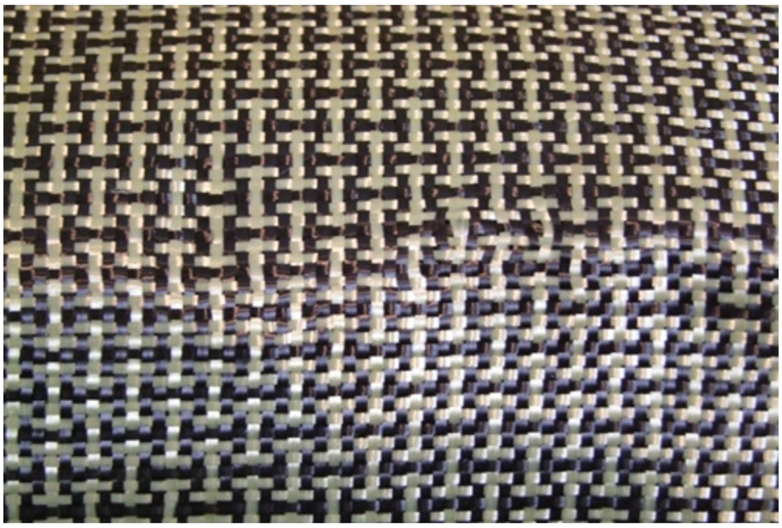


Figure 11. *Carbon fiber and aramid hybrid fabric. [11]*

2.4 Prepregs

Prepregs are pre-impregnated reinforcements where the fibers have been impregnated with the matrix material, commonly thermoset. In thermoset based prepregs, the resin has been left into a half-cured state, B-state. Since the thermoset based prepregs contains all the ingredients needed for the curing, their storing times are limited. With prepregs there are a possibility to achieve a very high fiber content on the composite. [5, p. 21]

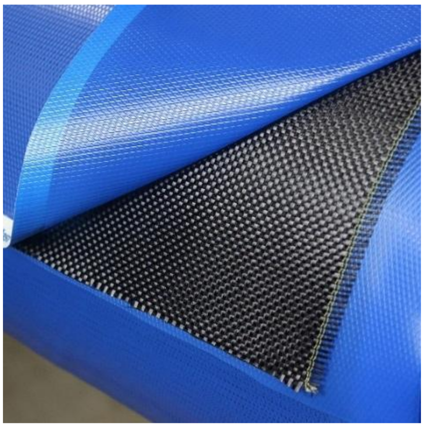


Figure 12. *Carbon fiber prepreg. [12]*

2.5 Materials storing and handling

Reinforcements and resins have limited shelf time. Commonly, polyester resins can be stored for half year and epoxy resins over a year while their hardeners are limited on one year. This is because the properties of the resins may change significantly if they are stored for a long time. [5, p. 400]

Since low temperature decelerates chemical reactions, many of the raw-materials for composites are stored at low temperatures. Polyester resins can be stored at below 0 ºC but epoxy resins requires storing above 0 ºC. From prepregs, only thermoset based ones requires cold storing at -18 ºC where the shelf time varies between 6-12 months. [5, p. 400]

The temperature and humidity conditions of the production facility have great impacts on the composite manufacturing. Temperature affect on the viscosity and hardening properties of the polymers while humidity can prevent the curing reaction of resins. Therefore, in the ideal working environment the temperature is kept at 20-25 ºC and humidity at 40-60 %. [5, p. 400]

2.6 Manufacturing methods

There are variety of different methods for composite manufacturing, which can be categorized into four groups based on the technique used (Table 2): lay-up, injection, compression molding and continuous methods. [5, p. 21]

Manufacturing method			
Lay-up	Injection molding	Compression molding	Continuous methods
- hand lay-up - spray-up - wrapping - filament winding	- resin transfer molding (RTM) - vacuum injection (VI) - centrifugal casting - reaction injection molding (RIM) - injection molding	- compression - molding - transfer molding	- pultrusion - extrusion - rolling

Table 2. *Composite manufacturing methods. [5]*

In lay-up techniques the reinforcement and matrix are molded in layers on the mold. In injection techniques the reinforcement-matrix mixture is injected into the mold with the aid of pressure. In compression molding the raw-material is charged into the lower mold half. After the lower mold half is charged, the both halves are then compressed together. Continuous methods are used to manufacture tubes and profiles continuously. [5, p. 21] [13]

In addition, composites can be manufactured by combining the basic methods mentioned previously. A good example of combining the basic methods is the combination of filament winding and pultrusion, pull-winding. [5, p. 21]

2.7 Composite applications

Composites have various applications where they can be used including aeronautics, automotive, marine, civil engineering and sport industry. In general, for light weight structures requiring high strength and stiffness are commonly used more costly, high-performance carbon fiber composites and much lower-cost fiberglass composites are used in less demanding applications where the weight and price are not as critical. [4, pp. 18-19] [5, p. 433]

2.7.1 Aeronautics

The major reason that composites are used in aviation industry is their light weight. Composite structures that are manufactured with the modern techniques are 15-20% lighter than those made of aluminum. Additionally, composites provide smoother surface structures, thus reducing the air resistance. [5, pp. 433-434]

In helicopters the rotor-blades are built of glass fiber–reinforced composites for improved fatigue resistance, and their airframes are built of carbon-fiber composites. In military aircraft applications, high-performance continuous-carbon-fiber composites are mainly used, since carbon fiber provides high specific strength. In commercial aircrafts, high-performance composites are used to decrease weight and increase fuel performance. From commercial aircrafts, the most outstanding example of composite use is the 50 percent composite airframe for the new Boeing 787 (Figure 13). [4] [5]

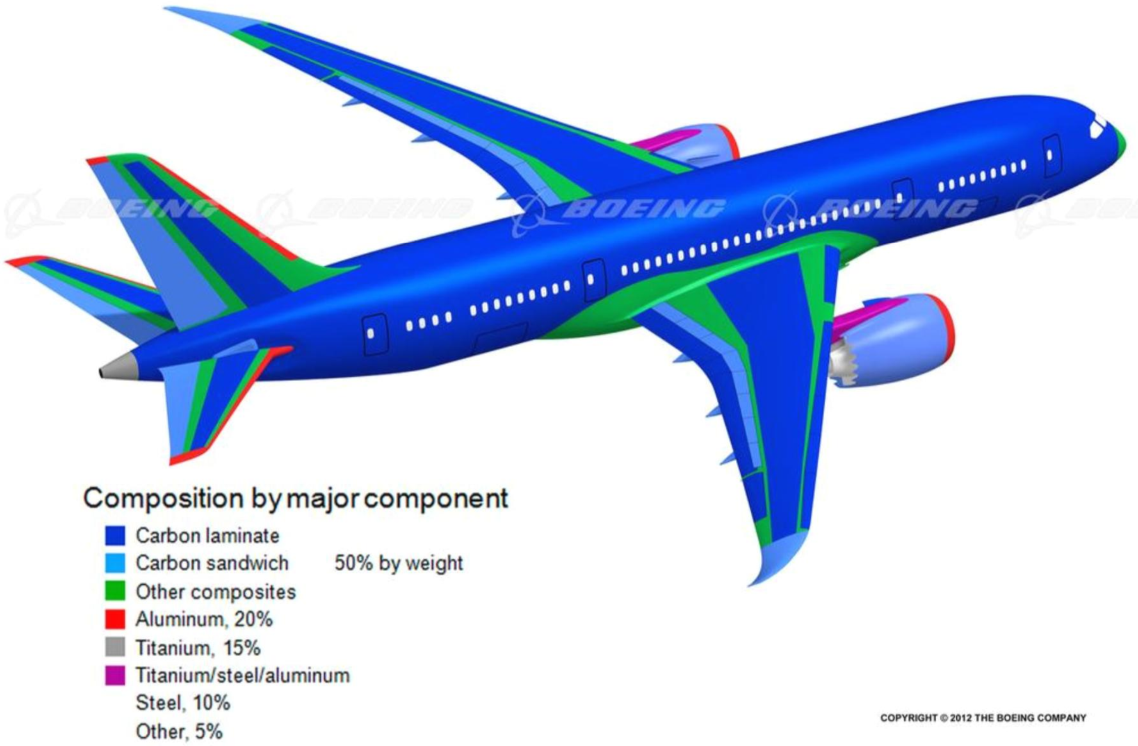


Figure 13. *Boeing 787 Dreamliner commercial airplane. [14]*

2.7.2 Automotive

In automotive industry such as in aeronautics, composite are used for weight reduction of the structures and therefore improved fuel efficiency. In commercial transportation composites are used since they provide lower weight and maintenance costs along with good surface quality and recyclability. [4, pp. 20-21] [5, pp. 434-435]

Typical applications of composites in automotive industry are bumpers and the plate-like parts of the car interior that are made of fiberglass together with polyurethane or polyester matrix. In leisure vehicles, buses, trains and trucks, for the outer panels and other interior parts are used glass fibers, mostly for their durability and weight savings over metal. For high-performance Formula 1 racing cars (Figure 14), where cost is not a question, most of the chassis, including the monocoque, suspension, wings, and engine cover, is made from carbon fiber composites. [4, pp. 20-21] [5, pp. 434-435]

Figure 14. *Formula 1 racing car. [15]*

2.7.3 Marine

In marine industry the primary reasons for composites applications are their cheap price, low maintenance costs and light weight along with good strength and stiffness properties when compared with metal and wood based applications. Another important factor is the good corrosion and environmental resistances of the composites, where the metals are more prone to corrosion and wood to rupture. [4, pp. 20-21] [5, p. 436]

The boat hulls are mainly made of glass fibers and polyester or vinyl ester resins while the masts are fabricated from carbon fiber. In many naval ships, the topside structures are also fabricated from composite. [4, pp. 20-21] [5, p. 436]

Fiberglass filament-wound pressure tanks and pipes are used in marine industry. These tanks and pipes are 40 % lighter, and can hold more air while they require less maintenance than the metallic ones. Composite based superstructure in oil platforms are lighter and requires less maintenance. Additionally, the composite structures in oil platforms are safer since their maintenance do not require welding and their heat transfer rate is low, which provides good protection in the case of fire. [4, pp. 20-21] [5, p. 436]

2.7.4 Civil engineering

In civil engineering the major reasons to use composites are their light weight, good weather, chemical and corrosion resistance as well as their thermal insulation properties. Also their flexibility in design has increased the favor as construction material. [5, p. 440]

The main applications are outer panels and window frames of facades along with outdoors. In indoor applications, composites are mostly used in bathroom furniture and panels. In construction, fiber-glass rebar is used to strengthen concrete. [4, pp. 20-21] [5, p. 440]

Since composites provide longer life with less maintenance, they are used to improve infrastructure. Typical infrastructure applications made of glass fiber composites are different light poles and masts (Figure 15), and electrical towers as well as randomes. Carbon fibers are used in demanding infrastructure applications such as bridges and as a repairing material for old bridges and building. [4, pp. 20-21] [5, p. 440]

Figure 15. *Frangible approach lighting masts made by Exel Composites Plc. [2]*

2.7.5 Sport and leisure industry

Due to fast product development, open-mindedness and fast adaptation of new solutions and methods are very common for sports and leisure industry. Therefore composites have become one the key materials for the industry by providing ability for differentiation in prices and product properties. Commonly, non-professional products are made out of cheap materials such as glass fiber-reinforced polyester and products for professional use are made of carbon fiber-reinforced epoxy. Other materials that are used in sports industry products, are aramid, polyethylene, boron, ceramic fibers and vinyl resins as well as some prepregs. [5, pp. 444-445]

The main applications are winter sport equipment such as skies, snowboards (Figure 16), ice hockey sticks and sleds as well as summer sport equipment like tennis rackets and golf bats together with bicycle frames (Figure 17), surfboards and many other applications. Generally, there are no other limits than the cost for composites use in sports industry. [5, pp. 444-445]

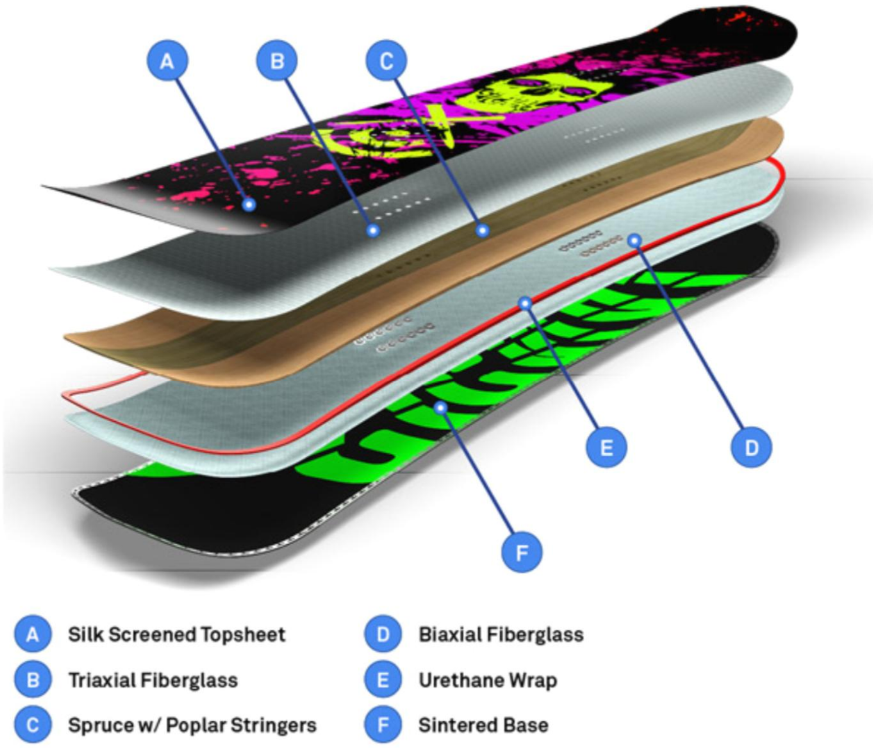


Figure 16. *The anatomy of a snowboard. [16]*

Figure 17. *Carbon fiber reinforced bicycle frame. [17]*

2.8 Future prospects for composites

On 2016, Lucintel estimated in their market report the increasing development of low-cost carbon fibers to be used in mass volume applications. Since carbon fiber is significantly more costly than glass fiber, it is mainly used for high-performance applications where weight requirements are critical. According to Dr. Sanjay Mazumdar, development of specific applications are increasing carbon fiber demand in the U.S., including the rising use of carbon fiber in next-generation aircraft, electric and sports cars, and wind turbine blades, which are getting increasingly longer. Along with carbon fiber predictions, Lucintel estimated increased development of high-performance glass fibers to meet higher mechanical and chemical requirements, as well as development of high-strength natural fibers to enter better in automotive, construction and other industries. [18]

In the resin market, on 2016 Dr. Sanjay Mazumdar named four development trends that will continue for next years: development of shorter cure times for mass volume applications, development of resins with optimum gel times for long wind blades, development of low-cost and high-strength nano-resins, and development of bio resins for various applications. Despite these advances, in many industries such as construction, marine and automotive polyester resin continues to be the most demanded due to its low cost and high corrosion resistance. [18]

From 2017, the global composite materials market is expected grow at a CAGR (compound annual growth rate) of 5.1% to reach an estimated $39.1 billion by 2022. The global composites end product market is expected to reach an estimated $113.2 billion by 2022. The major reasons for growth in this market are increasing demand for lightweight materials in the aerospace, defense and automotive industry, corrosion and chemical resistance materials demand in construction and pipe & tank industry among with electrical resistivity and low flame retardant materials demand in electrical and electronic industry. [19]

2.8.1 Major market segments

Based on Lucintel's market report on 2016, transportation, construction and aerospace were the largest market segments within the composites industry in 2015, representing 62% of its total value. In the Lucintel's chart, from 2016, (Figure 18) has estimations for several composites market segments from 2015 to 2021 in terms of billions of dollars shipped. Out of all markets listed, aerospace has the highest growing potential, with a CAGR of 9.5% over the six years. [19]

U.S. Composite Materials Demand Forecast ($Billion)

Applications	2015	2021	CAGR (2015-2021)
Transportation	2.4	3.3	5.2%
Marine	0.4	0.5	3.2%
Wind Energy	0.2	0.4	8.0%
Aerospace	0.8	1.4	9.5%
Pipe & Tank	0.7	0.9	3.0%
Construction	1.4	1.8	4.1%
Electrical & Electronics	0.7	0.9	3.8%
Consumer Goods	0.4	0.5	3.6%
Others	0.4	0.5	5.7%
Total ($B)	7.5	10.2	5.1%

Source: Lucintel

Figure 18. *U.S. Composite Materials demand forecast. [18]*

On 2017 are estimated that automotive composites market is evaluated to grow at a CAGR of 8.08% from USD4.965 billion in 2017 to USD7.322 billion by 2022. The estimation is based on the increasing fuel prices and growing concerns over the availability of limited non-renewable resources. These concerns are expected to be avoided with the properties and advantages of composites such as weight reduction of the vehicle, resistance to chemical corrosion and improved performance. Also, the growing economies like China and India are expected to provide growth on the automotive markets. [20]

For the aeronautic composites market are estimated growth from USD 26.87 billion on 2017to reach USD 42.97 billion by 2022, at a CAGR of 9.85% between 2017 and 2022. The growth is based on the increasing use of composites in the exterior and interior in commercial and military aircraft. However, high processing and manufacturing costs of composites and lack of standardization in aeronautic composite manufacturing technologies are seen restraining factors on the growth of the aerospace composites market during the forecast period. [21]

2.8.2 Opportunities and challenges in the future

According to Dr. Sanjay Mazumdar and Lucintel's market report, in the next 50 years, there will be significant innovations in the composites industry for increasing composites performance, reducing their cost and process time, and making composite applications more environmentally friendly. Together with the future innovations, composite industry is already continuously moving toward automated manufacturing process and better design and simulation tools. These techniques and tools requires deep understanding of composites so that the designers and engineers are able to figure out better solutions for current and future challenges. [18] [19]

However, based on Lucintel's market report, the composites industry struggles to attract and educate new talent. The challenge for companies is not only to attract graduates but also to retain existing skilled technicians and designers. [18] [19]

Another challenge for the composites industry has been and still is its inability to grow in various industries by replacing traditional materials such as steel and aluminum. For the future growth, the industry needs to work on four areas to gain competitive edge over traditional materials: Education of engineers and designers about the benefits and use of composites in mass volume markets; Development of a cradle-to-cradle infrastructure emphasizing composite repair and recycling issues; Development of advanced manufacturing processes by targeting one to two minutes cycle time for mass volume markets; Reduction in the price of advanced fibers and parts to make them competitive with steel and aluminum. [18]

3. BASICS OF MARKETING

"*Good marketing is no accident. It is both an art and a science.*" [22, p. 25]

Without marketing, most of the business actions do not have much sense. If the product is not introduced to the market there is no demand for that product and therefore the business does not make any profit of it. By good marketing businesses build strong brand and in best cases a loyal customer base. Strategic marketing is the art and science of determining what your customers really want now and in the future and to meet these specific needs profitably. [22, pp. 25-27] [23, p. 7]

The modern marketing decisions based on analytical and mathematical models places its roots at the beginning of the sixties. Before that time, marketing decisions were mainly based on result and experience. The emphasis was more on collecting facts than on analyzing these facts in the way that they would help on an executive decision making. After sixties the development of marketing decision models has expanded from its areas, such as economics and operations research, to a field of its own by incorporating a variety of new approaches over a time. [24, pp. 3-20] [1]

3.1 Understanding marketing

As in every business area, for successful marketing there is one most important rule: customer is always right and they buy for their reasons not for the company's. Some customers can be selfish, demanding, ruthless, disloyal, and unpredictable. But they are always right, based on their own needs, wants, desires, and ways of thinking. Customers will change suppliers whenever they feel that there would be someone else providing them better service. Therefore the success of the business is largely determined by the ability to appeal to customers real desires, and to satisfy their wants and needs as they perceive them. By evaluating the today's and yesterday's trends and predicting the customers future needs, the business can often be advanced over the competition and dominate new markets even before they emerge. [23, p. 7]

In general, the purpose of marketing is to create utility, usefulness, and satisfy the needs of the customers to achieve a specific result. The customers are offered something they need and can use to accomplish their other goals. For instance, people do not buy entrances to concerts; they buy the experiences. There the entrance ticket has the utility value for achieving the wanted result, the experience. [23, pp. 10-11] [1]

For a customer each purchase is a risk and a possibility to satisfy their need at the same time. Therefore it is important to adapt to the customer's reality, both social and economic. Every product has the primary reason why the customer would buy it but it also triggers a fear which holds the customer back from buying that product. For instance, the customers are mostly afraid of losing their money on a product that does not serve them in the desired way or that they would pay too much of the product. Whatever the fear is, it will hold the customer back from buying the product. Optimizing the primary reason and minimizing the possible fear and risk creates bigger markets for the product. For instance, the risks and fears can be minimized by giving the customers a possibility to try that new product for 30 days and if they are not satisfied they have full right to return it and get their money back. [23, pp. 10-11]

As highlighted before, the customer has the major role for the company to succeed in business. Customer's needs and fears greatly controls their purchasing behavior, therefore a successful marketing is winning over the customers' trust and treasure the built relationships with them to keep them loyal by working closely with the customers. If something goes wrong or not in the desired the most important is not to leave the customer alone with the problem. It is essential that the customer has the feeling that after the purchase they are as important as before purchasing the product. Working closely with customer also requires to show the full potential and possibilities of the purchased product which can be achieved by good product instructions and tutorials. [23, pp. 10-11] [25]

3.2 Business versus consumer markets

The market structure and product characteristics are very different in business-to-business (B2B) markets compared with business-to-customer (B2C) markets. This results differences at the purchasing behavior and decision making process. [26]

Marketing actions for selling products to B2B markets are generally very different from those used on B2C markets. Business customers, including manufacturers, wholesalers and retailers, governments, and nonprofit organizations, very often are purchasing for the purpose of creating another product. Thus, their needs are different from those of general consumers. Generally, products that are sold in B2B markets are more complex than those at B2C markets. Therefore, in B2B markets there is more need for more detailed technical knowledge. The technical knowledge can be built from understanding the supplier's operations or product functions or customers' needs and operations because very often, when selling solutions, the potential customer wants to know does that particular solution fits for their needs. [25] [26]

In many ways, marketing for business customers is often easier. Most likely they have clearly defined needs and purpose for the product that they are buying, they are less sensitive for the price and more willing to study information of the product that may help them to make their job better. Nonetheless, marketing to business customers can be complicated. For instance, in organizations usually a purchasing process can go through several decision makers. Very often business customers are be more doubtful about trying a new product or a new company because they do not want to be responsible of a making a poor decision if the product does not meet the organization's expectations. [25] [26]

Generally, the difference between marketing to business and consumer markets is that consumers are typically considering purchasing a product that they might enjoy but do not really need it while business customer needs that product for finishing their own product. It is hard to say whether it is more difficult to sell consumers than to business customers. However, consumers typically make a buying decision on their own, or at least through an informal decision-making process involving family members or friends, and are much more likely to buy on impulse than business customers. [25] [26]

3.2.1 Role of the sales material in B2B markets

Nowadays businesses are more interested for having a longer term relationships with their customers. The long term relationship causes businesses to focus on finding value adding partners, which lead businesses adopt value-based selling. The objective of value-based selling is to demonstrate for the customer how the offerings can be aligned in the customers' operations in a way that creates value for them. To demonstrate the objective clearly, different sales materials may become very convenient. [26, pp. 62-67]

Companies rely on the sales department for building profitable relationships with their customers in the business markets. In B2B markets, personal selling is the most important way for marketing products, therefore sales persons need to be skilled to explain the technological capabilities of their components and services to the customers. [26, pp. 62-67]

There are many tools for sales persons to use to succeed in the sales process from where ones to mention are brochures and handouts with given details of the product features, benefits and technical specifications. These brochures support the sales persons to position the products effectively in the customers' mind. In many cases, things that can seem self-evident for the seller may actually require more explanation for the customer. In these cases the brochures may become handy since the customer can always return to them to find more information. In addition, sometimes these brochures may even awake bigger interest towards the products and services that the company is providing. [26, pp. 62-67]

4. DEFINITION OF A HANDBOOK

There is not any clear difference between the terms manual and handbook so it can be considered that difference is more the context where the term is used. Mostly, the term manual is used when talking about certain types of practical information providing publications such as technical documentations for machine operation or maintenance or documentation for new employee. The term handbook is more used when referring to more theoretical fact consisting publications about materials, formulas or, for instance, about law. However, all these same sort of publications may be termed as guide and reference books as well.

As noted above, not all manuals and handbooks are similar but all of them share same target: to encapsulate the core of the subject area and pass the knowledge from those who creates it to those who needs. [27]

4.1 Scope of a handbook

A handbook should be as comprehensive as possible but within clearly defined boundaries: it should contain all the information that is required by the audience to understand the topic or follow instructions. The purpose and audience determine the scope of a handbook by giving it the boundaries. [1]

It is important to define the audience for the publication because the knowledge of a certain topics and language varies among different groups of people. The used terminology and assumption of what is considered to be explained of the topic, and what is kept obvious knowledge, depends mostly on the reader. For instance, if a handbook contains technical terms or illustrations, charts and diagrams, the explanations should fit to the audience level of knowledge. [1]

4.2 Types of handbooks in business

As noted before, not all handbooks and manuals are alike. Whether one handbook or manual is for a new employer, the one is for machine operation. All of these publications have their target audience with their specific information need. [28, p. 8]

In business, different handbooks are used as a corporate documentation. The companies uses handbooks and manuals to keep employees, suppliers, customers, shareholders, and anybody who has an interest in their business up to date of their policies, procedures, and regulations. Mostly, these types of handbooks are for promoting the corporate publicity as well as clarifying the policies. [1]

Other important field where handbooks are used is technical documentation. This type of documentation is used to guide how to use technology. In this type of documentation there is explained how the equipment or program works, how it should be maintained and what to do when a malfunction or emergency occurs. These documentations are needed to prevent misusage of the machinery and therefore to avoid any possible emergencies or breakages. [1]

Tutorials and instruction handbooks are used to support learning and working. The objective of these types of documentation is to teach something of some specific subject and provide support for already existing knowledge. These documentations contain statistics, lists of constants and standards, formulas, and many other kinds of information that is not easy or so necessary to remember. [1]

4.3 Examples of handbooks

4.3.1.1 Design handbooks

> *"Design is a funny word. Some people think design means how it looks. But of course, if you dig deeper, it's really how it works."* (Steve Jobs) [29]

As Steve Jobs noted, the term *design* creates many associations. It can be used as a noun, referring to an objects esthetic appearance, or as a verb, describing the function of creating the object. [30, pp. 1-3]

Whether it would be technical or fashion product, the term design covers the whole concept of the product development process, therefore in this section there is discussed handbooks of engineering design to narrow down the scope of the study.

Engineering design handbooks are used to support the product development process. They provide information about different design methods and formularies to go through the necessary calculations and the importance of tolerances and correct uniting. Since in the engineering world the final products can be varying from buildings to software, each of the product fields have their own design handbooks where the design processes are explained more detailed. [30] [31]

4.3.1.2 Handbooks of technical writing

Handbooks of technical writing are writing guides for persons working in technical or scientific field. These books present the basic characters of an engineering document. They guide how the structure is build and what kind of information each section should contain and the way it should be presented. They also provide information about correct writing style and grammar to avoid misuse or overuse of the words, and for making clear and logic structure for the document. [28] [32]

Mostly, these handbooks are used to support the writing processes of engineering publications which, occasionally can be really difficult tasks to proceed.

4.3.1.3 Material handbooks

Material handbooks are reference books that provide information about the characteristics of the material and its properties. These books describes the chemical structure and manufacturing methods for the particular material, what are the materials advantages and disadvantages and its possible applications. These books also presents the mechanical properties (Figure 19) or other technical data of the material and, in some cases, formulary to proceed in calculation to define the material properties. [33] [34] [31]

These handbooks are used with technical design handbooks to support material selection during design processes, for teaching or as a reference book in a research.

Table 18.4. Properties of selected polymer matrix composites (PMCs)

Polymer matrix composite materials	Density (ρ/kg.m^{-3})	Young's modulus (E/GPa)	Ultimate tensile strength (/MPa)	Linear thermal expansion coefficient (α_L/10^{-6}K^{-1})
Epoxy resin reinforced with 50 vol.% boron fibers	2020	201		6.1–30
Epoxy resin reinforced with 60 vol.% kevlar 49	1450	65	1365	56
Epoxy resin reinforced with 60 vol.% carbon fibers	1580	131	1516	30
Epoxy resin reinforced with 60 vol.% zirconia glass fibers	2004	45	1426	
Epoxy resin reinforced with 72 vol.% S-glass	2130	61	1688	17
Nylon 66 reinforced with 40 vol.% glass fibers	1460	11	1350	25
Polypropylene reinforced with 40 vol.% S-glass fibers	1230	9	1220	

Figure 19. *Table 18.4. from the Materials Handbook [33, p. 1031]*

PART II: METHODOLOGY

5. CASE DEFINITION

The need for the Design Handbook of Composites comes from Exel Composites Plc. They want to update their old designer's handbook (Figure 21) and collect information together to serve more versatile and better-qualified information of composites and on the side market the solutions that Exel Composites is offering. (Mikko Lassila, Exel Composites)

The new design handbook should clarify the design and manufacturing processes of composite products and introduce the factors, such as selection of materials and manufacturing method that have effects on the final product properties. It should be an aid for the customers and personnel of Exel Composites. Moreover, the handbook should make working with composites more straightforward.

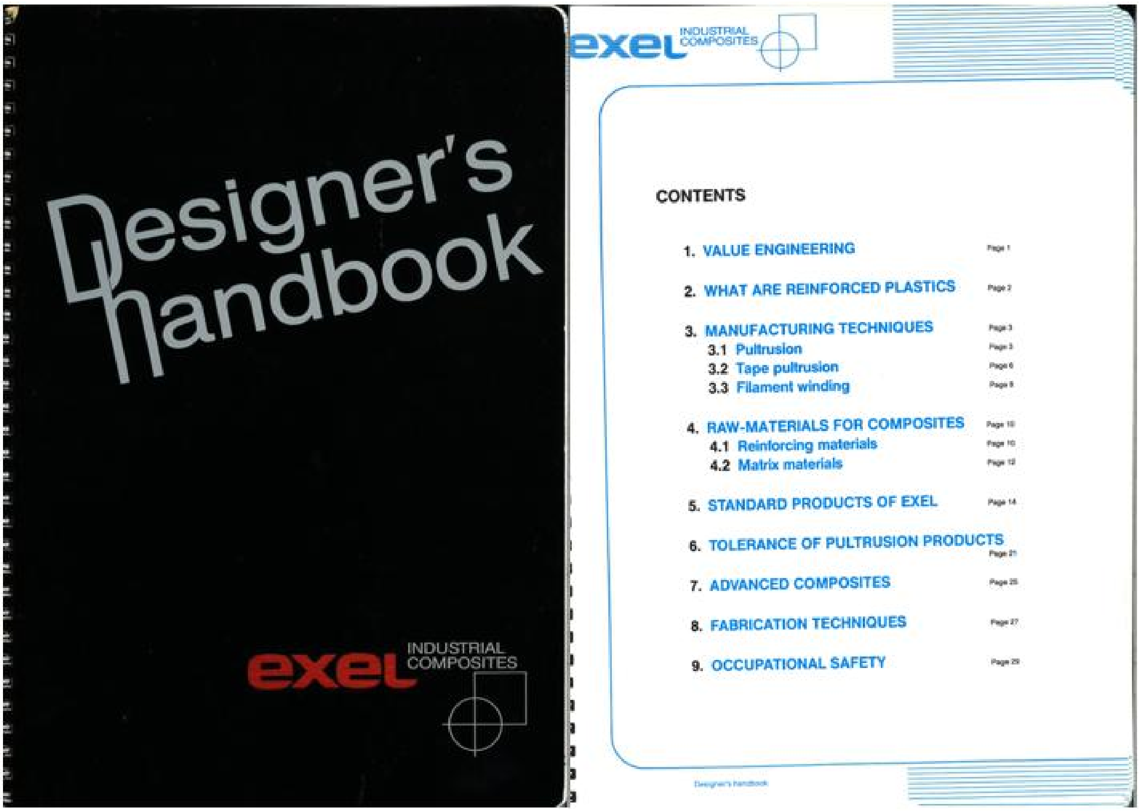


Figure 21. *Old designer's handbook's front and contents page [35]*

6. METHODS FOR CREATING A DESIGN HANDBOOK

To create a handbook, it is important to identify the main purpose of the book. The creating process (Figure 22) of this handbook begins with visualizing and identifying the problem, which follows by defining the concept.

In this case, the problem is that the old handbooks are outdated and the vision is to replace them with a new handbook that would collect the useful information from the old handbooks together. The constructing concept is a design handbook and the sub-constructing concepts are to help understand composites and make composite related designing more straightforward as well as marketing the products and services of Exel Composites Plc.

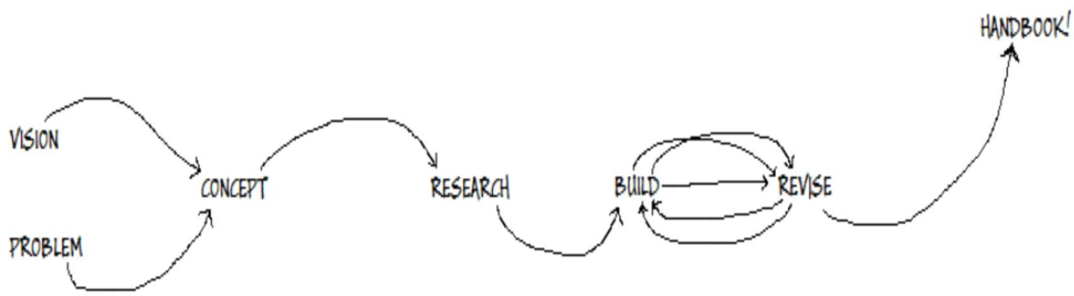


Figure 22. *The creating process of the handbook.*

After defining the concept, the next step is to start the research by collecting the needed data. The data is collected by studying basics of marketing, material handbooks, manuals and interviewing persons with different work backgrounds. These work backgrounds consists of designers, researchers, buyers and marketing personnel, but mostly of persons that have some contact with composites. These answers are then evaluated and compared with other composite material- and design handbooks and user manuals as well as with the Exel Composites' old designer's handbook.

The last step is to gather the collected data together and build the book. To be sure, that the handbook has all needed information to provide for the readers, and that it will be sufficiently clear to understand, it will be revised with the personnel of the company and composite experts as many times as needed.

6.1 Personal communication

The information research for the handbook is partly done by face-to-face or email conversations with the personnel of Exel Composites. These persons are market development manager Mikko Lassila, product design manager Jari Ristola and development chemist Jani Sippola.

6.2 User interviews

The targets of the interviewing is, firstly, to overview how useful the handbooks are seen and secondly to survey what kind of information those interviewed persons are expecting and hoping to find from a design handbook of composites. It is also requested to evaluate that if a use of a design handbook of composites would change the view of composite related working.

The interviewing is done through email or calls with preselected persons that could be possible users for the handbook. All these persons have some level of knowledge of composites because of their studies or work. The interview consists of following questions:

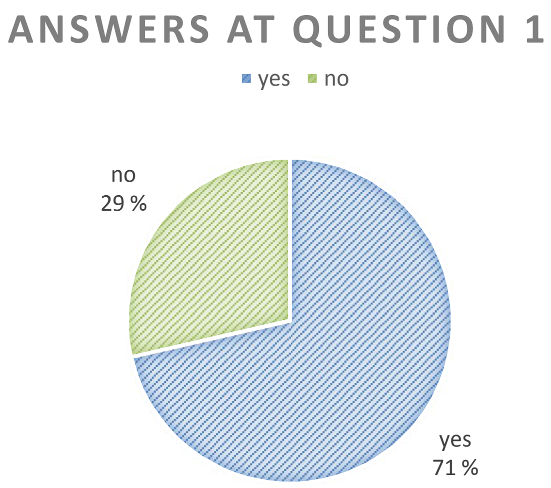
1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10)?

2. Working as a ____________, what kind of information would you like to find or you would expect to find from a design handbook of composites?

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

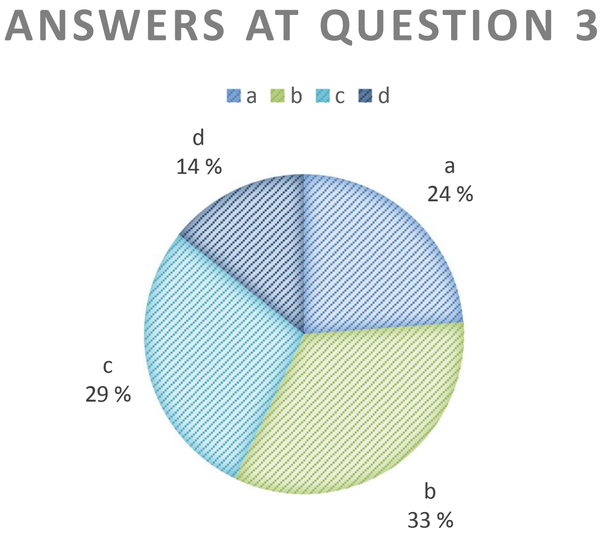
For the first question 71% responded, that they have used some material handbook in their work or studies and 29% answered that they have not used any material handbook (Graph 1). From those who had used material handbooks, many found the handbooks useful, but incomplete, missing some essential information or the structure were unclear. One third ranked the handbooks they used to be full 10. The reasoning were that these handbooks were clear, reliable and they covered the presented topic. Those, who had not used any material handbook, were afraid that the information in them might be expired and therefore kept them less trustworthy. These persons trusted more companies' data banks in electronic forms or direct data inquiries from the manufacturer.



Graph 1. *Distribution of the answers on Q1*

Based on the second question, all the respondents are expecting to find information about the mechanical properties of the reinforcements and resins. Which are the best materials, their advantages and limitations. Respondents assume that there will be explained how to design with composites covering the topics of main design rules and possible manufacturing methods with their advantages and disadvantages. Additionally, the material resistance and sustainability of composites is thought to be important information, which should be found from the design handbook as well.

On third question, there were possibility for multiple choices. As can be noted from the Graph 2, 33 % said that working with a design handbook of composites would make selecting of the products faster and 29 % of the answers say that the design process of composites would be more straightforward. 24 % of respondents believe that working with a design handbook would make composite materials more appealing and only 14 % of the respondents believes that it would be easier to estimate costs of composite structures or products.



Graph 2. *Distribution of answers at Q3*

As a summary of the interview, the respondents are looking for a versatile design handbook, with clear structure and updated information about material properties and manufacturing methods. They also believe that a design handbook of composites would make selecting of composite products faster and designing more straightforward. The interview responses can be seen in Appendix A.

PART III: CASE STUDY

7. INTRODUCTION TO THE CASE STUDY

The design handbook of composites is build based on the interview results and information obtained from the thesis' part two and three; theoretical background and research. For the content and structure, the requirements set by the company will be also respected. Since the handbook will be a design handbook for composites, the focus covers also aspects to make the reader to understand the main issues of the design process and the concept of composite structure: what they consists of and what are their key properties.

7.1 Determination of the handbook structure

The original structure for the design handbook of composites was designed by the company beforehand and it is presented on Figure 23. From the original content, chapters 3.3. Laminating, 5.1. Case study and 7 occupational safety will be excluded after further consideration with the company.

In addition for the original structure, there will be changed the chapter of designing wall structures to a chapter about composite design. In that chapter, there are presented the composite design process, general guidelines for composite design as well as tolerances, so that the handbook user will understand the main steps that are involved to the process. The updated handbook structure is presented at Figure 24.

A handbook must be occasionally updated to include the latest technological achievements for composites. Also, it should be noted that the final formation, visual lay-out and update of the handbook will be offset by Excel Composites Plc.

EXEL DBOC (Design Book of Composites)

Content

1.	**Value Engineering**	Foreword, sustainability
2.	**What are composites (reinforced plastics)?**	Definition of composites, background for reinforced plastics, material comparison table
3.	**Manufacturing techniques**	Insights
3.1.	Pultrusion	
3.2.	Pullwinding	
3.3.	Laminating	
4.	**Materials**	
4.1.	Reinforcements	GF, CF, Aramid, Synthetic, Natural fibers, etc.
4.2.	Matrix	VE, PE, EPOXIES, PU, thermoplastics? etc.
4.3.	Hybrids	What are hybrids, what needs to be taken into consideration when incorporating with other materials
5.0.	**Designing wall structures**	Different layouts, structures, example cases, tolerances, design limitations
5.1.	Case study	
6.0.	**Fabrication**	
6.1.	Cutting	including beweling
6.2.	Drilling	
6.3.	Machining	
6.4.	Punching	
6.5.	Glueing	
6.6.	Painting	
7.0.	**Occupational safety**	
8.0.	**Sustainability**	Code of conduct for sustainability

Figure 23. *Original structure for the design handbook of composites.*

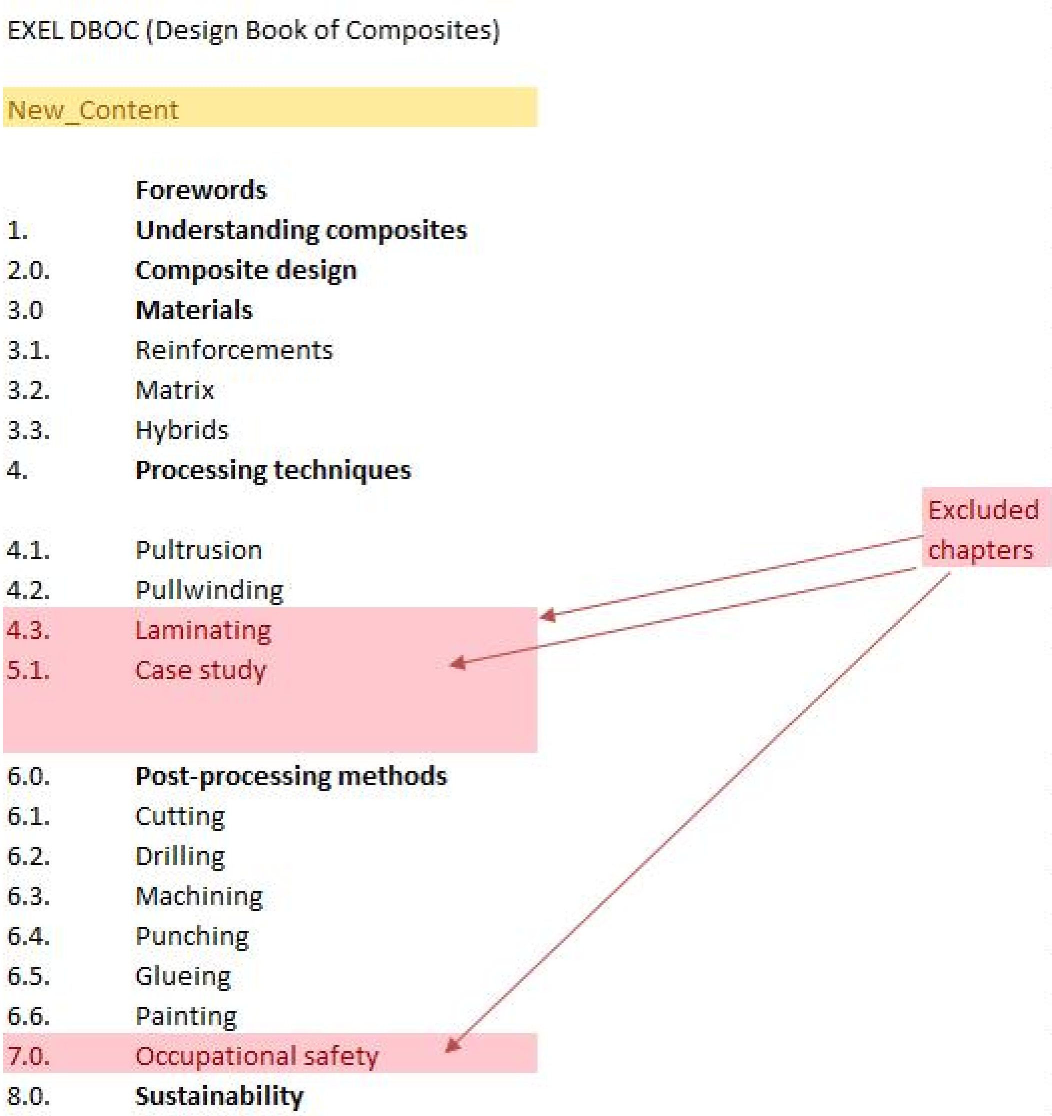


Figure 24. *Updated structure for the design handbook of composites.*

7.2 Content of the design handbook

Based on the interview results, the typical design process of composites covering the topics of selection of material and manufacturing method will be presented in the handbook. In the part describing materials, the main materials of matrices and reinforcements are discussed, as well as their advantages and limitations, their mechanical properties and usability.

The company set a requirement that, in the handbook the competitive features of composites and the possible post-processing methods of composites are presented. In the part describing manufacturing method selection, only technologies of pultrusion and pullwinding will be presented since they are the most important manufacturing methods from the company point of view. In addition to the design handbook, there will be a chapter about the composite sustainability because all the possible handbook users (by questioner and anticipated) and also the company are hoping to find such an information from the design handbook.

In the design handbook, the formula related to the design process of composites or determinations of composite properties are not presented. This is because the company stated that the handbook shall not be overly complex and confusing for its users, but merely an easy approach to the world of composites.

8. DESIGN HANDBOOK OF COMPOSITES

This handbook is developed and maintained to provide information about composites and their properties for the customers of Exel Composites Plc. as well as for their personnel. Its secondary function is to be an aid for all designers, engineers and architects working in the field of composites.

8.1 Understanding composites

Composites are materials that consist of more than one component material, and they result in better properties than separate component materials alone. In composites, each material component has a role that is based on specific (separate) chemical, physical, and mechanical properties. These materials can be divided into two groups: reinforcements and matrix materials. [4, p. 1]

Composites themselves can be divided into three groups based on their matrix material. These groups are: Polymer matrix composites (PMC), ceramic matrix composites (CMC) and metal matrix composites (MMC). In this publication, the term composite is identified as a polymer matrix composite.

8.1.1 Features

Composites offer many good features compared to other traditional materials. They can be molded into any regular or irregular geometry, providing flexibility in design. Since each component material provides its special material properties, composites are like tailored suits with their own unique properties. Nevertheless, the main advantages of composite materials are their high specific strength and stiffness when compared to steel and aluminum as can been seen from Figure 25. [2] [4, p. 1]

Main advantages of composites are listed below. [31, p. 2]

- Light weight
- High specific stiffness
- High specific strength
- Tailored properties
- Easily moldable to complex net shapes
- Part consolidation leading to lower overall system cost
- Easily bondable
- Good fatigue resistance
- Good damping
- Crash worthiness
- Internal energy storage and release
- Low thermal expansion
- Low electrical conductivity
- Low radar visibility
- Thermal conductance (mostly carbon fiber)

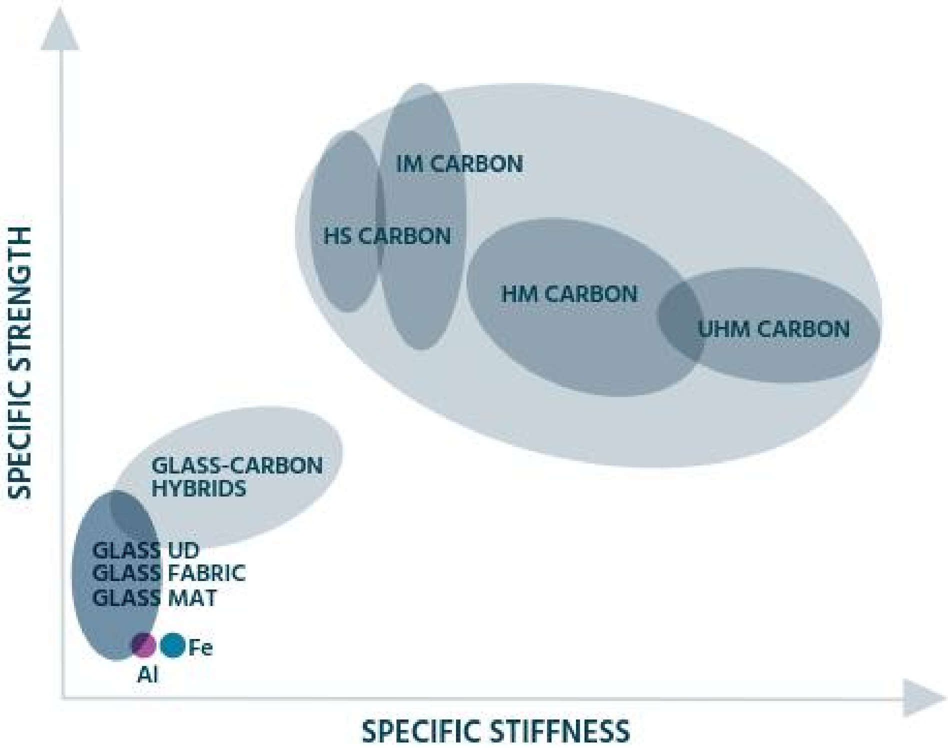


Figure 25. *Comparison of composites, steels, and aluminum. [36]*

8.1.2 Laminate notation

Composite is a structure that consist of laminates. A layer of unidirectional fibers is called a lamina or a ply. When two or more unidirectional laminae or plies are stacked together in different orientations, the structure is called laminate. To indicate the amount, type, orientation and stacking sequence of the laminae, the composite laminate is designated. These designations vary between different publications.

Here are some examples of possible laminate designations:

Unidirectional 4-ply: $[0/0/0/0] = [0_4]$

Cross-ply symmetric: $[0/90/90/0] = [0/90]_S$

Angle-ply symmetric: $[+45/-45/-45/+45] = [\pm 45]_S$

Angle-ply asymmetric: $[30/-30/30/-30/30/-30/30/-30] = [\pm 30]_4$

Multidirectional: $[0/45/-45/-45/45/0] = [0/\pm 45]_S$

$[0/15/-15/15/-15/0] = [0/\pm 15/\pm 15/0]_T = [0/(\pm 15)_2/0]_T$

Hybrid: $[0^A/45^C/-45^C/90^G/90^G/-45^C/45^C/0^A]_T = [0^A/\pm 45^C/90^G]_S$,

where subscripts and symbols mean the following:

Number subscript = Multiple of plies or group of plies

S = Symmetric sequence

T = Total (amount of plies)

In the case of a hybrid laminate, superscripts A, C and G indicate, respectively, aramid, carbon and glass fibers. [37, pp. 22-23]

8.1.3 Loading

Similar to any material, composites must withstand the following four main loads: tension, compression, shear and flexure. In composites, the ability to withstand these loads depend on the properties of the reinforcement and the matrix.

8.1.3.1 Tension

Composites' response to tensile loads is greatly dependent on tensile strength and stiffness properties of the reinforcement.

Figure 26. *Composite under tension.*

8.1.3.2 Compression

Composite response to compressive loads is greatly dependent on the adhesion and stiffness of the matrix but also on the compressive strength of the reinforcement. During compression, the role of the matrix is to keep the reinforcements as straight columns, i.e. to prevent them from buckling.

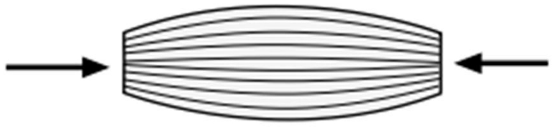


Figure 27. *Composite under compression.*

8.1.3.3 Shear

When laminate is imposed to shear loads, both the reinforcement and matrix are experiencing shear forces. These loads make the adjacent layers of fibers to snide over each other. To obtain the best function for the composite under shear loads the matrix must exhibit good mechanical properties and adhere well to the reinforcement.

Figure 28. *Laminate imposed on shear loads.*

8.1.3.4 Flexure

Flexural loads are a mixture of tension, compression and shear loads. The upper part of the laminate needs to withstand compression while the lower part is imposed to tension. Along the central part, the laminate is experiencing shear forces.

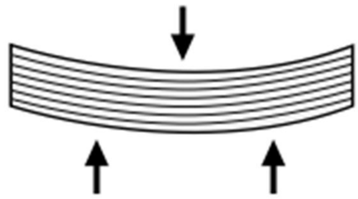


Figure 29. *Laminate under flexural loading.*

8.2 Composite Design

It is evident that composite are more complex in their structures than traditional materials such as metals and ceramics. For this reason, also the design process of composite structures may require more detailed planning.

When designing with composites, it is necessary to understand the principle characteristics and issues that good structures and components must have. It is needed to understand the roles of reinforcements and resins to the final structure, and how the manufacturing process affects composite structure design.

In addition, it is important to understand that composites are anisotropic materials. They provide different material properties in all directions and, therefore, many variables need to be understood to achieve desired behavior and performance of the composite product. [31, p. 307]

8.2.1 Design process

As can be seen in Figure 30, the design process of a laminate structure can be divided into four phases: determination of requirements, pre-designing, detailed designing and approval of the final structure.

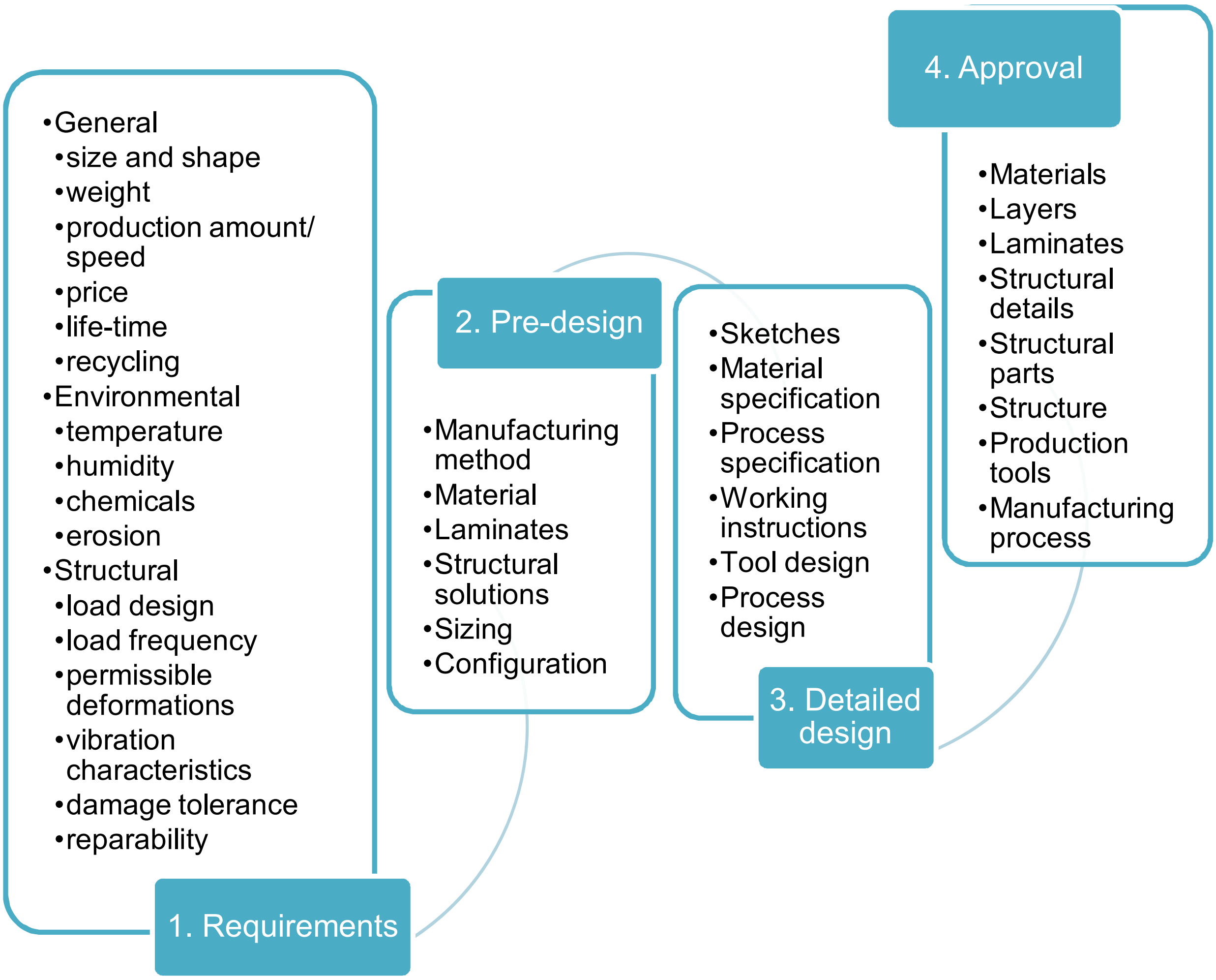


Figure 30. Schematic of composite design process. [5, p. 366]

8.2.2 Requirements for composite structure

All the possible loads and environments that can be imposed to the composite structure need to be determined before the design of the structure is possible. If the loads are unknown they are determined through calculations and analyses. All final loads that are used during the design process are chosen the way that they are unlikely to be exceeded during normal operation. [38, pp. 366-368]

8.2.2.1 Static load conditions

Static loads are loads that are result in deformation via insignificant acceleration of the construction, i.e. so that inertia loads are not needed to be considered alongside. Alongside these types of loads it is also important know their durability to evaluate the life-time for the designed structure. [38, p. 368]

8.2.2.2 Dynamic load conditions

Dynamic load conditions result in significant inertial loads that must be considered in the design along with the (dynamic) loads. For these types of loads, the magnitude and occurrence must be determined. [38, p. 368]

8.2.2.3 Impact and damage tolerances

Occasional loads that result in local damage, such as impacts, should be determined in order to evaluate the damage tolerance of the composite structure whenever seen possible. In addition to damage tolerance, repeated loads and occasional loads lead to fatigue of the structure, so that life time of the structure might need to be evaluated for long-term operation, say tens of years of operation. [38, p. 368]

8.2.2.4 Environment and knock-down

Besides the loads, environmental factors such as temperature, humidity and chemicals, which may affect negatively the material properties of the structure and weaken it must be considered. Similarly, the effect of manufacture deviation can be considered. Material properties can be adjusted using factors related to environmental or manufacture effects. [38, p. 368]

8.3 General design guidelines

In most cases, there is no straightforward method of designing a composite laminate, but there are three steps that are good to follow when designing a composite laminate [39]:

1. Selection of reinforcement, resin, and fiber volume fraction as well as the correct reinforcement form(s).
2. Selection of the optimum reinforcement orientation in each ply and the lamina stacking sequence. Typically, symmetric laminates are preferred over un-symmetric laminates, since this eliminates the extension-bending coupling.
3. Selection of the number of plies needed in each orientation, which also determines the final thickness of the part.

8.4 Dimensional tolerances

Tolerance controllability is needed due to the shrinkage properties of the polymer. Shrinkage is caused by a volumetric change in a material as its state changes from molten to solid. Most of the shrinkage happens in the mold, but it can continue for up to 24 to 48 h after molding. Therefore, to meet tolerances (or shrinkage) it is important that the mold subcontractor is familiar with the plastics behavior. [40, pp. 658-660]

In general, thermoset based composites are more suitable to meet tight tolerances than thermoplastic based ones since thermosets are more controllable. [40, pp. 658-660]

8.5 Materials

The composite properties and functionalities are based on the interaction between the matrix and the reinforcement. However, some of these properties are dominated by either the matrix or the reinforcement. These key roles of matrix and reinforcement are seen in Table 3. Even though one of the components governing a property in general, both components must work together to an obtain optimal performance. [31]

MATRIX	REINFORCEMENTS
• Shapes the composite part • Protects the reinforcement • Transfers loads amidst reinforcement • Brings toughness (dependent of the reinforcement as well)	• Give strength, stiffness and primary mechanical properties • Governs other properties such as the coefficient of thermal expansion, conductivity and thermal transport

Table 3. *Generalized roles of matrix and reinforcements in composites [31, p. 5]*

8.5.1 Reinforcements

The most important role of the reinforcement is to provide strength, stiffness, i.e. primary mechanical properties of the composite. In most cases, the reinforcement is harder, stronger and stiffer than the matrix. The mechanical properties of composite products are largely determined by the type of the reinforcement, its position and orientation, the fiber content in the composite and the interaction between the fiber and the resin system. [31]

The interaction between fiber and the resin system, at the interface, is controlled by the degree of bonding between these two components. It is mainly influenced by the surface treatment given to the fiber. Fibers with a smaller diameter provide higher fiber surface area for spreading the fiber-matrix interfacial loads and can affect the laminate strength. [31]

The amount of fibers in the composite is largely determined by the processing method applied. However, reinforcing fabrics with closely packed fibers will give higher Fiber Volume Fractions (FVF) in a laminate than those fabrics, which are made with rough fibers, or which have large gaps between the fiber bundles. The stiffness and strength of laminate will increase in proportion to the amount of fibers. However, above 70% FVF the tensile stiffness still may increase but the laminate strength begins to decrease due to the lack of sufficient resin to hold the fibers together (Figure 31). [31, pp. 197-203]

The selection of the reinforcement is largely based on the moduli of elasticity and tensile strength. Very often these properties are presented in proportion to density and, furthermore, these quantities are called specific stiffness (E/ρ) and specific strength (σ/ρ). [4, pp. 370-372]

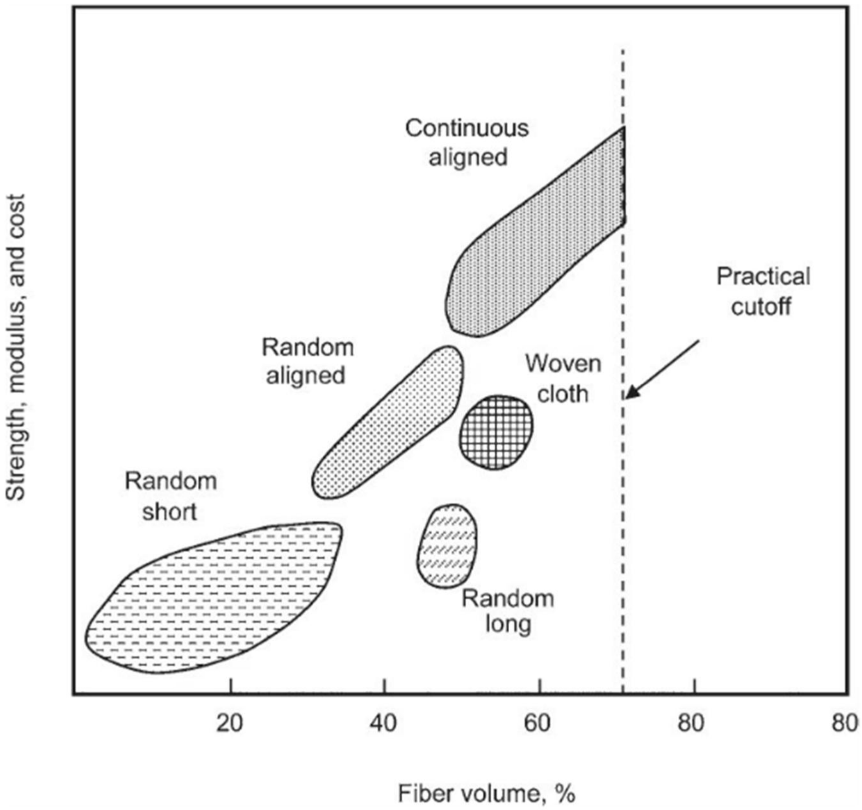


Figure 31. *Influence of reinforcement type and quantity on composite performance [16, p. 3]*

8.5.1.1 Possible reinforcement structures

There are many possible forms to use reinforcements in composites. The fiber content and orientation affect the mechanical properties giving their own characters and, therefore, modifying the final properties of composites.

Depending on the structural and manufacture requirements, the degree of orientation in the reinforcement can be built to vary - ranging from completely random to 100% unidirectional. It is typical to use more than one different form of reinforcement in one composite product.

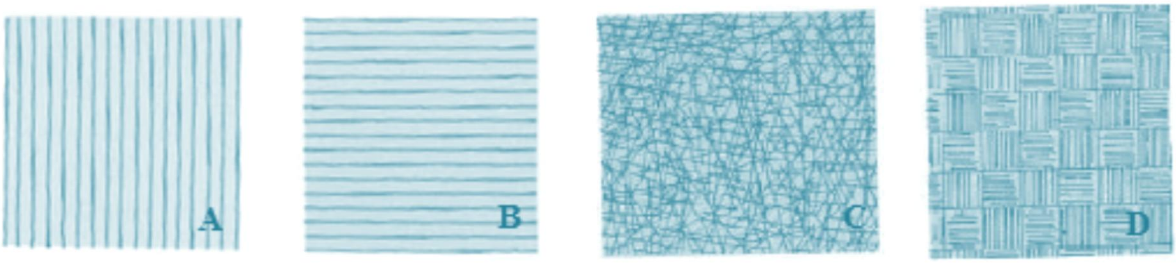
The four basic structures of reinforcing material, designated as A, B, C and D, are illustrated below.

A) The reinforcing fibers i.e. roving are oriented longitudinally in the composite. This gives the maximum longitudinal modulus of elasticity in the composite. On the other hand, the transverse strength is about the same as the matrix material and may be insufficient in thin-walled structures in particular.

B) The continuous fibers in the reinforcement are placed crosswise in the product. Such an arrangement gives good transverse strength and, for instance, can be achieved by winding reinforcement fibers around the axis of the composite product. Structure B is usually used together with structure A.

C) The reinforcement is in the form of a felt. Such a plane structure is obtained using either staple fibers or continuous filaments, which after plane formation are bound into a continuous mat. The weight of the felts usually ranges from 150 to 1000 g/m^2. The strength of the felt is nearly the same in all directions of the plane.

D) The reinforcement is in the form of a fabric. Strength characteristics are determined by the tape of threads and the ratio between longitudinal and transverse threads. The threads in the fabric are usually either roving (untwisted multifilament) 150-2000 tex or twisted yarns 10-15 tex. The usual raw-materials are glass, carbon and aramid.



8.5.1.2 Reinforcement materials

FIBER	DENSITY [g/cm^3]	MODULUS OF ELASTICITY [GPa]	TENSILE STRENGTH [MPa]
E-Glass-boron free	2,62	76 - 78	3100 - 3800
ECR-Glass	2,67	80 - 81	3100 - 3800
S-Glass	2,5	88 - 91	4380 - 4590
Carbon fiber HS	1,8	230	3500–8000
Carbon fiber HM	1,8	400	2100–6000
Basalt fiber	2,65	89	4150–4800
Kevlar	1,44 -1,47	150	3480-3620
Polyester	1,38	2,8 - 3,1	55-75
Hemp*	1,48	70	550-900
Jute*	1,46	10 - 30	400-800
Flax*	1,54	35	365
Aluminum	2,7	70	230–700
Steel	7,9	210	500-2200

Table 4. *Technical characteristics of reinforcing fibers.*

** Tensile strength of a natural fiber strongly depends on the type of the fiber being a single filament or a bundle.*

Glass fibers

Glass fiber is made of a mixture of silica sand and various subcomponents such as limestone and boric acid and some minor components such as clay, quartz and colemanite. These ingredients are dry mixed and then molten at the temperature of 1400 °C. Then the molten glass flows through the platinum nozzle to form filaments with a diameter of 13-24 µm.

In addition to typical mechanical properties, glass fibers acts that the fiber acts as an electrical and thermal insulator. Products, that are made using glass fiber reinforcements, can be dyed in any conceivable manner.

The most used glass fiber type is E-glass (Electrical glass). E-glass has good electrical and mechanical properties and also moderate resistance against chemicals.

ECR-glass is a modified glass type of E- and C-glass that combines both glasses the best properties of other glass fiber types, i.e. the good mechanical properties of E-glass and the chemical resistance of C-glass.

S-Glass (High strength glass) and R-glass (Reinforcement glass) are developed especially for aviation industry. Their modulus and tensile strength values are higher than those of E-glass and they provide outstanding thermal resistance. Their wider usage is constricted by their relatively high price.

Carbon fibers

Carbon fiber, made by carbonizing a polyacrylonitrile fiber is called PAN-based carbon fiber. The diameter of the fiber ranges from 5-8 µm. Fibers with quite different technical properties can be obtained by varying the end temperature of the carbonizing process. For instance, different temperatures have a great effect on the tensile modulus and -strength as can be noted from the Figure 32.

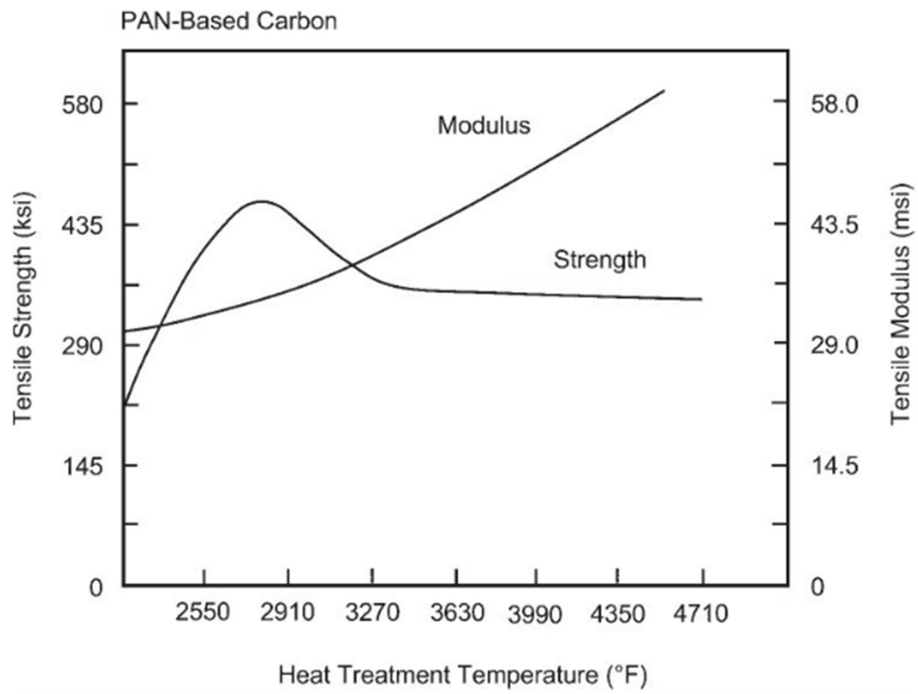


Figure 32. *Effect of the heat treatment temperature to the tensile strength and modulus of the PAN-based carbon fiber [4, p. 46]*

Carbon fibers are fabricated as continuous bundles, where typical filament amounts are 1000 (1K), 3000 (3K), 6000 (6K), 12000 (12K), 15000 (15K), 24000 (24K), 48000 (48K), 50000 (50K) and 60000 (60K). Most commonly, the carbon fibers are now divided by their modulus.

By far, the most used carbon fibers are HS-fibers (High strength) for which are typical to have high tensile strength and modulus of elongation at break at 230 GPa. IM-fibers (Intermediate modulus) are fibers with medium stiffness, whose modulus is 270-320 GPa and they obtain good tensile properties. HM-fibers (High modulus) are rigid fibers whose modulus is 340 GPa or more but the HM-fibers have lower tensile strength and elongation at break than HS- and IM-fibers. Fibers with higher modulus than 440 GPa are called UHM-fibers (Ultra high modulus).

Carbon fiber has typically a high strength and relatively high modulus of elasticity. The special characteristics of carbon fibers include electrical conductivity, negative thermal expansion (dimensional stability), thermal conductivity and X-ray penetration. The nature of carbon fiber can be greatly affected considering the above mentioned characteristics in the design.

The products cannot be dyed because of the inherent black color of the carbon fiber. However, other colors can be obtained by painting the surface.

Polyester

Polyester fibers are used to enhance impact-, abrasion- and fatigue strengths in thermosetting polymers as well as chemical resistance. Typical nature of these fibers include low modulus of elasticity and high elongation at break. In addition, polyester fibers have low density and low price, and the fibers can be readily dyed.

Other fibers

Natural fibers

Natural fibers are animal or plant based fibers derived from animal hairs, plant frames, leafs, seeds and seedcases, fruits and nuts. Mostly plant based fibers are used as reinforcements in composites. Most usable natural fibers in composites are flax, hemp, jute and cotton fibers.

The most common characteristics of natural fibers are their damping abilities, low density and sustainability. Plastics reinforced with natural fibers have low mechanical properties than compared to those with synthetic or inorganic fibers, but they are biodegradable and sustainable. [31, pp. 228-230]

Aramid fibers

Aromatic polyamide-fibers are carbo-hydrate fibers made by spinning. The diameter of the fiber varies from 10-15 µm. Aramid-fibers are lightweight and have a combination of good tensile strength and modulus, excellent toughness, and outstanding ballistic and impact resistance. When compared with glass fibers and carbon fibers the compression characteristics of aramids are clearly lower.

Aramid fiber is an efficient damper of vibrations. Due to its organic base, it also absorbs water more than glass and carbon fibers. The fiber has a low thermal expansion coefficient, which means that products made by using this reinforcement have good dimensional stability.

The excellent impact strength of the fiber can be utilized in a number of applications, where the most common ones are protective jackets and military helmets. Even though the fiber has yellow color itself, it can be dyed.

Basalt fibers

Basalt fibers (an inorganic mineral) have high modulus and high tensile strength, being a good substitute for glass fibers. Generally, their material properties are located between E- and S-glass, but Basalt fibers are able to withstand fire and alkaline environment better. Basalt fibers are considerably cheaper than carbon fibers, but more expensive than glass fibers. The fiber cannot be dyed because of its peculiar dusky color. [31, p. 228]

8.5.2 Matrix

The matrix is the continuous phase of the composite. Its principal role is to bind the fibers together and form the shape of the product.

As matrix is the component that takes the first hit of the forces and conditions that are imposed to the composite, its key task is to protect the fibers from the outside environment. In general, the matrix is not as strong as the fibers and might not withstand completely the imposed forces during the operation. However, the matrix must transfer the imposed loads onto the fibers and the effectiveness of load transfer is one of the most important qualities for the proper performance of the composite. [31, pp. 2-4]

Although matrices have relatively low mechanical properties, compared to those of fibers, matrix significantly influences mechanical properties of the composite. These properties include transverse modulus and strength, shear modulus and strength, compressive strength, interlaminar shear strength, thermal expansion coefficient, thermal resistance, and fatigue strength. [34, p. 15]

The selection of the resin system is based, alongside the price, on the mechanical properties and thermal and chemical resistance of the resin as well as its processability. [5, pp. 373-374]

8.5.2.1 Matrix materials

Matrix materials can be divided into two groups based on their moldability: thermoplastics and thermosets.

Thermosets

Thermosets are composed using resins via chemical curing reaction. During the reaction, the polymer chains of the resin are chemically bonded, cross-linked, creating a net-like structure as can be seen from a Figure 33. This net-like structure cannot be remolded, melted. [5, pp. 18-19]

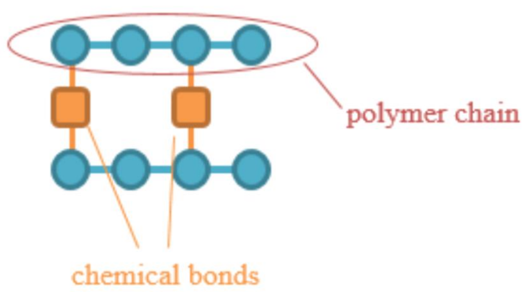


Figure 33. *Structure of thermoset molecules. Courtesy A. Lahti*

Some of the resins can be cured just with the aid of heat but many of these resins requires to be mixed with a hardener to establish the curing reaction. The curing reaction is in most of the cases an exothermic reaction, where heat will be released. During the reaction, shrinkage occurs, but it can be avoided with shrinkage agent. [5, pp. 18-19]

In the beginning of the curing reaction (Figure 34), cross-linking advances slowly, which allows shaping of the product at this phase. The time that is required for the resin to become solid, is called gel-time. After gel-time, the curing reaction advances fast and the temperature of the laminate arises. The highest temperature during the curing reaction is called the peak exotherm. [5, pp. 18-19]

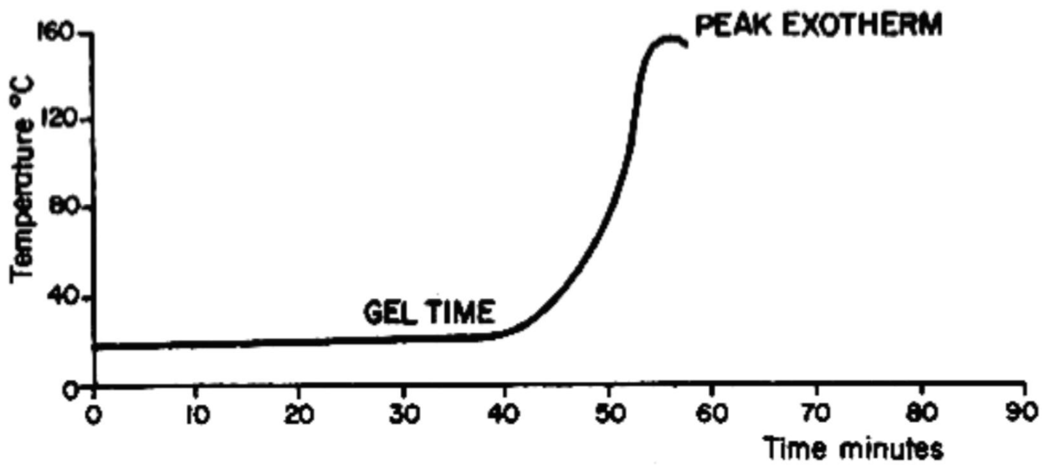


Figure 34. *Curing reaction of a thermosets.*

The thermoset matrix materials can be divided into three main groups according to their special properties: polyester, vinyl ester and epoxy resins. The properties of the end product can be greatly affected by selecting a certain type of resin. Generally, the resins are selected according to the following criteria:

- Polyester for applications with no special requirements.
- Vinyl esters for applications requiring relatively good mechanical properties and good chemical resistance.
- Epoxy resins are used when the product must have very good static/dynamic properties, and always in high-quality carbon fiber pultrusion products. [35]

Characteristics of thermoset resins

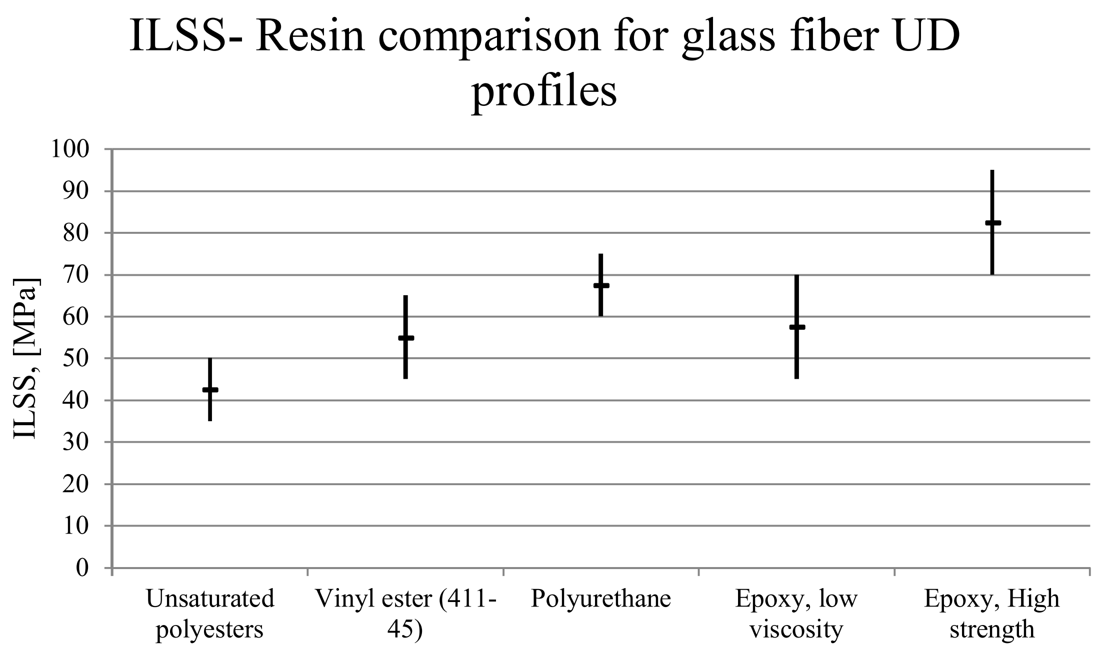
	Tensile strength [MPa]	Modulus of elasticity [GPa]	Flexural strength [MPa]	Elongation at break [%]	T_g [°C]
Unsaturated polyesters	60-80	3,5-4,0	100-130	2,0-4,5	75-110
Vinyl ester (411-45)	80-90	3,5-4,0	130-140	4,0-5,0	110
Vinyl ester (470-300)	80-90	3,5-4,0	130-140	3,5-4,0	150
Vinyl ester (470HT-400)	80-90	3,5-4,0	130-140	3,0-3,5	195
Polyurethane	70-90	3,5-4,0	120-140	3,0-3,5	120
Epoxy, low viscosity	65-75	3,0-3,5	120-140	3,0-5,0	90
Epoxy, high strength	75–90	3,0-4,0	120-150	3,0-5,0	100-120
Epoxy, high strength	80-95	3,5-4,0	120-150	3,0-5,0	180-220

Thermoset resin comparison of properties

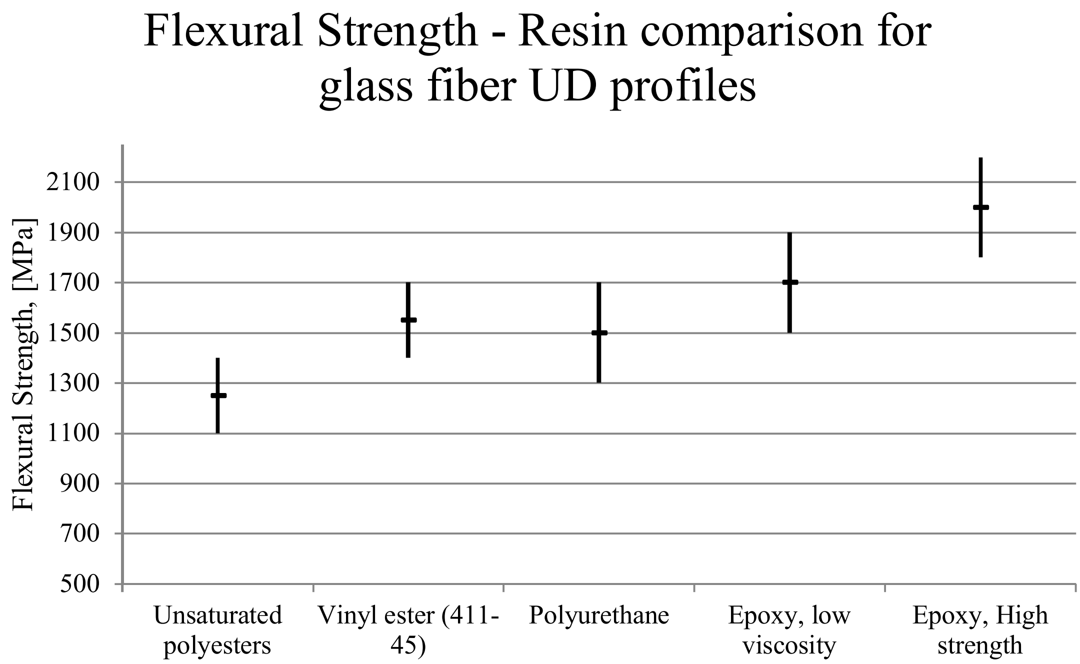
	COST	STRENGTH	CHEMICALS	ELECTRICAL
Polyester	1	2	2	2
Vinyl ester	2	2	1	2
Epoxy	3	1	1	1
Other	2-4	2	2	1-3

** 1=superior, 2=excellent, 3=good*

Interlaminar Shear strength comparison of different resins for glass fiber



Flexural strength comparison of different resins for glass fiber



Polyester resin (UPE)

These resins are often coded according to their acid component thus, we talk about orthophthalic or isophthalic acid based polyester resins. Although a fairly rough division, it provides some information about the character of the products.

Resins based on orthophthalic acid are the most economical ones and typically used in hand lay-up products. They are often brittle and have a rather poor chemical and weather resistance. In spite of such undesirable characteristics, they have a number of applications where such factors are not driving the design.

Polyester based isophthalic acids are the most common resins in pultrusion. Typically, they have a relatively good chemical resistance, especially against acids, and their mechanical characteristics are usually satisfactory.

Main advantages of polyester resins
- Cheap when compared with vinyl ester and epoxy based resins - The polyester resin has good balance of mechanical, electrical and chemical properties. - Polyester resins perform well against weak alkalis and excellent against weak acid conditions. - With additives, they can be modified so that they are flame-retardant of self-extinguishing.

The maximum recommended operation temperature is 80 °C for the basic grade polyesters.

The polyester resins are mainly used in glass fiber profiles. Typical mechanical properties of the polyester/glass fiber profiles are described in the following table.

Structure*	Glass content [%-vol]	Tensile strength [MPa]	Tensile modulus [GPa]	Flexural strength [MPa]	Flexural modulus [GPa]	Thermal expansion [$10^{-6}/K^{-1}$]	Density [Kg/dm^3]
UCU	55-58	600-900	38-42	700-1000	35-40	9-11	1.9-2.0
U	58-65	1000-1200	42-45	1000-1300	40-43	6-8	1.9-2.0

**Structure: U = unidirectional, C = Cross-wound*

Vinyl ester resin (VE)

Vinyl ester resins are a compromise between polyester and epoxies and they provide many good properties. Good chemical resistance against acids, alkalis and solvents means that these products can be used in environments imposing heavy chemical stresses. They also have excellent resistance to weather and corrosion. In addition, epoxy based vinyl ester resins have good chemical resistance at elevated temperatures as well. Vinyl ester resins do not only have good chemical resistance but also good mechanical properties, and have also been used rather widely in the manufacture of carbon-fiber reinforced products.

The dispensary of both polyesters and vinyl esters can be greatly affected by using suitable additives. Shrinkage during manufacture, for instance, can be regulated and even reduced to zero. Other additives can be used in order to improve the fireproof characteristics of products, making them self-extinguishing.

Main advantages of vinyl ester resins

- Vinyl ester resins combine the best features of polyester- and epoxy resins.
- The vinyl ester resin has good strength and a very good chemical resistance in acids and alkalis environments, especially at high temperatures.
- The glass fiber-vinyl ester profile has good electrical and thermal insulation properties.
- With additives, the fireproof characteristics can be improved as well as the shrinkage during manufacturing.

The maximum recommended operating temperature is 90-150 °C.

Epoxy resin (EP)

Epoxy resins have very good properties and are commonly used with high performance reinforcements such as carbon fibers or with glass fibers when the reinforcement content is very high.

The chemical resistance of epoxy resins is generally good, but greatly dependent on the hardener system used. Chemical resistance can be roughly divided according to the hardener as follows:

1. Amine cured
   - Poor resistance to acids

2. Anhydride cured
   - No resistance to strong alkalis or organic solvents

There is a wide selection of epoxy resins and hardeners with a wide range of temperature resistance from 40 to 270 °C. The temperature resistance of resins commonly used in pultrusion can be varied from 80 to 170°C.

The price of epoxy resins varies greatly depending on the raw materials used, but as a rule, the prices are clearly higher than those of polyesters. Although the prices of epoxy resins are clearly higher than those of polyesters, it may be worth the cost when high performance is required.

Main advantages of epoxy resins
- High performance resins. - The epoxy resins have very small cure shrinkage, which refers to good mechanical properties of the composite both under static and dynamic stresses. - With additives, they can be modified so that they are flame-retardant of self-extinguishing.

Polyurethane resin (PU)

Polyurethane resins can be tailor made for many applications. In pultrusion, PU can be an excellent alternative to epoxy for mechanical high performance applications like springs, thanks to good physical properties and for the possibility to use high fiber volume content. The fiber volume content also ensures high stiffness of the material, allowing to use thinner wall sections, thus saving weight.

Especially toughness of the PU composite is superior compared to UPE/VE, and screw retention is outstanding even without the use of crosswise reinforcement. PU is compatible with both standard glass fiber and high performance carbon fibers.

Thermoplastics

The molecules in thermoplastics consist of long polymer chains that are not chemically bonded to each other (Figure 35). Forces that hold those molecules together get weaker when thermoplastic is being heated, and get back stronger when cooled. This phenomenon establishes the re-moldability of thermoplastics. The most common thermoplastic matrix material for composites is polyamide. [5, p. 18]

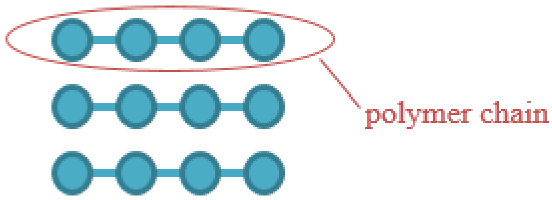


Figure 35. *Structure of thermoplastic molecule. Courtesy A. Lahti*

Reinforced thermoplastics' properties and fabrication methods are different from those of reinforced thermosets. Thermoplastic matrix materials are more compatible with hot forming and injection molding fabrication where the maximum temperatures that the material must withstand, can rise up to 400 ºC.

The greatest advantages of thermoplastics are their high melting temperature and the ability of remolding. These properties make joining of thermoplastic matrix composite parts easier as well as their recycling. [5, p. 53]

Polyamide

Polyamides, commonly nylons, are polymers, which have a repeating group of amides (-CONH-) as a structural part of the polymer chain. There are over 60 different known polyamides, where the most common ones are PA 6 and PA 66.

Characteristics for polyamides are their hygroscopicity, which means that they are able to absorb water even 8-10 wt%. Other properties vary depending of the polyamide type. Typical glass transition temperature varies between 45-80 °C and melting temperature between 180-265 °C. Most common reinforcements used with polyamides are glass- and carbon fibers. The strength of a reinforced polyamide can be three times higher than the unreinforced one. The tensile strength of reinforced polyamide varies between 9-10 MPa while the tensile strength of unreinforced polyamide varies between 1-3 MPa.

The most common applications for reinforced polyamides are in automotive industry. For instance, glass fiber reinforced polyamides are used in engine fans and valve covers. [5, p. 54]

8.5.2.2 Additives

There is a wide range of additives that can be used with resins to assure the highest performance of the composite.

Flame retardants

Flame retardants are additives that are mixed with the resin to inhibit or delay the spread of fire by suppressing the chemical reactions in the flame or by forming a protective layer on the material's surface. [5, p. 66]

Colorants and pigments

Coloring of composites is done either by colorants or by pigments that are mixed with the base resin. Colorants and pigments do not have any remarkable effect on the mechanical properties of the final composite products if they are used in low quantities. [5, p. 70]

UV-stabilizers

Ultraviolet radiation contributes polymer degradation and affects greatly on the mechanical and physical properties of the composites. Therefore, UV-stabilizers, which are capable of interfering with the physical and chemical processes of light induced degradation, are used to inhibit these degradation reactions. [41, p. 88]

Anti-statics

Anti-static agents are used to eliminate electrostatic surface of composite material. These agents are commonly added to the resins or the surface of the molded composite products in order to minimize the accumulation of static energy. Normally the used material are carbon particles. [41, p. 112]

Anti-bacterial

Anti-bacterial additives prevent mold, mildew, bacterial and fungi growth on composite materials. Without these additives, composites may experience surface growths, producing allergic reactions, unpleasant odor, staining, embrittlement, and even permanent product failure. Most common anti-bacterial additives are silver containing glass particles and biocides. [41, p. 120]

8.5.3 Hybrids

Materials that combine two or more types of reinforcements are called hybrids. Typical combos would be carbon with aramid, glass with carbon (Figure 36), and glass with aramid. The advantage of hybrids is that the superior properties of the various reinforcement types can be utilized to optimize the part. Laying another material on top of another improves the energy absorption properties, because energy dissipation is increased across dissimilar material layers. In addition, an economical solution can be reached by optimizing the structure and fiber types used. [31, pp. 260-261].

Figure 36. *EXEL EXELITE ™ hybrid fiber tubes.*

8.6 Processing technique

The correct manufacturing method is selected based on the size and shape of the final product and on the production rate. All manufacturing methods, in some extent, set the design limitations and, therefore, the selection of the manufacturing method is always a compromise. Production rate requirements for pultrusion and pullwinding are relatively neutral since for being profitable they require >1000 pieces annual production. [5, p. 369]

8.6.1 Pultrusion

Pultrusion is a continuous and high-volume manufacturing process for composite profiles. In pultrusion, resin impregnated fibers are pulled through a heated die where the curing takes place. [2]

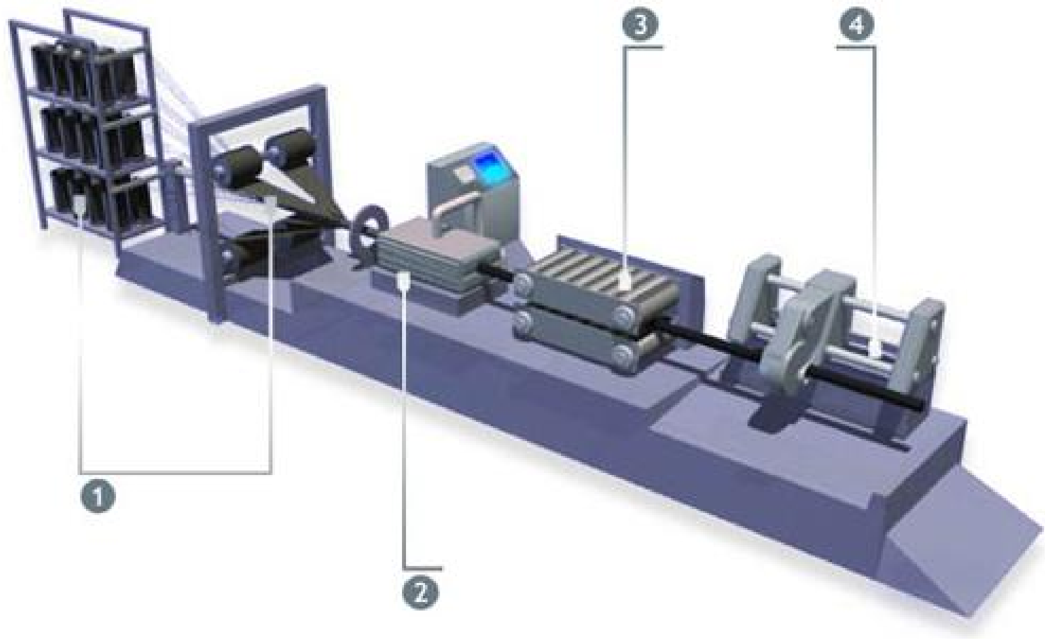


Figure 37. *Schematic of pultrusion process. [2]*

The pultrusion process, which is given in Figure 37 begins with continuous fibers being drawn from reels and then subjected into a resin bath (1) or the resin is injected to the mold, which makes the process less human dependent and by that way ensures more accurate resin control. In the resin bath, the fibers are wetted and then gathered together as they move toward the die. If desired, additional reinforcements such as mats or cloth can be directed into the reinforcement preform to include some fibers in another direction than just the machine direction. It is also common to add a veil to the reinforcement preform. The wetted reinforcements then enter to the heated die where they are cured (2). When the formed parts exit the die, they enter to the pulling system (3). The pulling units provides the force for movement of materials through the entire system. At the end of the process, the pultruded part goes through a cutter and trimming station where it is being finished (4). [2] [31, pp. 453-454]

Best material options:
Resins: epoxy, polyester, vinyl ester and phenolic
Fibers: Any

Main advantages of the process:
- Can be very fast and very economical way of impregnating and curing materials.
- Resin content can be controlled.
- Minimized fiber cost since majority is taken from a reel.
- Good structural properties because the profiles have very straight fibers and high fiber volume fractions can be obtained.
- Limited volatile emissions by closed resin impregnation area.

Main Disadvantages:
- Limited to constant or near constant cross-section components
- Heated die costs can be high.

Application ideas:
- Telescopic poles,
- Barriers
- Tool handles,
- Fences
- Roll up systems
- Bike parts,
- Defense applications and many more

Figure 38. *EXEL ULTRALITE ™ carbon or/and glassfiber tubes are made by pultrusion process.*

8.6.2 Pullwinding

Pullwinding is a process to manufacture high-performance round tubes and profile tubes combining the techniques of pultrusion and continuous filament winding. This technology has accurate control of the crosswise and longitudinal properties of the final product by adjusting the amount of fibers lengthwise and crosswise.

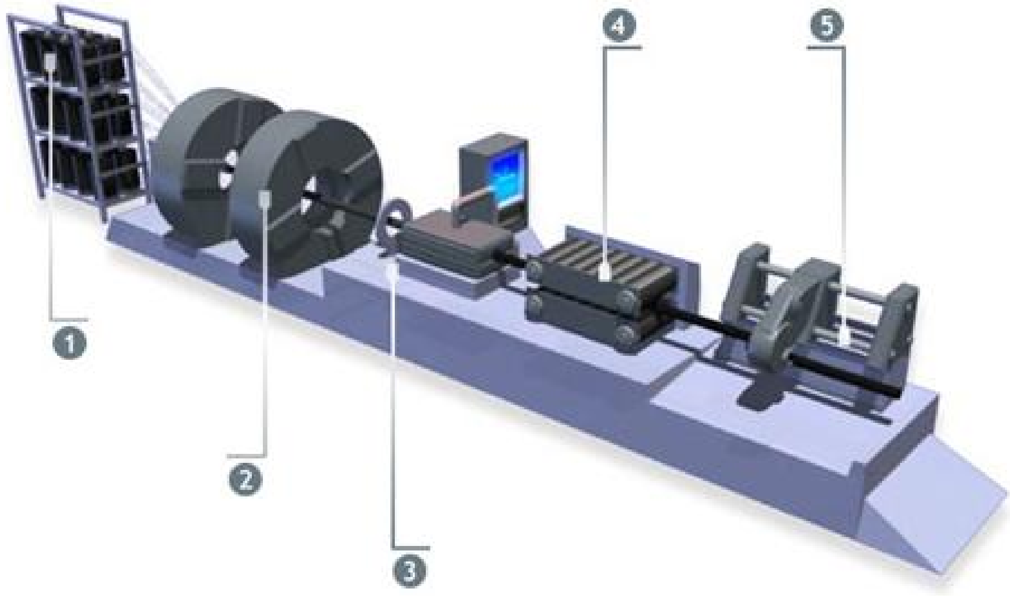


Figure 39. *Schematic of pullwinding process [1]*

The pullwinding equipment, which is given in Figure 39**Error! Reference source not found.** consists of twin winding heads, which revolve in opposite directions over a hollow spindle. The fiber can be angled with the preferred direction.

The pullwinding process begins with continuous fibers being drawn from reels (1), and then passed through one to four winding units (2). The pultrusion mandrel and impregnated fiber pass through the hollow spindle, while the winding heads apply dry fiber over the impregnated fiber. Subsequent layers of impregnated unidirectional can be fed between the winding heads and after the last winding head before the package of reinforcement enters the pultrusion die where the curing takes place. As in pultrusion process, after the curing, the formed part enters to pulling unit (4). The pulling unit provides the force for movement of materials through the entire system. At the end of the process, the part goes through a cutter and trimming station where it will be finished (5). [2] [42, p. 153]

Best material options:
Resins: Any
Fibers: Any

Main advantages of the process:
- Can be a very fast and, therefore, an economic method to prepare composites
- Resin content can be controlled
- Minimized fiber cost since majority is taken from a reel

Main Disadvantages of the process:
- Limited to constant or near constant cross-section components
- Heated die costs can be high.

Application ideas:
- Support structures
- Robot arms
- Mass critical machinery items such as textile machine parts
- Telescopic poles
- Camera tripods
- Tool handles
- Kite tubes
- Microphone booms
- Hi-Fi music stands
- Defense applications and many more

Figure 40. *EXEL CROSSLITE ™ carbon fiber tubes are made by pullwinding process.*

8.6.3 Tooling

When manufacturing composite parts, the tool selection plays an important role. After all, the tool has a great impact on the final part's surface quality and performance.

There are many requirements to consider when selecting a tooling material and manufacturing methods for a given application. However, the amount of parts to be made on the tool and the part configuration are often the dominant factors when deciding correct tooling.

Another thing to consider is to select the right material for the tool. Generally, reinforced composites can be used for low to intermediate temperatures, metals for low to high temperatures and monolithic graphite or ceramics for very high temperatures. [4, pp. 101-103]

8.6.3.1 Tooling for pultrusion

In pultrusion, the tools are constantly working under a high pressure and temperature, while the moving reinforcements are causing erosion on the tools inner surfaces. For these reasons, the material used in pultrusion tools must be highly wear-resistant.

Typical tooling of pultrusion consists of two or more changeable parts that are covered with an outer structure that is supporting the tooling. During the process, resistance bands or -discs heat the tool. To produce hollow parts there is used an inner mandrel that can be heated as well.

Pultrusion tooling is steel-machined and chrome-coated. Chrome coatings reduce friction between the part and tool, and provides longer durability for them. Tool length varies from 500 mm to 1 500 mm and the price varies according to the size. Therefore, the curing time should be well determined to avoid overly expensive tooling.

To maintain part quality and process functionality, the fibers have to be well fed into the tooling. The infeed, at the beginning of the tool, is used to control the fiber feeding and to set fibers to their final locations. In addition, with infeed, the fiber tension is controlled to ensure straight profiles. [5, pp. 213-214]

8.6.3.2 Tool categories

For Exel Composites, all the tools are personalized for each customer. To ensure cost efficient tooling solutions for the product demands, there are three different tooling categories to be chosen according to production volumes and the degree of difficulty of a part geometry.

Category I	Category II	Category III
High accuracy requirements	Lower accuracy requirements	Proto tooling
High-end, hardened materials	Lower grade materials, soft/semi-hard steels, easy and fast to manufacture	Low grade materials, even non ferrite materials
Chrome or PVD coating	Chrome coating	none
Service life +100 km	Service life of 30 km, with overhauls every 50km	Life-time is typically less than 50m
Easy to maintain and repair	Repair to original condition usually is not possible	Cannot usually be repaired or upgraded to a production tooling

Category I

The category I tools are for big production volumes or demanding products. These tools are designed to last long and to produce complicated profiles for demanding solutions. Tools may not be the cheapest ones, but total lifetime cost is still very low due to high overall performance.

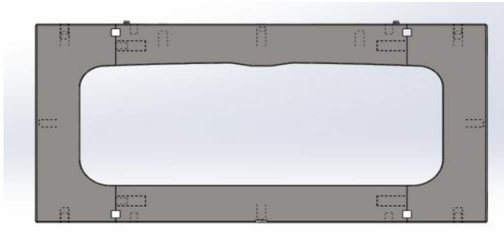


Figure 41. *Illustration of possible category I tool. There are four changeable parts for better maintenance.*

Category II

The category II tools are for small volumes. These tools are cost optimized solutions for mid-range products where criteria is not extreme but, dimensionally and functionally, products must be good.

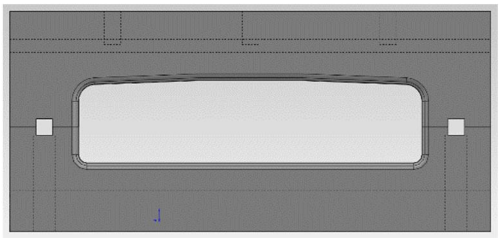


Figure 42. *Schematic of possible category II tool. There are possibility to change two parts of the tool.*

Category III

The category III tools are proto tools, normally half of the length of production tools. These tools are a solution for very short runs. A proto tool can be made fast and cheap when customer needs a small amount of products for their testing purposes. Despite the die being cheap, the infeed must still be made and little savings can be done in this part.

8.7 Post-processing methods

Although, composite profiles are often processed until the finished shape, trimming, finishing and assembling may be required. There is a wide range of different post-processing methods for composite parts that can be used separately or together.

8.7.1 Cutting

The best cutting results are obtained with a diamond-cutting wheel, which has a peripheral speed of 35-40 m/s. Water emulsion can be used to bind the cutting dust. The smoothness of the cut surface is dependent of coarseness of the diamond edge. [35]

8.7.2 Drilling

Drilling is done with a hard-alloy or diamond-coated bit. A diamond-coated bit should be sharpened at an interval of about 300 holes. The roughness of the drilled surface is primary dependent on the speed rotation. The leaving end of the drilled hole is of a poorer quality than the straight end. There are no limits to the size of the hole. [35]

8.7.3 Machining

Machining can be done by using the same tools as for steels. The fiber direction of the product must be taken into account to ensure good surface quality. [35]

8.7.4 Punching

Punching is a very useful machining technique as long as the tool is of a correct design (concave head). The lifetime of an ø 6 mm punching tool, for instance, is 50 000 holes. Best results are obtained with material thickness of less than 5 mm. [35]

8.7.5 Adhesion bonding

Adhesion bonding is a convenient method to bond polymer composites permanently together. Its main advantages are uniform stress distributions in the material, smooth surfaces, no galvanic corrosion, small weight of the bond and different layers are easy to bond.

Bonding composites by using adhesives must be done with sufficient care and according to the same principles as when bonding any other materials. The surface must be properly roughened and all dust and grease removed. The adhesive is typically a two-component epoxy or urethane product. The bonded surfaces must be pressed tightly together, preferably by a force higher than 1 kg/cm^2. When compared with mechanical joints, adhesive joints normally require larger bonding surface because the strength properties of the adhesives are lower than those of traditional fastener materials. [5, p. 221] [35]

8.7.6 Coating

8.7.6.1 Painting and lacquering

In most cases, a pultrusion and pullwinded surface can be treated as such (painting, lacquering etc.) suitable materials include epoxy and polyurethane paints. Spray application is recommended for profiled surfaces.

Film thicknesses vary between 40-80 µm, and the paint is usually matt or semi-gloss. Electrostatic painting is not suitable for pultrusion or pullwinded products. Infrared drying is the best drying technique, although resistance oven can also be used. The painting area must always be ventilated properly. [35]

8.7.6.2 Gel coating

Gel coatings are used to give appearance and protect the laminate from stresses caused by humidity, chemicals, or environment. The coating can be clear or pigmented depending on the use of the product. If the product requires a good chemical resistance, there will not be mixed any pigments or other additives with the gel.

Most common gel coating materials for water and chemical resistance coatings are isophthalic acid-, neopentylglycol- and bisfenolic-A based resins. For weatherproof gel coatings, methyl methacrylate and styrene based monomer mixtures are more suitable. The gel coating after treatments varies in thickness between 40-70 µm. [5, p. 100]

8.8 Sustainability

Sustainability is one of the megatrends driving the growth in the composites industry business. Exel Composites is committed to continuously improve the performance to reduce environmental impact as well as to support the whole organization to act as a responsible global citizen. Quality, environment and safety are an essential part of management and are developed according to objectives based on Exel Composites Group's operating principles. [2]

The quality and environmental policy complies with the requirements of the standards ISO 9001:2008 and ISO 14001, and the Safety Management System is according to OHSAS 18001. Exel composites is working according to ISO 26000 for social responsibility. [2]

For the future material development, it is essential that the materials are sustainable and less energy consuming. Compared with traditional materials, such as metals, composite materials provides many benefits. Especially, during manufacturing and use, composites require less energy consumption and, in many cases, they provide longer service-life by being more durable than traditional materials. As composites are a durable solution, neither frequent maintenance nor replacement is needed. Together with composites' long life span, composites are a preferred choice for the most lasting performance. [43] [2]

PART IV: SUMMARY

9. SUMMARY

In this thesis, the objective was to understand the influence of handbooks in the field of composite materials. Second, a case study was carried out to create a handbook for Exel Composites Plc. In order to achieve the targets, a survey was made to study the most common types of handbooks and manuals that are used in the business environment and overview their content and usability. The basic strategies for successful marketing were briefly reviewed to build the bridge between marketing theory and the business of composites – i.e. to find out if design handbooks can add value for the marketing strategies by creating a stronger communication with customers. Based on the background theory and interviews performed, a methodology for creating the design handbook of composites was created and applied for the case of Exel Composites Plc.

For the theoretical background, the composites and their applications as well as the fundamentals of marketing and different types of handbooks used in business environment were reviewed. By the study of marketing, it was possible to recognize the main differences between consumers and business marketing. The definition of these differences helped to understand how the content and language should be selected in the design handbook of composites. Actually, the handbook is going to work as a connecting bridge with the company and its business customers. In addition to the background study, it was also studied how the structure and contents of different engineering design guides and material handbooks together with technical writing guides form a common baseline. Based on the additional study, it was possible to gather more understanding about the design of handbook structure and how the handbook content is logically and correctly expressed.

At the second part of the thesis, it was first presented and illustrated how the methodology of creating the design handbook of composites can be analyzed. The research for this part was done by studying different composite, design, and sizing handbooks. Also, a national survey was performed by interviewing people working in the field of composites and with the aid of the personnel of Exel Composites Plc. By the interview, the usefulness of handbooks and the basis of what kind of requirements the possible readers could have for the case study handbook's content. The answers of the interview gave valuable information for the design handbook's structure and its content. The interview also helped to understand the reasons why some handbooks are seen impractical.

In the design handbook of composites (case study), an especial emphasis was given to the establishment of understanding composites since understanding that topic is the key for working and designing with composites. Generally, the structure of the handbook was built in such an order that it follows a general composite design process. In the beginning, it is explained how is the actual design process. In the materials' chapter, it is explained how are the manufacturing methods of pultrusion, and pullwinding. To complete the design process of composite manufacturing, suitable post-processing methods taking account main issues of product and manufacture were included in the handbook. Finally, there is a chapter about the sustainability of composites since it was addressed by both the company and possible users. In this thesis, there was no stress given to the visual layout of the book, which is a matter to be finished later by an external advertising agency.

During the work of this thesis, it was noted that there has not been done research about the emphasizing of customer communication by tutorial handbooks. Therefore, for further discussion and future work, this study brought up questions about the usability of tutorial handbooks in marketing. Could the tutorial handbooks emphasize the communication with customers, by creating more informative and loyal relationship to customers? Additionally, could it be a way to strengthen co-working with customers?

REFERENCES

[1] Advameg, "Reference for business - Encyclopedia for business - Handbooks and Manuals," Advameg, 2000. [Online]. Available: http://www.referenceforbusiness.com/. [Accessed 21 June 2017].

[2] Exel Composites, "Exel Composites Plc.," 18 January 2017. [Online]. Available: http://www.exelcomposites.com.

[3] Exel Composites , *Logo,* Exel Composites Plc.

[4] F. Campbell, Structural Composite Materials, Ohio: ASM International, 2010.

[5] O. Saarela, Komposiittirakenteet, Helsinki: Muoviyhdistys ry, 2007.

[6] A. K. Jha, "Keyshone," 22 December 2016. [Online]. Available: http://www.keyshone.com/9-interesting-facts-know-aircraft-composite-materials/. [Accessed 9 December 2017].

[7] Fujian Zhongde Energy Co., [Online]. Available: http://en.fj-zd.com/products_detail/productId=25.html. [Accessed 28 November 2017].

[8] Indiamart, [Online]. Available: https://www.indiamart.com/proddetail/polypropylene-pp-iocl-10608854988.html. [Accessed 28 November 2017].

[9] Wikipedia, "Polyethylene," [Online]. Available: https://en.wikipedia.org/wiki/Polyethylene. [Accessed 28 November 2017].

[10] EAS Fiberglass, [Online]. Available: http://www.eas-fiberglass.com/products/Kevlar-Fabric.htm. [Accessed 28 Novemeber 2017].

[11] Glaspies, "Carbon Fibre Kevlar Hybrid Fabric," [Online]. Available: https://www.glasplies.co.uk/Carbon-Fibre-Kevlar-Hybrid-Fabric-p/carbon-fibre-kevlar-hybrid-.htm. [Accessed 7 December 2017].

[12] Fiberglast, [Online]. Available: http://www.fibreglast.com/product/Prepreg_3K_Plain_Weave_Carbon_Fiber_Fabric_03115/All_Carbon_Fiber. [Accessed 28 November 2017].

[13] Shaw and Christler Equipment technologies, [Online]. Available: http://shawequiptech.com/services/compression/. [Accessed 28 November 2017].

[14] "Boeing images," [Online]. Available: http://www.boeingimages.com/archive/Boeing-787-Dreamliner-Composition-by-Major-Component-2JRSXLJW4ZHP.html. [Accessed 5 December 2017].

[15] "Formula 1," [Online]. Available: https://www.formula1.com/en/latest/features/2017/2/F1-cars-of-2017.html. [Accessed 5 December 2017].

[16] The Snowboard Asylum Ltd 2017, "The snowboard asylum," [Online]. Available: https://www.snowboard-asylum.com/advice-inspiration/guides-and-advice/buying-guides/snowboard-buying-guide. [Accessed 9 December 2017].

[17] "Ecplaza," [Online]. Available: https://fbcomp.en.ecplaza.net/products/carbon-framecarbon-bike-framebicycle-frame_2005247. [Accessed 9 December 2017].

[18] D. S. Mazumdar, "State of the Composites Industry," *Composites Manufacturing,* Vols. January-February Issue 2016, 2016.

[19] Lucintel, "Growth Opportunities in the Global Composites Industry," June 2017. [Online]. Available: http://www.lucintel.com/composites-industry-2017-2022.aspx. [Accessed 9 December 2017].

[20] Research and Markets, "Business Wire - Automotive Composites Market - Forecasts from 2017 to 2022," 25 July 2017. [Online]. Available: https://www.businesswire.com/news/home/20170725005824/en/Automotive-Composites-Market---Forecasts-2017-2022. [Accessed 9 December 2017].

[21] Research and Markets, "Business Wire - Aerospace Composites Market 2017-2022 by Fiber Type, Resin Type, Aircraft Type, Manufacturing Process, & Application," 1 December 2017. [Online]. Available: https://www.businesswire.com/news/home/20171201005397/en/Aerospace-Composites-Market-2017-2022-Fiber-Type-Resin. [Accessed 9 December 2017].

[22] P. Kotler and K. L. Keller, Marketing management, 15th edition, Essex: Pearson, 2016.

[23] B. Tracy, Marketing, AMACOM, 2014.

[24] B. Wierenga, Handbook of Marketing Decision Models, Boston, MA: Springer, 2008.

[25] Advameg, "Reference for business - Encyclopedia for business - Marketing," 2000. [Online]. Available: http://www.referenceforbusiness.com/encyclopedia/Man-Mix/Marketing.html. [Accessed 21 June 2017].

[26] Lyly-Yrjänäinen, Martinsuo and Suomala, Sales - Solving problems for customers, pp. 62-67.

[27] S. Milojević, C. R. Sugimoto, V. Larivière, M. Thelwall and Y. Ding, "The role of handbooks in knowledge creation and diffusion: A case of science and technology studies," *Journal of Informetrics, Volume 8, Issue 3,* p. 693–709, July 2014.

[28] D.-J. Weatherford, Technical Writing for Engineering Professionals, Tulsa: PennWell Corporation, 2016.

[29] G. Wolf, "Steve Jobs: The Next Insanely Great Thing," *Wired Magazine,* 1996.

[30] P. R. Childs, Mechanical Design Engineering Handbook, Oxford: Elsevier, 2014.

[31] A. B. Strong, Fundamentals of Composites Manufacturing: Materials, Methods, and Application, Dearborn, Michigan: Society of Manufacturing Engineers, 2008.

[32] H. Silyn-Roberts, Professional Communications - A Handbook for Civil Engineers, Reston , Virginia: ASCE Press, 2005.

[33] F. Cardarelli, Materials Handbook, 2nd edition, Tucson, Arizona: Springer, 2000.

[34] A. K. Kaw, Mechanics of composite materials, 2nd edition, Boca Raton, Florida: CRC Press, 2006.

[35] Exel Composites Oyj, *Designers handbook.*

[36] Oyj, Exel Composites, "COMPOSITE PROFILES," 2009. [Online]. Available: http://www.exelcomposites.com/Portals/154/documents/Brochures/Exel_Composites_Profiles_web.pdf. [Accessed 29 September 2017].

[37] O. I. Isaac M. Daniel, Engineering Mechanics of Composite Materials, Oxford University Press, 1994, pp. 22-23.

[38] O. Saarela, Komposiittirakenteet, Helsinki: Muoviyhdistys ry, 2003.

[39] P. K. Mallick, Fiber reinforced composite materials - materials, manufacturing and design, 3rd edition, CRC Press, 2007.

[40] D. V. Rosato and D. V. Rosato, Reinforced plastics handbook, 3rd edition, Elsevier, 2005.

[41] M. Chanda and S. K. Roy, Plastics technology handbook, 4th edition, Boca Raton, Florida: CRC Press, 2007.

[42] G. Akovali, Handbook of Composite Fabrication, Shropshire: Rapra Technology Limited, 2001.

[43] J. Teng, "FRP COMPOSITES IN CIVIL ENGINEERING Volume 1-2," in *International Conference on FRP composites in Civil Engineering*, Hong Kong, 2001.

[44] "Fiber Glast Developments Corporation," [Online]. Available: http://www.fibreglast.com/product/glossary-of-terms-in-composites/Learning_Center. [Accessed 29 March 2017].

[45] O. C. Frank O'Brien-Bernini, "Composites and sustainability – when green becomes golden," *Reinforced Plastics,* vol. 55, no. 5, pp. 27-29, 2011.

[46] H. Boeriu, "Carbon Core body of the new BMW 7 Series wins EuroCarBody Award 2015," BMWBLOG, Chicago, Illinois, 2015.

[47] Geolam AG, "Wood hybrid systems (WHS), cutting-edge technology," Geolam AG, [Online]. Available: http://www.geolam.com/en/why-geolam/high-tech. [Accessed 6 August 2017].

[48] Government of Canada, "Canada business developer," Government of Canada, [Online]. Available: https://canadabusiness.ca/managing-your-business/marketing-and-sales/marketing-basics/what-is-marketing/. [Accessed 9 November 2017].

[49] D. Brook and J. Kiatlertpongsa, "Mechanics of Fiber-Reinforced Composites," University of Cambridge, [Online]. Available:

https://www.doitpoms.ac.uk/tlplib/fibre_composites/stiffness.php. [Accessed 16 November 2017].

[50] Wikipedia, "Glass fiber," [Online]. Available: https://en.wikipedia.org/wiki/Glass_fiber. [Accessed 28 November 2017].

[51] Amazon, "Fibre Glast Real Carbon Fiber Fabric," [Online]. Available: https://www.amazon.com/Fibre-Glast-Carbon-Fiber-Fabric/dp/B015NM0JFA. [Accessed 28 November 2017].

APPENDIX A: ANSWERS OF THE POSSIBLE USERS INTERVIEWS

The appendix A consist the six responds of the possible users interviews that are examined in chapter 6.2 User interviews at page 32.

Respondent: Designer at automotive industry

1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10)?
Laboratory material, to follow up practical lab experiments. Normally it was useful but sometimes information about procedures were missing.

2. Working as a *designer*, what kind of information would you like to find or you would expect to find from a design handbook of composites? *How to proceed in case of having a mistake during the procedure or how to fix common mistakes and go back to the beginning. A FAQ page.*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 43. *Respondent n:o 1*

Respondent: PhD student of automatic control

1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10)?

2. Working as a *researcher*, what kind of information would you like to find or you would expect to find from a design handbook of composites? *I would be interested in finding information about the fatigue life of the composites in terms of the cycles and the stress. S-N curves of the material or an analytical damage model that describes the degradation or damage growth of the composite material with a physical meaning of damage such as stiffness loss, delaminations, matrix cracks, etc.*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 44. *Respondent n:o 2*

Respondent: *Student of material technology*

1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10?
Many different material handbooks during studies. I found them very useful (8).

2. Working as a *student*, what kind of information would you like to find or you would expect to find from a design handbook of composites? *Explain the design process of composites, information about material properties*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 45. *Respondent n:o 3*

Respondent: *Senior Vice President Product and Technology Development*

1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10?
Pultrusion handbook.
Usefulness: 5. Covers the basic but leaves a lot to be learned before mastering the process.

2. Working as a *Senior Vice President Product and Technology Development*, what kind of information would you like to find or you would expect to find from a design handbook of composites? *How to design with composites, information about the process limitations – possibilities – advantages – disadvantages (limitations)*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 46. *Respondent n:o 4*

Respondent: *Composite designer (Phone interview)*

1. Have you used any kind of a material handbook in work/studies?
a) No
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10)?
Aluminum profile manuals, manuals about paints and adhesives, certain product manuals.

2. Working as a *designer*, what kind of information would you like to find or you would expect to find from a design handbook of composites? *Comprehensive information about the topic, case studies (can the same materials be used in another product), mechanical properties of the materials, approximations about the costs*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 47. *Respondent n:o 5*

Respondent: *Senior Specialist (Phone interview)*

1. Have you used any kind of a material handbook in work/studies?
a) No, *suspects that the manuals aren't updated. Asks information directly from the manufacturer*
b) Yes. Which kind of a handbook? How useful did you find it (on a range from 1-10)?

2. Working as a *Senior Specialist,* what kind of information would you like to find or you would expect to find from a design handbook of composites? *Mechanical properties of the materials, advantages and limitations of the materials, best reinforcement materials, different manufacturing methods, material comparisons between chemical resistances and temperatures*

3. Would you consider that working with a design handbook of composites...

a) Would make using composites more appealing
b) Would make selecting of composite products faster
c) Would make design of products with composites more straightforward
d) Would make easier to estimate costs of composite structures / products easier.

Figure 48. *Respondent n:o 6*