CompoWIN
More Skilled Hands for Hi-Tech Production

Potential Technologies Focus Catalogue (PTFC)

IO1: Competence and Skills Framework

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AFormX, Aviation Technology and Precision Mechanics Ltd., August 2021

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1. Introduction

The Potential Technologies Focus Catalogue (PTFC) was created as part of the CompoWIN project (http://www.compohub.eu), which aims to support the development of composite manufacturing industry in the European Union (E.U.). The CompoWIN project is funded by the Erasmus+ program. One of the goals of the CompoWIN project is to develop a comprehensive training program for workers in the composite industry.

For the needs of creating the PTFC, the partners performed an analysis of the technological processes in the partner countries. Based on this analysis, we have identified processes that are interesting from the production point of view in terms of its potential, material labour/equipment/tooling costs, automatization potential and the overall cost of mass production, and are therefore expected to be most used in the future. On the basis of our research for the PTFC, it will be possible to prepare educational programs for existing and future workers in composite production industry, and to direct the company's strategy in the right direction using suitable technologies that have the greatest potential.

The PTFC is primarily intended for educational institutions, which can offer theoretical and practical learning content on the basis of our work. The PTFC can support both formal and non-formal education offerings on the market. The PTFC is also intended for companies that are (re)focusing on composite production and also for companies with a long tradition of operating in the composite industry. Based on this Catalog of Potential Technologies, companies can more easily identify the direction of composite production in the future as well as identify potential techniques or procedures that will give them the greatest added value in the future. Additionally, the PTFC is also interesting for individuals who want to engage in composite production for their own needs as employees. With this catalog, they will gain insight into various technologies available in the production of composite products and will be able to decide on the process or technology that is most suitable for them and consequently enroll in (interesting) practical training.

The PTFC is designed in mind with all the afore mentioned target groups. In the first part, we explain the methodology behind our evaluation of particular process/material in terms of its potential, implementation costs and possibilities for automation. Then we proceed with a brief overview of the composite technology. We also touch on the basics of a composite manufacturing process, and describe the most common processes/materials used. In the second part of the document, we analyse the results and share some basic conclusions.

2. Methodology

The processes for the production of composite parts, which will be described in more detail below, were evaluated in terms of its potential, implementation costs and possibilities for automation.

2.1. Familiarity

Familiarity is defined as "theoretical or practical knowledge of a process, technique or material".

The respondents had several options to choose from in the questionnaire (listed below):

- **Not familiar** - I do not know the process/material/technique and have never heard of it;
- **Theoretical knowledge only** - I have heard of this process/material/technique and I have (a basic) understanding of its theoretical principles;
- **Practical knowledge only** - I have performed such a process/used this material/use this technique but I do not have theoretical knowledge regarding this process/material/technique;
- **Practical and theoretical knowledge** - I have performed such a process/used this material/use this technique and I have theoretical knowledge regarding this process/material/technique;

We assessed the accumulated replies from the respndents according to the below criterion:

- 0 - 1; 0% - 20% knowledge of the process, technique or material;
- 1 - 2; 20% - 40% knowledge of the process, technique or material;
- 2 - 3; 40% - 60% knowledge of the process, technique or material;
- 3 - 4; 60% - 80% knowledge of the process, technique or material;
- 4 - 5; 80% - 100% knowledge of the process, technique or material;

2.2. Potential

We have defined the potential as "having or showing the capacity to develop into something in the future". For the purpose of our research, the potential is the possibility that the process, technique or material will increase its share in the product market in the future. The potential of the process will reinforce the notion that it will be widely used in the future of the composite industry, even if its share in the production volume is low at the moment.

The potential of the procedure was assessed according to the following evaluation criteria (listed below):

- **1** - this process, technique or material will no longer be used in the future due to exceptional restrictions or other reasons;
- **2** - this process, technique or material will lose its popularity, however it will still be used in some special applications;

- **3** - this this process, technique or material will more or less remain the same with minor ups and downs in terms of popularity and use;
- **4** - this this process, technique or material will gain some popularity and its use will increase in the future, but it will not be a complete all-round solution;
- **5** - this process / material will become increasingly popular and its use will increase significantly in the future.

If a processes, techique and material has achieved less than three points, we can estimate that its use in the composite industry production process will decrease in the future. The lower the overall score, the faster the use of the process or material will decline.

Processes, techniques and materials that have scored more than three points will gain in popularity in the future. The higher the overall score, the faster and to a greater extent the process will establish itself in the composite industry.

For processes, techniques and materials rated with a medium rating, we anticipate that they will remain at their current level.

2.3. Process/Technique or Material Costs

The production costs of a process, technique or material are related to purchasing, making and maintaining tooling necessary for the use of a certain process, technique and or material. We divided the production costs of a process, technique or material in three categories:

Labour costs

Labour costs are directly related to the people involved in the work process or in performing the technique. This includes costs such as the annual wage for workers, the cost of training the workforce, the cost of sick leave and other labour costs associated with the work process);

Equipment costs

Equipment costs encompass the cost of purchasing and maintaining various equipment required to carry out the process, technique or use the raw material to produce composite parts. In the scope of equipment costs we mean personal protective equipment for the workforce, small equipment such as knives, brushes, scissors, and larger equipment such as vacuum pumps, autoclaves, resin injection equipment, a winding machine, tools and fabric cutting machines (either manual or CNC), tools and machines for final trimming of composite parts, robotic hands for manipulation, and other costs incurred in the working process. We estimated both purchasing and maintenance costs.)

Tooling costs

In the scope of Tooling costs, we took into account the costs associated with the purchase, manufacture and maintenance of tools required for a particular process or technique. By the phrase Tooling costs, we have in mind patterns, moulds, jigs and other equipment that is part specific and can not be transferred to make another completely different part. For example, patterns and moulds are usually part specific. In some cases, it is possible to make different versions of the same part using only one mould. But this still counts as tooling. To simplify, the difference between equipment and tooling is that with the equipment you can work on multiple different parts while tooling is used to produce only one part (or very similar versions of this part).

All the three above categories of production costs were assessed according to the following evaluation criteria (listed below):

- 1 - Low Tooling Costs
- 2 -
- 3 - Medium Tooling Costs
- 4 -
- 5 - High Tooling Costs

2.4. The possibility of automation

At this point, we also assessed whether a process/techinque or part of a process could be automated and if so to which scope. This means that an employee is partially or completely removed from the production process using this process/technique.

The possibilities of automation were then evaluated according to the following evaluation criteria (listed below):

- 1 - this process/techinque cannot be automated in any step.
- 2 - this process/technique may or may not be partially automated. Only minor steps in the process/techinque are or can be automated. The main steps are or can only be performed manually.
- 3 - this process may or may not be partially automated. Most of the main steps in the process/technique are still done manually. A small part of the main steps is automated or can be automated.
- 4 - this process may be partially automated. Most of the main steps are/can be automated, but not every main step, due to a specific task that a person still performs manually.
- 5 - this process may be fully automated. Every major step in the process is automated, only small operations are manual (for example, shifting, moving, etc.).

3. A brief overview of composite industry production

The term composite can be used for a variety of materials. In the CompoWIN project we use the term composite to encompass carbon fibre-reinforced polymers (CFRP), glass fibre-reinforced polymers (GFRP) and aramid products. The most commonly used polymers are polyesters, vinyl esters and epoxies. The most commonly used reinforcing fibers are glass, carbon and aramid. Throughout the PTFC, the emphasis will be on the use of these materials, which represent the vast majority in the production of composite products.

The global market for composites has been growing steadily in recent decades. Market growth is also forecasted for the future. Trends show that the composite industry will be extremely important in the future, as it brings certain advantages compared to other industries, which coincide with the global orientation towards sustainable development of society. A typical composite product can be up to five times lighter than the same product made from other conventional materials. Because of these properties, the use of composites in applications where mass is of paramount importance will increase significantly.

Composites have and will continue to have the greatest impact in the transport industry. The aerospace, marine and automotive industries are investing huge amounts of resources in the development of composite materials and in the manufacturing processes for the use of these materials. Composites are also extremely important in the sports and medical industries, where the market is also growing rapidly. The goal of the investment is to reduce the cost of mass production of composite parts. In the past, composite products have only been used in specific applications and in small batches. The problem was mainly that the production of a composite piece required a lot of manual work, which made the products more expensive. The current trend is the development and use of processes and materials that allow automation of all or part of the process for the production of composite pieces. In the future, processes that can be partially and / or fully automated and with which a large number of high-quality products can be achieved are expected to be used and developed the most.

Due to the increased need for composite products, companies are increasing their production capacity and more and more companies are choosing to enter the composite market. As a result, there is a shortage of skilled and experienced labor in the market. It turned out that supply does not follow demand and that due to the underdevelopment of the market in certain E.U. countries, the educational mechanism is also underdeveloped, especially in terms of knowledge required to work in the production of the composite materials. It also happens that the educational mechanism (for work in production) is underdeveloped despite the development of the market in certain EU countries. One such example is Slovenia, where the composite market is fairly well developed, but there is no formal or non-formal education where the knowledge needed to work in composite production could be acquired. The development of the market in Slovenia was based on companies that sent their staff to training abroad. These composite workers educated abroad then educated their colleagues and developed the industry in their base country. In this way, the market has developed and human resources have also developed, but in the current situation they cannot meet all the demand. It should be emphasized that the majority of qualified and experienced workers lacks workers in production. The deficit is also noticeable in the engineering sphere, but where their knowledge is not in question, this staff mainly lacks experience.

4. The basics of Fibre Reinforced Plastics polimers or FRPs

Composites are materials made from two or more constituent materials with significantly different physical or chemical properties. When such materials are combined, a whole new material with the characteristics that are different and usually superior from the individual components is made. When coming across the phrase composite materials (often shortened to composites) we are usually referring to modern composite material such as fibre (glass or carbon) reinforced polymers. Such fibre reinforced polymers were first used at the beginning of the 20th century. However, the concept of man-made composites has been in existence for the past 6000 years. This original composite material was wattle and daub.

There are two categories of constituent materials: the matrix and the reinforcement. At least one portion of each is required to make a composite. The matrix surrounds and supports the reinforcement material by maintaining its position. The reinforcement material enhances mechanical and physical properties of the matrix, by making the material more durable, lighter, resistant to impacts, etc. Most of the tensile loads in the composite are carried by the reinforcement material, while the matrix carries the compressive loads and fixes the reinforcing material in the desired shape. We use different fillers to adjust the properties of the matrix so that it can be used in different ways - for the wet layup, as adhesives, as sealants, etc. Different cores are used to achieve the desired thickness of the composite, thus increasing the resistance moments and increasing the stiffness of the end-product.

4.1. Matrices

A matrix is a surrounding structure, it is a material that surrounds the reinforcing fibres. In FRP composites, we speak of resin systems when we talk about matrices.

The most commonly used matrices in composite production are:

• Polyester resins;

Polyester resin is the most widely used resin system, especially in the marine industry. By far the majority of dinghies, yachts and workboats built in composites make use of this resin system. Polyester resin is also very common in tooling - the molds that are used to make a product are usually made of polyester. A major reason for this is it's rigidity. It is more rigid than it's epoxy counterpart and was one of the core products that launched the modern plastic industry.

• Vinylester resins;

Vinylester resins are similar to polyesters, but tougher, more resilient, resistant to water and many other chemicals than their polyester counterparts. They are frequently found in applications such as pipelines and chemical storage tanks. The material is therefore sometimes used as a barrier or 'skin' coat for a polyester laminate that is to be immersed in water, such as in a boat hull.

• Epoxy resins;

Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components. As a laminating resin their increased adhesive properties and resistance to water degradation make these resins ideal for use in applications such as boat building. Here epoxies are widely used as a primary construction material for high-performance boats or as a secondary application to sheath a hull or replace water-degraded polyester resins and gel coats.

All three matrices belong to the group of polymers. In other words, matrices can also be called plastic. The matrices listed above belong to the subgroup of thermosets. The second subgroup is thermoplastics, which due to their process properties are increasingly gaining ground in composite production, but currently do not reach the production volumes as achieved by thermosets.

The difference between a thermoset and a thermoplastic is that thermoplastics can be reshaped after polymerization as the temperature rises, whereas this is not possible with thermosets.

4.1.1. Polymerization

Because the matrix is a polymer, polymerization is required to fix the matrix in place and thus the reinforcing fibers. Simplified polymerization is a process in which short molecules combine into long molecules and thus form long three-dimensional chains. To further simplify, polymerization transforms a liquid or soft matrix into a solid matrix that holds the reinforcing fibers in position.

Polymerization is a chemical process. The polymerization process can be initiated or accelerated by means of catalysts and hardeners. The process can be fast or slow. The rate of polymerization is usually controlled by the type of catalyst or hardener and by temperature and humidity. The lower the temperature (humidity) the slower the polymerization and vice versa.

For effective work in the production environment, it is desirable that the polymerization can be controlled throughout the working process. In the initial phase of making a composite part, we want the polymerization to take place as slowly as possible, as this keeps the matrix flexible and it can be nicely installed together with the reinforcing fibers. Once the matrix and reinforcing fibers are installed, however, we want the polymerization to proceed quickly. Rapid polymerization after matrix and fiber installation is important for high-batch composite production, as this way several composite parts can be produced in a time interval.

4.2. Reinforcing fibers

Fibre reinforcements increase mechanical properties of pure resin. Fibres can be of different materials. Each material has an array of properties. The properties of finished composite or FRP will most of all depend on the type of fibres selected.

The most commonly used reinforcing fibers are glass fibers, carbon fibers, and aramid fibers, better known as Kevlar. These fibers represent the vast majority of reinforcing fibers in composite production. There are many other reinforcing fibers, but they are extremely rare and are only used in special applications.

Ecological awareness and sustainable development strategies, however, have recently led to an increased use of natural fibers in various composite products. These are natural flax and hemp fibers that could replace other fibers in certain applications. An increase in the development and use of natural fibers is expected in the future, so these fibers could have an increased impact in the composite industry.

4.3. Fillers

Fillers are used in the composite industry for matrix modifications. Their purpose is to expand the range of application of the matrix. By adding fillers, the matrix can be changed into an adhesive, sealant (putty), or its density and viscosity can be changed. Depending on the desired needs, the following fillers are most often added to the matrix:

- cotton fibers;
- thixotropic agents;
- metal powders;
- glass beads;
- ground fibers (carbon or glass).

4.4. Cores

The cores are used in the composite industry to make so-called sandwich structures, where the core is inserted between two layers of reinforcing fibers. In this way, the stiffness of the composite piece is greatly increased with a small weight gain. The most commonly used cores are:

- metal honeycombs;
- aramid clocks;
- expanded PVC foam.

5. Introduction to the manufacturing process of the composite industry

Composite parts can be made in many ways. The use of different materials, processes and equipment defines different procedures. Despite the different procedures, all composite parts are made in the following four (4) phases. The phases are:

• Phase 1 - preparation of tools and materials needed;

• Phase 2 - laying of reinforcing fibers into a mould (layup) – lamination;

• Phase 3 - curing and postcuring;

• Phase 4 - finishing.

What all composite products have in common is that we need a form to make them, something that keeps the matrix and reinforcing fibers in the desired shape. To achieve the desired shape, the composite industry mostly uses:

• molds;

• mandrels, and

• dies – these should not to be confused with a matrices that surrounds and supports the reinforcement material by maintaining its position .

5.1. Moulds

Moulds are the foundation of every composite production. The mould is a tool in which the composite is laid to give it the desired shape and form. We can use practically anything as a mould, as long as it provides us with the desired shape of the matrix and reinforcing fibers after polymerization. Many materials such as wood, glass, metals and plastics are used to make the moulds. The quality and material of the mold determines the process of making a composite part.

Metal moulds (aluminum or stainless steel), which are made with the help of CNC machines, are most often used for mass serial production of composite parts. Larger composite parts are usually made in composite moulds, where the same or better material is used for the mould material than is used to make the part.

Most processes in the composite industry use an open mould to make composite pieces. Such a mould is open on one side, where a bag for the vacuuming process is usually placed. With the process of vacuuming, we achieve a uniform force on the surface of the composite part, which presses the reinforcing fibers against the mould. Thus, the final product fits perfectly into the mould. The surface force also removes any excess matrix and air from the piece, which would otherwise remain trapped between the different layers of reinforcing fibers. The piece can also be made without a vacuuming process, but such a process has certain drawbacks.

Many processes also use closed moulds, where the matrix and reinforcement fibers are compressed between the positive (core) and negative (cavity) parts of the mould.

Many metal moulds for high series production are also heated in order to accelerate polymerization.

5.2. Preparation of tools and material

To make composite parts, we need moulds, mandrels or dies to place the reinforcing fibers into the desired shape. These tools must be prepared before production can begin. When preparing tools, we usually have in mind cleaning and applying a separator. On moulds from previous processes, traces usually remain, such as hardened matrix and dust, which we do not want to introduce into the part we are making. Therefore, the molds must be cleaned before use. The preparation of the tools is in most cases done manually and is more intensive in certain procedures, as the moulds become more dirty between batches. One such example is the manual laying of reinforcing fibers by manually moving them. In this process, excess resin remains on the molds, which must be removed before we begin working on the next part. There are also procedures where the tool preparation process is less intensive. With certain procedures, the tools remain relatively clean between batches and cleaning can also be done automatically.

In order for the composite part to be removed from the mould, the mould must be coated with a separator. A separator is an agent that makes a thin layer between the mold and the piece and prevents the piece from chemically bonding to the mold. In most cases, the separator is applied to the mold (mandrel or die) manually. However, this process can also be automated.

Before starting to make the composite part, it is also necessary to prepare the material. In certain processes, the reinforcement fibers need to be tailored to match the shape of the mold. Cutting of reinforcing fibers can be done manually, with the help of cutting stencils or automatically on special CNC cutting devices. The preparation of reinforcing fibers is not required for certain processes.

5.3. Laying of reinforcing materials (fibers) - LAYUP

Laying of reinforcing fibers can be performed manually or automatically and is carried out according to the lamination plan determined by the engineer. Certain processes or materials are more suitable for automating this phase of the process.

The fibers we lay can be dry or wet (impregnated). In case of laying dry fibers, the matrix must be added after the fibers have already been laid. Most often, the addition of the matrix is carried out by means of vacuum or overpressure. The fibers can also be impregnated manually. We can also lay pre-mpregnated fibers.

The purpose of wetting the reinforcing materials (fabrics) is to wet them with just enough liquid resin to completely fill the voids between fibres and no more. Too much resin only adds to the weight and the cost of the composite and does nothing to add strength. The goal of wetting the fabrics is to drive out air and replace it with liquid resin or, told in a different maner, the air has to be displaced with a minimum of excess resin. Nothing but experiences can lead to the developing the knowledge of how to wet the fabrics quickly and accurately.

The wetting itself can also be done manually, with airless spray guns or special resin-fed rollers. With spray guns the resin and catalyst are mixed as they are sprayed onto the fabric. With rollers the resin is catalyzed just before being pumped to the roller head. Spray guns and rollers, compared with manual wetting, have the need to constantly mix small amounts of resin, which remains perfectly fluid for only a few minutes after it is catalyzed. All that contributes to the preference of the manual wetting.

For more complex mold shapes, we want the reinforcing fibers to fit the contours of the mold as closely as possible. Vacuuming or compression can be used to achieve this requirement.

5.4. Curing and postcuring

Curing is a process during which a chemical reaction or physical action takes place. This is a phase in which polymerization is initiated or accelerated, and thus the reinforcing fibers are fixed in the desired position. The liquid or semi-liquid matrix hardens and becomes solid, thus keeping the fibers in place.

Curing is carried out at certain parameters. The most important are the temperature and the curing time. In order to achieve the desired physical properties of the matrix, it is necessary to strictly follow the hardening parameters specified by the matrix manufacturer. Some curing processes require maintenance of a certain temperature and/or humidity level, others may require a certain pressure.

In composite technology curing time means the time that resin needs to set. Cured resin is usually chemically resistant hard solid.

In some cases, we want to further improve the physical properties of certain matrices. For this reason, we use postcuring. Postcuring can further strengthen the matrix and improve its physical properties. One of the properties we want to improve most often is the resistance of the matrix to elevated temperatures. This can be done for certain matrices by the post-curing process, taking into account the conditions prescribed by the matrix manufacturer.

The curing and post-curing process is highly dependent on the type of matrix. It can be carried out at room temperature in simple moulds, it can be carried out in complex heated moulds or in various furnaces in which we insert the moulds that need curing.

From the point of view of automation of this phase, the most suitable processes are those in which the composite parts are heated in the moulds.

5.5. Finishing

After the curing/postcuring is done, the composite parts must also be trimmed to their final shape (dimension). In this phase, certain properties can also be added into the finished composite part (such as holes, notches,..etc.) as per specification.

Automation of this phase is possible using CNC machines and is largely independent of the composite manufacturing process itself.

6. Most common processes in the composite industry

There are many ways on how to make a composite products. Listed below are some of the processes that are currently most popular in composite manufacturing:

- Manual layup using wet fabric inside or outside the moud;
- Pultrusion;
- Filament winding;
- Vacuum Assisted Resin Transfer Molding (VARTM);
- Resin transfer molding (RTM);
- RTM process adapted for the use of impregnated fibers;
- Balanced pressure fluid molding process;
- Prepreg compression molding process;
- Autoclave procedure;
- 3D printing of composites.

Some processes will gain in popularity in the future, some will only be used in specific applications. For mass production, processes that can be partially or fully automated are the most suitable. Such processes will in future be responsible for the majority volume of composite production. This does not mean that processes that are not the most suitable for automation will be forgotten, but that they will represent only a small percentage in terms of the total volume of composite production.

In addition to comprehensive processes, some materials that have been developed with the aim of simplifying, reducing the cost and speeding up the production process are also gaining ground in composite production. Listed below are the materials that we anticipate gaining in popularity in the future:

- Sprint material;
- Pre-impregnated fibers for use without an autoclave;
- Organic reinforcing fibers;
- Silicone vacuum bags;

7. Automation in the composite industry

Process automation is becoming increasingly important in the manufacture of composite products. Trends in increasing the degree of automation are also reflected in the composite industry. The use of robotics and the use of CNC devices is increasing. More and more composite products are produced in larger batches, making automation financially justified.

Due to automation, the structure of the workforce is also changing. The traditional workforce is increasingly being replaced by workers with knowledge of mechatronics, programming and machine operation (CNC). The share of manual labor will continue to decline in the future, but machines will not fully replace the composite worker in the composite industry. Certain procedures and techniques for making composite elements will still require the manual work only a man can do. These are mainly low-serial products and tools - moulds.

Processes that enable a higher degree of automation will be developed in the future, while the classic manual processes will be maintained, but their share will be reduced.

8. Results of the PTFC Questionaire

For the needs of creating the PTFC, AFormX first defined a methodology, mapping out guidelines for activities to be undertaken. The methodology included the main questions that must be answered by the data collection and analysis and later served as an outline for the tasks to be completed. Additionally, it contained relevant instructions for partners conducting the research – methods/tools to be used, procedures, target numbers, etc. The draft of the methodology was first provided prior to the CompoWIN Kick-off meeting, where it was discussed and agreed between partners.

After the methodology was set up, AFormX designed and prepared the structure of the online questionaires to be used in the analysis (in English). The partners translated it into their own national languages. Below are the links to the online questionaires in different partner languages:

PTFC Questionnaire in English

PTFC Questionnaire in Bulgarian

PTFC Questionnaire in Croatian

PTFC Questionnaire in German

PTFC Questionnaire in Estonian

PTFC Questionnaire in Slovenian

The objective of this analysis was to identify processes that are interesting from the composite production point of view in terms of automatization potential and the cost of mass production, and are therefore expected to be most used in the future. On the basis of our research for the PTFC, it will be possible to prepare educational programs for existing and future workers in composite production industry, and to direct the company's strategy in the right direction using suitable technologies that have the greatest potential. To support this objective, the partners of the CompoWIN project have identified different profile of respondents of the following target groups listed below:

1) **SMEs in the composite industry** (i.e. companies that use the composite materials to manufacture composite parts for different industries (e.g. aerospace, automotive, marine, etc.);

2) **SMEs, working in the regional wooden, textile, metal and other traditional manufacturing industries** (i.e. furniture production, joinery, etc.);

3) **Training organisations/institutions and VET providers**;

4) **Educational institutions in the field of VET**.

Indirect beneficiaries/participants of the analysis included stakeholders and other possibly interested entities and institutions such as:

- Regional and local branch, economic or other business support and intermediary organisations;

- VET and other providers in the field of vocational training and education;

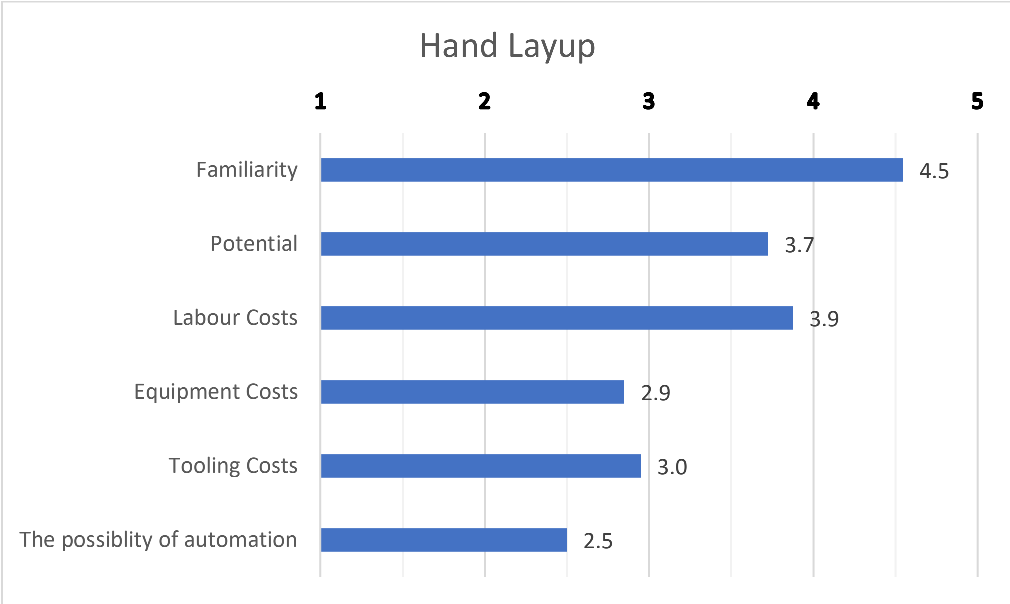
- Employment agencies and service providers;

- Regional authorities and their regional development agencies;

The analysis took place in all partner countries (Bulgaria, Croatia, Germany, Estonia, Slovenia). In the scope of activities, the partners conducted online questionaires and/or conducted face-to-face interviews with the different profiles of respondents, after a thorough preparation desk research period, focus groups involving target groups listed above.

The survey attracted 44 respondents from different target groups (14 respondents from Bulgaria, 8 respondents from Croatia, 1 respondent from Germany, 10 respondents from Estonia and 11 respondents from Slovenia). The results are listed in the following chapters.

8.1. Hand layup



Hand Layup is one of the most well-known and common processes in the composite industry. More than 90% of people working in the composite industry know and use this process. Hand Layup will also be used to some extent in the future, and we predict its use will slightly increase due to increased production.

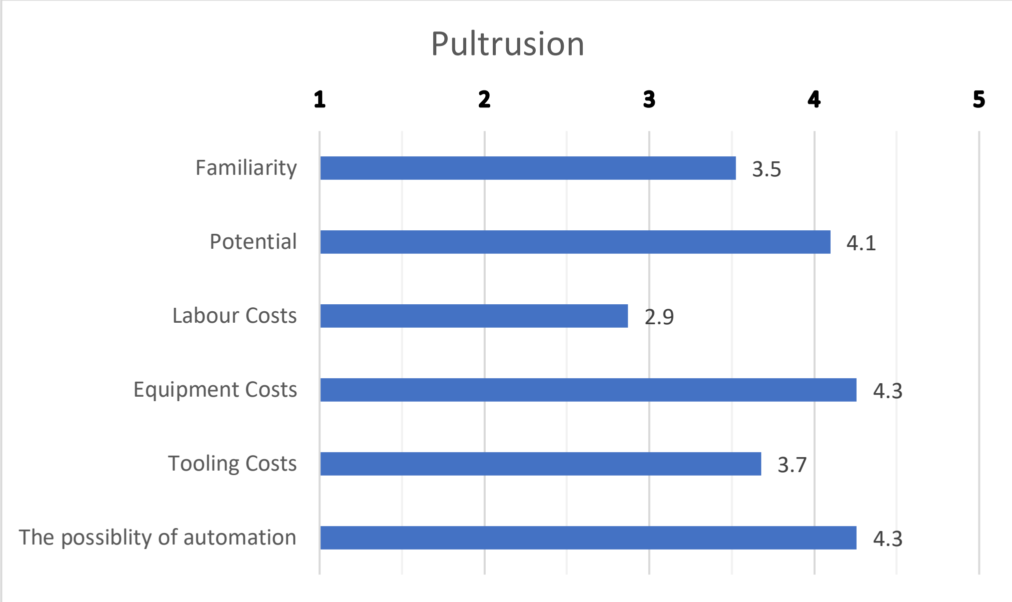
The biggest drawback of Hand Layup are high labor costs. In Hand Layup, all phases of the process are carried out manually, which requires a large and skilled workforce, which in turn means high labor costs. Additionally, due to manual labor, the cycles between composite parts are also long, which makes the process unfavorable for mass production.

On the other hand, the cost of equipment and tooling is lower compared to other processes. We do not need expensive and special equipment to process materials using Hand Layup. It can be performed using small hand tools and basic equipment. Also, the tools do not represent a high cost, as they are not very loaded in the process and do not need to have special properties, which reduces the cost of their manufacture.

The possibility of automating Hand Layup is low. The process can be partially automated but not fully.

The advantage of Hand Layup is that we can make all types, sizes and shapes of composite parts with it. It is especially suitable for low-batch series, which, due to their specificity (shape, size,…), would require large investments in equipment and tools if other processes were used to make them.

8.2. Pultrusion



Pultrusion is a continuous process used to manufacture fiber-reinforced polymer (FRP) composite profiles with a constant cross section. In this process the fibers are pulled through a heated die. While passing through the die, a constant pressure is applied, resulting in the resin melting and its impregnation into the fibrous reinforcement. The quality of thus fabricated products depends on many factors including the method of preheating, the temperature of the die, and the speed of the fiber passing. With Pultrusion, it is possible to produce composite pipes, rods and other forms of constant cross-sections. The process is known to 70% of those working in the composite industry.

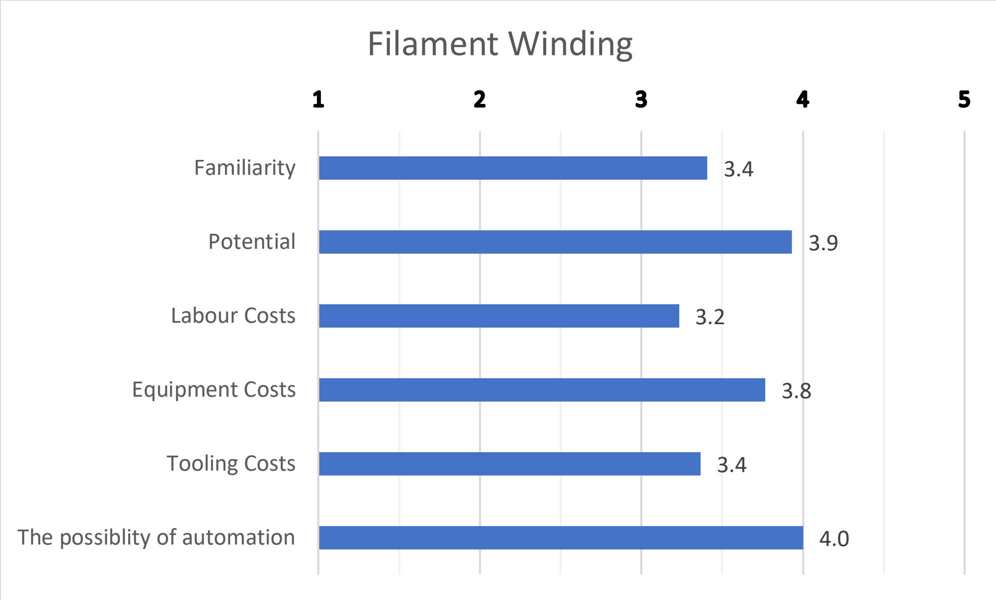
Pultrusion enables fast, mass and cost-effective production of composite products. As a result, this process has high potential. The process is almost completely automated. As a result, labor costs are also low compared to other processes.

The cost of equipment for the production of composite pieces by the pultrusion process is high. The largest share is represented by a creels (balls) of roving positioned on a rack, a complex series of tensioning devices and roving guides that direct the roving into the die, all of which is necessary for this process and is specific. The cost of tooling (mainly stencils for making different cross-sections) represents a cost, but lower than compared to other processes.

Together with processes such as resin-transfer molding (RTM), vacuum-assisted RTM, and compression molding, pultrusion falls into the family of closed-mold manufacturing processes for FRP composites. Compared to open-mold processes such as spray or hand layup, closed-mold processes share the advantage that raw materials require limited manual handling. This is not only important due to health and safety concerns (exposure to chemicals) but is also required to allow for partial or full automation of the manufacturing process. Automation is a key in enhancing consistency in quality and production output, and pultrusion is characterized by a high degree of automation, high production output, as well as high product quality.

Despite FRP composites being generally associated with increased production cost and manufacturing complexity, when compared to materials such as steel or concrete, pultrusion benefits from being one of the most cost-effective and energy-efficient manufacturing processes for the manufacture of FRPs. However, a clear drawback of pultrusion is that profiles have limited geometrical options as the cross section can only be constant in the lengthwise direction. In addition, only very few standards for FRP composites exist, which makes it challenging to get market recognition and approval.

8.3. Filament Winding



Filament Winding is a process in which the reinforcing fibers are wound around a rotating mandrel as the mold using a special machine. The fibers can be wound both transversely and longitudinally with respect to the axis of rotation of the mandrel. The male mold configuration produces a finished inner surface and a laminate surface on the outside diameter of the product. The Filament Winding process produces products similar to the poltrusion process, with some advantages and certain disadvantages, which will be described below.

The process is known to about 70% of those working in the composite industry.

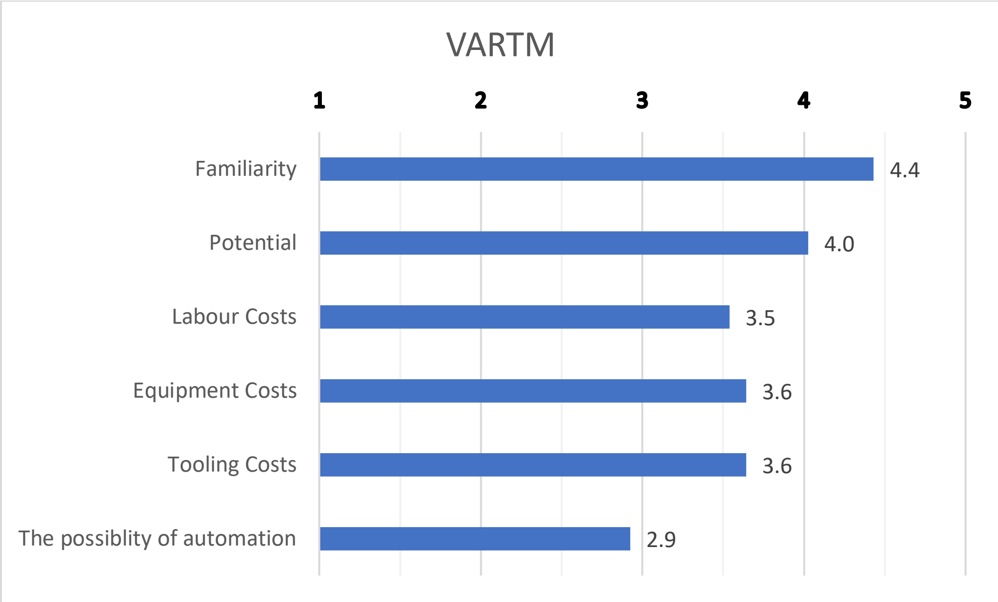
The potential of the process is high, as the process is almost completely automated and once the rotating mandrel as the mold is ready, only control of the process is required.

Labor costs are low because of this.

As with pultrusion, this procedure requires a special and specific rotating mandrel as the mold, which represents a high cost of equipment.

The cost of the tooling is comparable to Pultrusion. The largest share is represented by the costs of making thorns.

8.4. Vacuum Assisted Resin Transfer Moulding (VARTM)



Vacuum Assisted Resin Transfer Molding (VARTM) is a variation of vacuum bagging in which the resin is introduced into the mold after the vacuum has pulled the bag down and compacted the laminate. VARTM can produce laminates with a uniform degree of consolidation, producing high strength, lightweight structures. This process uses the same low-cost tooling as open molding and requires minimal equipment. Vacuum infusion offers substantial emissions reduction compared to either open molding or wet lay-up vacuum bagging.

The method is defined as having lower than atmospheric pressure in the mold cavity. The reinforcement and core materials are laid-up dry in the mold by hand, providing the opportunity to precisely position the reinforcement. When the resin is pulled into the mold the laminate is already compacted; therefore, there is no room for excess resin. Vacuum infusion enables very high resin-to-glass ratios and the mechanical properties of the laminate are superior. Vacuum infusion is suitable to mold very large structures and is considered a low-volume molding process.

The mold may be gel coated in the traditional fashion. After the gel coat cures, the dry reinforcement is positioned in the mold. This includes all the plies of the laminate and core material if required. A perforated release film is placed over the dry reinforcement. Next a flow media consisting of a coarse mesh or a “crinkle” ply is positioned, and perforated tubing is positioned as a manifold to distribute resin across the laminate. The vacuum bag is then positioned and sealed at the mold perimeter. A tube is connected between the vacuum bag and the resin container. A vacuum is applied to consolidate the laminate and the resin is pulled into the mold.

The VARTM is known to 80 - 90% of those working in the composite industry, as it is extremely used in the nautical industry.

With the increase in world composite production, the use of this process will also increase, so this process has potential in the future.

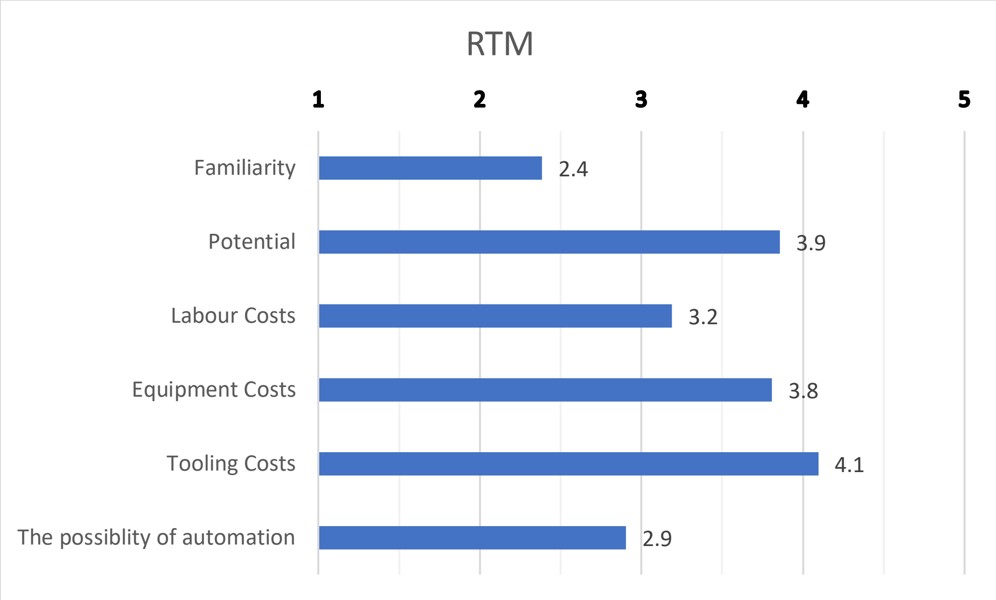
Labor costs are high compared to other processes, as all phases except for moving the fibers are performed manually, which requires experienced workforce. Installing and sealing the vacuum bag is also a big time consuming task. The wet layup is not performed manually, but this phase must be closely monitored.

The cost of the equipment is similar to that of Hand and Wet Layup. The tools we need are powerful vacuum pumps and additional consumables such as for example matrix flow control nets.

To perform the procedure, we need tools that seal very well and are not porous. Procedures for making such tools are more expensive and therefore vacuum infusion tools are more expensive than tools for Hand or Wet Layup.

The process cannot be automated. In this process, it is possible to automate the preparation of the fabric and the final finishing phase of the composite part, which can greatly affect the cost of equipment.

8.5. Resin Transfer Moulding (RTM)



Resin Transfer Moulding (RTM) is a process in which dry reinforcing fibers are sealed in a closed mould, which is then filled with a matrix. The matrix can be added by means of overpressure, underpressure or a combination of both.

The molds are prepared manually – cleaned and coated with a separator. The reinforcing fibers are manually or automatically tailored and manually inserted into the mold. The mould is filled with a matrix and then the hardening phase begins. The molds can also be heated and subsequent hardening of the composite part can be carried out in the mould. The piece is then removed from the mould and finally processed manually or automatically on a CNC machine.

About 55% of people working in the composite industry know and use this process.

The potential of the RTM is high, as the process has many positive features such as:

- quality surface on both sides of the composite part;
- the possibility of making parts in narrow tolerances;
- the possibility of optimizing the placement of reinforcing fibers;
- reaching up to 65% by volume on the side of the reinforcing fibers;
- achieving a uniform composite part thickness and fiber load;
- the possibility of inserting inserts;
- the possibility of making thinner and thicker composites;

These are just some of the main features provided by the RTM process.

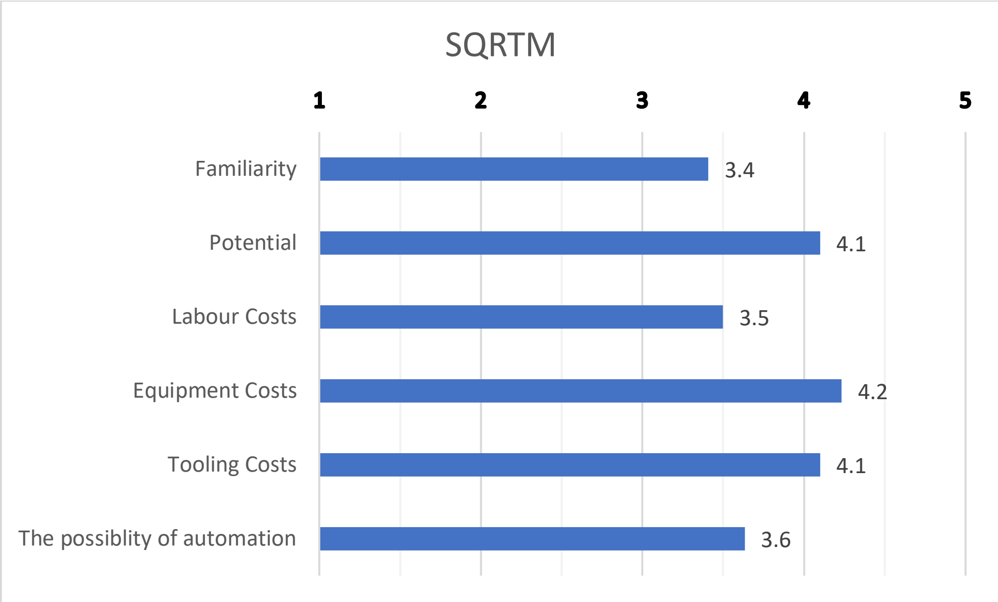
The labor costs are low, as RTM does not require the installation of a vacuum bag, which saves a lot of manual labor and removes potential chances of errors in the process.

The cost of equipment in this process is slightly higher than in the VARTM process, because in order to inject the matrix into the moulds, we need a special system that injects the matrix into the moulds using overpressure. Other equipment is similar to vacuum infusion equipment.

However, the cost of the tooling is extremely high, as the tools must be massive so that it can withstand the loads of overpressure filling (rigid so that the geometry is not lost) and well processed so that the surfaces of the end-product are of good quality. Usually the tools are metal, made on CNC devices or composite, reinforced with metal elements.

The possibility of automation largely depends on the composite part we want to make. The process can be almost completely automated (only certain parts of the phases are done manually), but it is extremely expensive. With process automation, the cost of equipment increases dramatically and post-automation only makes sense in the case of high-volume production. For medium and small batches, automation of the entire process is financially unjustified. In these series, only certain phases are automated.

8.6. Same Quality Resin Transfer Moulding (SQRTM)



Same Quality Resin Transfer Moulding (SQRTM) is a process similar to the RTM process. The main difference is that in the SQRTM process, pre-impregnated fibers are placed in the mould. The matrix (of the same characteristics) is added to the mould only in order to achieve hydrostatic pressure in the mould (similar to the autoclave process) and thus reduce the gaps (potentially trapped air between the layers of fibers) in the composite part. Using SQRTM, it is possible to produce composite parts of extremely high-quality.

The SQRTM process is well-known among those working in the composite industry (around 70% know and use it). It has potential as it brings all the positive features of the RTM process and the autoclave process.

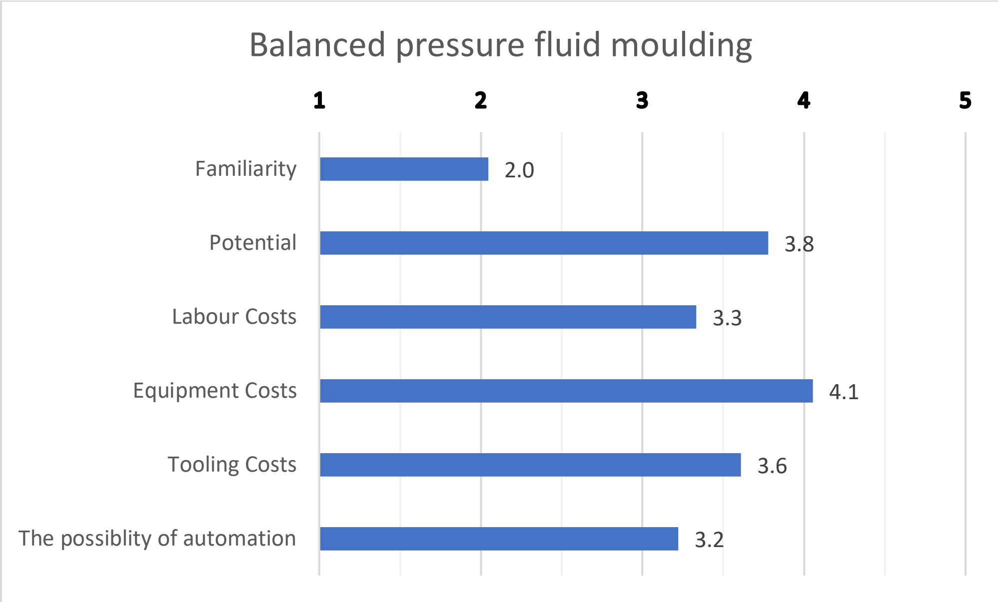
Labor costs are quite moderate compared to other processes, as SQRTM does not require the use of a vacuum bag. There is also no need for Wet Layup. The preparation of moulds and cutting of reinforcing fibers is done manually, but it can also be done on a CNC cutting device. Finishing can be done manually or by machine on a CNC trimmer.

Equipment costs are high in the SQRTM process, as in addition to small equipment, we need powerful vacuum pumps, space for storage and preparation of pre-impregnated fibers (freezer) and a device for pressure dosing of the matrix.

The cost of the tooling is also high, as the moulds must be massive and rigid to withstand the loads of the process and not lose their shape during the process. In addition, the surfaces must be flawlessly treated to ensure surface quality on the end-product. The moulds are usually metal, machined on a CNC machine. In the case of larger composite parts, reinforced composite is used.

The process can be partially automated. The mould preparation phase is manual.

8.7. Balanced Pressure Fluid Moulding



Balanced Pressure Fluid Molding is a fairly new process, so its popularity is also low. It is a process by which composite parts of the same or better quality can be made than by using autoclaves. The advantage over autoclaves is in the field-controlled hardening process and in lower equipment costs. The process is carried out by inserting a mould with vacuum reinforcing fibers between the two chambers. The chambers are on the side where they are closed in contact with the mould and the composite part with a silicone membrane, which perfectly fits the shape of the mould and the composite part by adding pressure in the chamber. In this way, the fibers are compressed against the mould. The chambers can have several zones with which we can control the hardening phase very precisely. The chambers are filled with a special liquid that provides the required temperature and pressure conditions. The special liquid formula allows for a high temperature range. The process is very interesting because it practically allows you to make composite parts with all kinds of materials. We use hand-impregnated or pre-impregnated fibers, we can use thermoset and thermoplas matrix.

The potential of the process is somewhat limited, as the Balanced Pressure Fluid Molding is best suited for composite parts that have moderate curves (for example aircraft wings), but it also allows for the production of more complex shapes. The process is projected to increase its share in the composite production in the future, but will be most useful for making the most demanding composite parts. In this segment, it could compete with autoclave process.

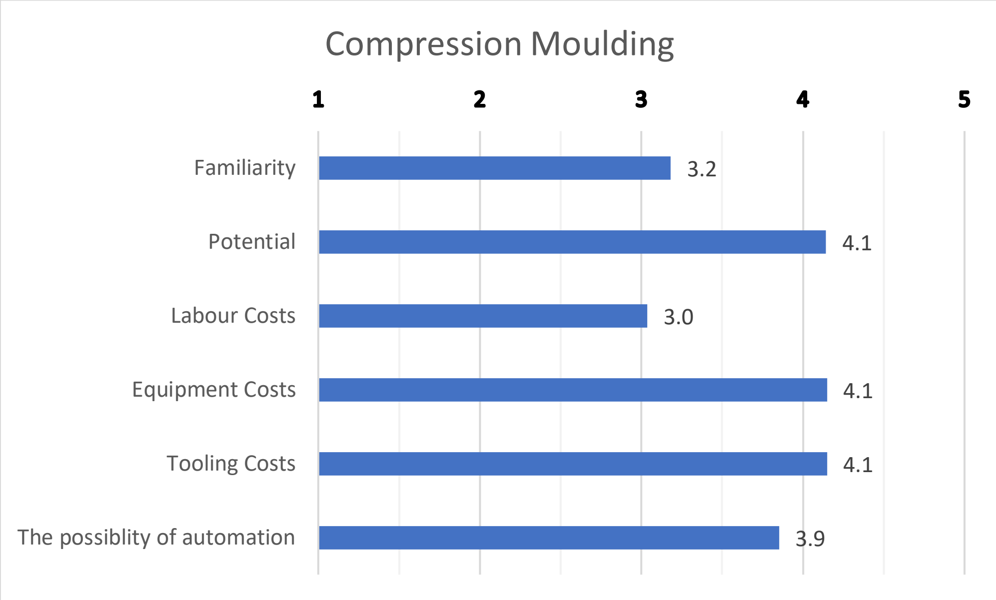
The cost of labor in this process strongly depends on how we want to make the composite parts, as this process improves the hardening phase the most , whiel the other phases depend on the desired end-result.

The cost of the equipment is quite high. The largest part of this cost is the device for hardening, which is complex.

The cost of the tooling is low compared to the cost of use of autoclave processes, as the tooling does not need to be massive and rigid, but must be temperature resistant.

The Balanced Pressure Fluid Molding process cannot be fully automated, as in most cases it is necessary to install a vacuum bag and adjust the membranes manually. The amount of automation also depends on the use of materials.

8.8. Compression Moulding



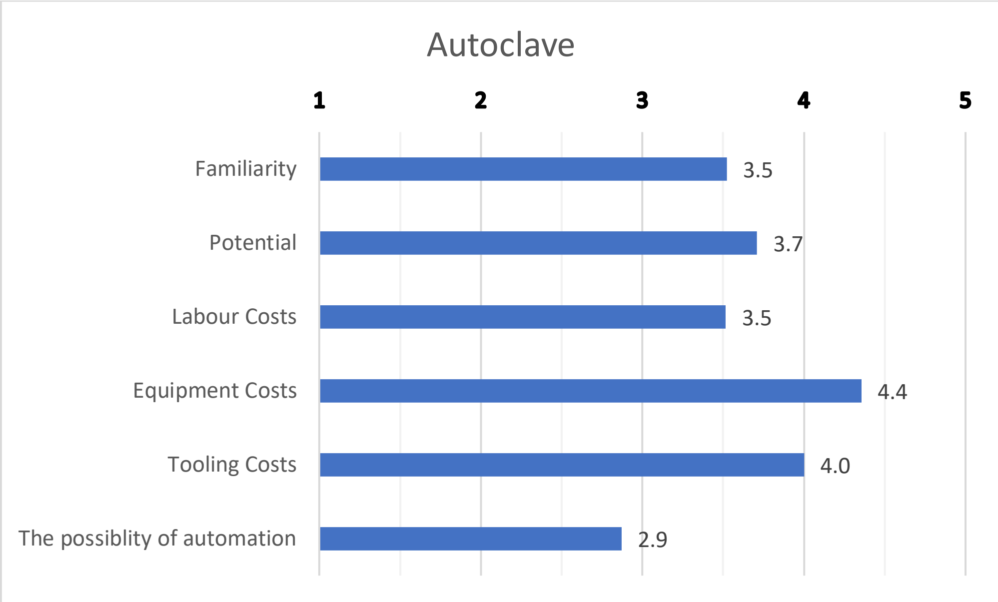
Compression Moulding is a fairly well-known process in the composite industry, 64% of our respondents know and use the process. The potential of the process is very high, because this high-volume, high-pressure production method is suitable for molding complex, fiberglass-reinforced polymer parts on a rapid cycle time. The process also allows for a high degree of automation.

Compression Moulding tooling consists of heated metal molds mounted in large hydraulic presses. The process can be automated. Compression molding enables part design flexibility and features such as inserts, ribs, bosses and attachments. Good surface finishes are obtainable, contributing to lower part finishing cost. Subsequent trimming and machining operations are minimized in compression molding. Consequently, labor costs are low, as the design is carried out in a closed mould and therefore there is no need to manually install the vacuum bag. The preparation of molds and fabrics can be manual or partially automated. The composite part needs relatively little finishing after the hardening phase is completed.

The process is quite pricey in terms of equipment costs, as the process requires the mold set mounted in a hydraulic or mechanical moulding press. The moulds are heated from 120°C to 205° C. After the moulding material is placed in the open mould, the two halves of the mold are closed and pressure is applied. Depending on thickness, size, and shape of the part, curing cycles range from less than a minute to about five minutes. After cure, the mold is opened and the finished part is removed. Typical parts for manufacture using this technique include automobile components, appliance housings and structural components, furniture, electrical components, and business machine housings and parts.

Tooling usually consists of machined or cast metal or alloy moulds that can be in either single or multiple-cavity configurations. Steel moulds are hardened and sometimes chrome plated for enhanced durability. The moulds are heated using steam, hot oil, or electricity. Side cores, provisions for inserts, and other refinements are often employed. Mold materials include cast of forged steel, cast iron, and cast aluminium. Matched metal molds can cost 50 times as much as an FRP open mold and tooling in the 40,000 EUR – half a million EUR range is not uncommon. The cost of the toolling is also high in this process, as the tools must be extremely massive and rigid, and surface flawless in order to meet the required highest standards.

8.9. Autoclave



The process by which pre-impregnated fibers are hardened in autoclaves is a known process to more than 70% of those working in the composite industry. The process is used in the most demanding applications, such as the aerospace industry. It is also very common also in the sports car and nautical industry. The autoclaves is used for controlled curing and post-curing of the matrix. An autoclave is a heated pressure vessel into which a vacuumed composite part is inserted. The desired conditions for hardening are then created in the vessel by means of pressure and temperature.

The potential of the process is slightly lower compared to the processes with which we can achieve the same quality pieces. The reason for this is mainly in the high cost of equipment and tools.

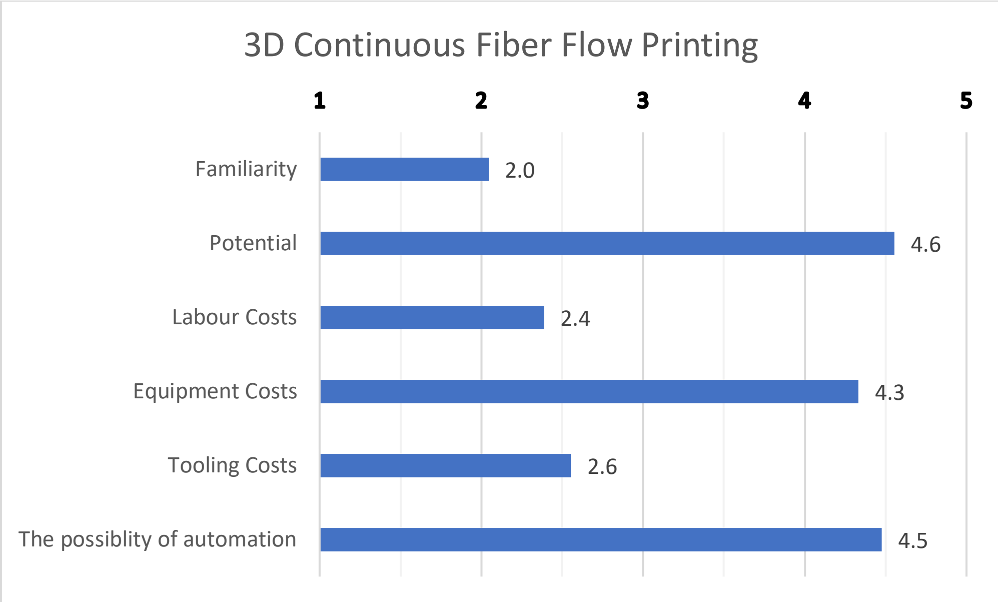
The cost of labor is relatively high due to the need for vacuuming compared to similar processes.

The cost of equipment for this process is high, as the cost to purchase and operate an autoclave is extremely high.

The tools must also be suitable for the process using an autoclave, and of high quality. Due to the high pressures during the hardening phase, the tools must be massive and rigid. Tools for smaller composite parts are usually metal, while larger parts are made in reinforced composite tools.

Due to the need to use a vacuum bag, the process cannot be fully automated.

8.10. 3D Continuous Fiber Flow Printing



3D Continuous Fiber Flow Printing is a fairly new process in the composite industry. The process is already used in some of the industrial environments, but its potential is still evolving. As a result, 3D Continuous Fiber Flow Printing is not yet widely known, but is considered as process with extraordinary potential. The process of 3D printing of composites is very similar to the process of 3D printing of plastic. The only difference is in the filler material, which is reinforced with reinforcing fibers.

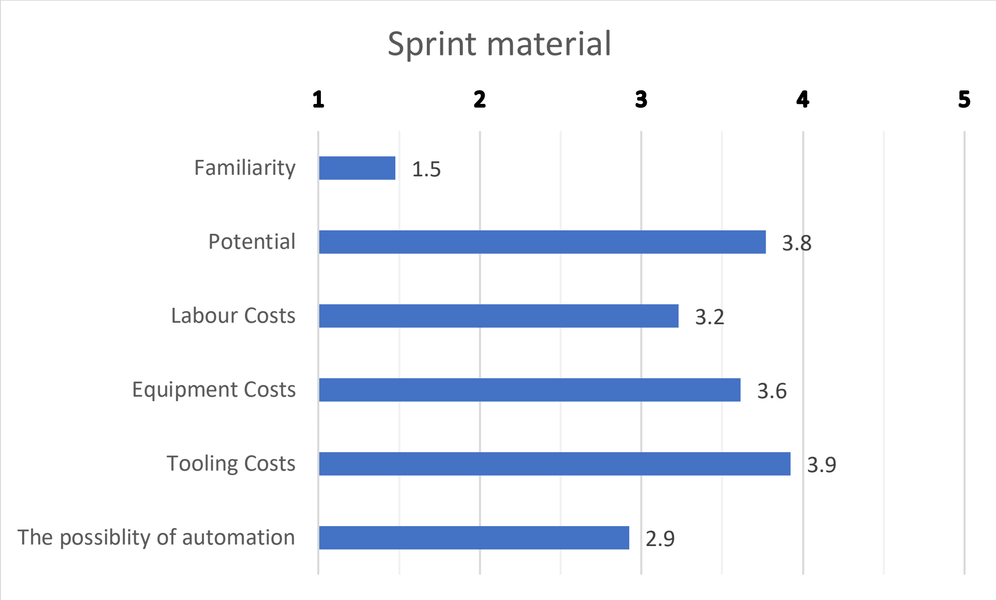
Because this is a process of adding (and subtracting material) it takes extremely little time to finish. Most pieces are ready for installation immediately after the manufacturing process without any finishing touches. There is no manual work during the cutting process itself. As a result, the labor cost of making composite part using this process is extremely low.

The equipment required for this process is expensive as the process is still in its infancy. In the future, it is anticipated that equipment will become cheaper with mass use.

On the other hand , the cost of the tooling is extremely low in this process, as no molds or other dedicated tools are required to make the composite parts.

The process of making a composite part is largely automatic.

8.11. Sprint Material



Sprint material is a relatively unknown material in the composite industry. It is known to 30% of people working in the composite industry. The sprint material is similar to pre-impregnated fibers. The difference is that in the sprint material the fibers are not impregnated but a thin film of matrix is laid on the fibers. Since the fibers are not impregnated, it is possible to remove the air trapped between the layers of reinforcing fibers by vacuuming. In this way, the final product is less subject to air gaps between the layers of reinforcing fibers.

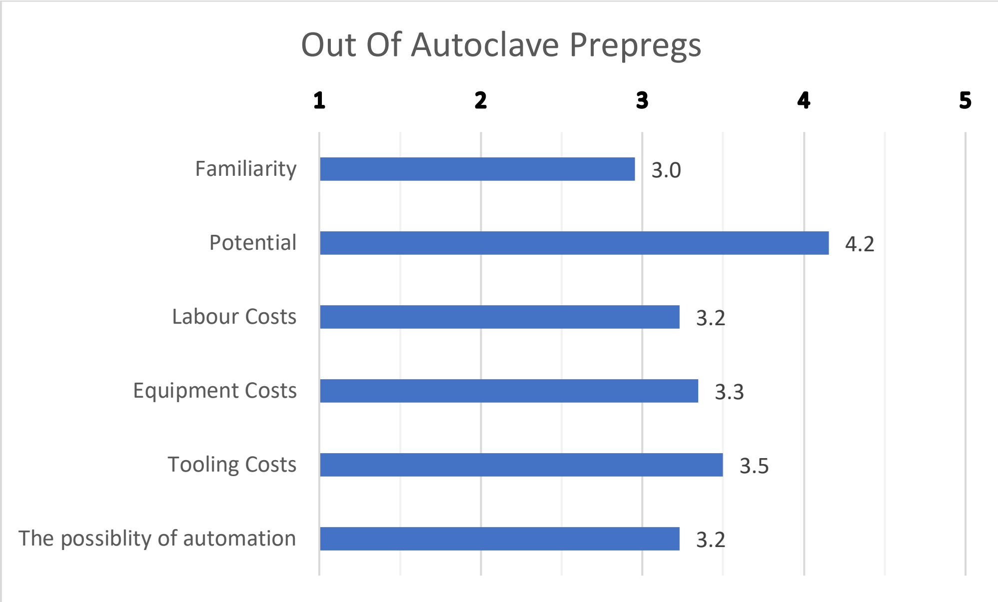
The cost of labor is similar to that of processes where pre-impregnated fibers are used.

The cost of the equipment is also similar. The biggest cost is a powerful vacuum pump and a furnace used for solidification.

The cost of tooling is also comparable. Sprint material can also be used without autoclaves. However, since it is necessary to harden the piece in the furnace, the tool must be temperature stable, which makes the tool slightly more expensive.

The possibility of automation is comparable to other processes where pre-impregnated fibers are used.

8.12. Out Of Autoclave Prepregs



Preimpregnated fibers for use without autoclaves are fairly well known in the composite industry (59% of our respondents know and use the process). Their goal is to reduce the cost of making quality pieces by excluding autoclaves from the process, which represent a high cost on both the equipment and tooling side. Such fibers are much more ventilated in a vacuum, which means that they are adapted to the process that removes air gaps between the fibers.

As a result, the potential of this material is very high, as high-quality results can be achieved with a relatively small input, which are to some extent comparable to autoclave pre-impregnated fibers.

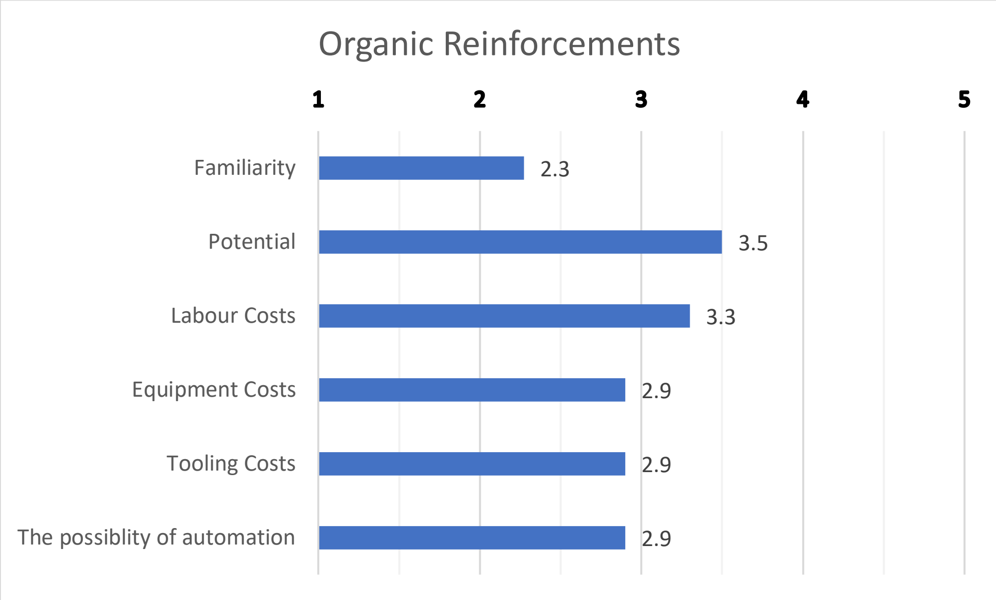
Labor costs are comparable to costs in other processes where a vacuum bag is used and the fibers are not manually layed.

Equipment costs are significantly lower than for processes using an autoclave, which is the biggest advantage of this material.

Tooling costs are also lower as a result, as there is no need for extremely massive and rigid tools, as the pressure loads are not as high as in autoclave processes.

The possibility of automation is moderate and coincides with similar processes.

8.13. Organic Reinforcements



Organic reinforcing fibers (such as flax, hemp and cotton) and more environmentally friendly bio matrices (eco epoxy) are not yet well recognized and used in the composite industry. Knowledge of these materials is between 40 and 50%.

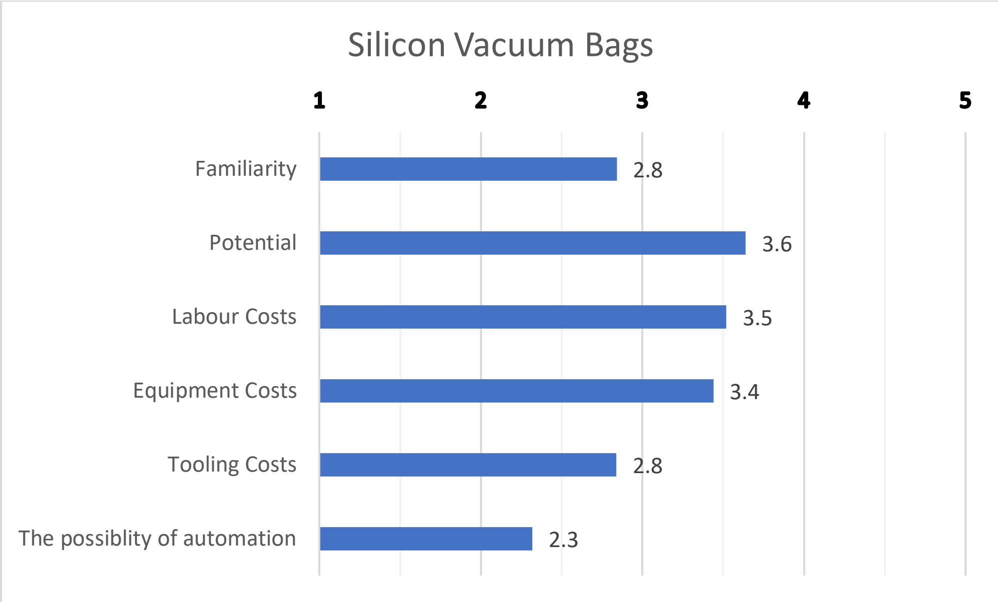
Their use will certainly increase in the future due to the desire to reduce the environmental impact within the composite industry, but this material will not become the leading material for use in a wide range of applications.

The costs associated with these materials largely depend on what form and quantity these materials will be used in production. Namely, the fibers can be used as dry or impregnated and this has a decisive influence on the process, which is then used to make the composite end-product. Its price also depends on the amount of ecologically friendly matrix used.

The equipment used to process these fibers is the same as the equipment for pre-impregnated fibers or for dry fibers. The same is true for tooling costs. By using certain procedures, tool costs can increase. The cost of a tool for making pieces using autoclaves is higher than for using a VARTM process or manual layup.

The possibility of automation also depends on the shape of the material. Cutting pre-impregnated fibers and installing them in molds is much easier when using pre-impregnated fibers.

8.14. Silicon Vacuum Bags



Silicone vacuum bags are mainly used in series production. With their help, we can greatly speed up the process of vacuuming the composite parts and thus reduce labor costs. Silicone bags can also be used several times and in this way we also reduce the cost of equipment in the process.

Silicone vacuum bags are relatively poorly known in the industry due to the fact that vacuuming is performed in many processes and that this is one of the more time consuming parts of the process phases.

To reduce costs, silicone bags will gain in use in the future.

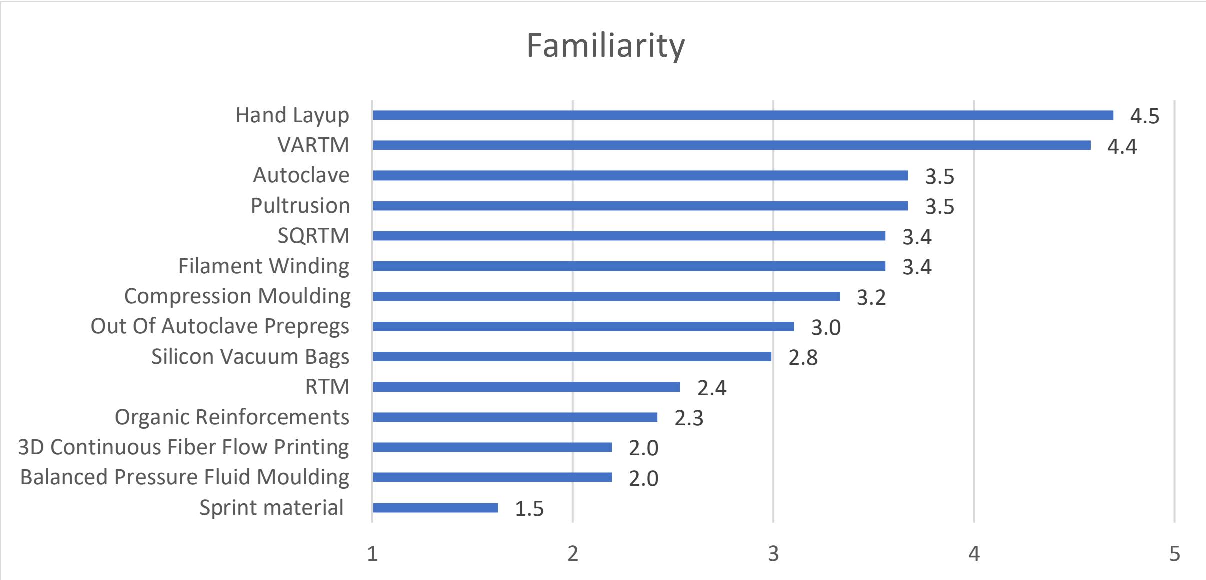
One of the downsides of making silicone bags is that the labor cost to make such a bag is high compared to disposable bags. It makes sense to make a silicone bag for serial pieces, because otherwise the cost of production is too high. To make silicone bags, we also need special equipment with which we apply silicone to the mould. This equipment increases manufacturing costs.

The silicone bag is made using the tool for the composite part, so no special tool is needed. However, the tool for the composite part must be usually slightly modified (it must have larger flanges, etc.).

Making a silicon bag is a manual process.

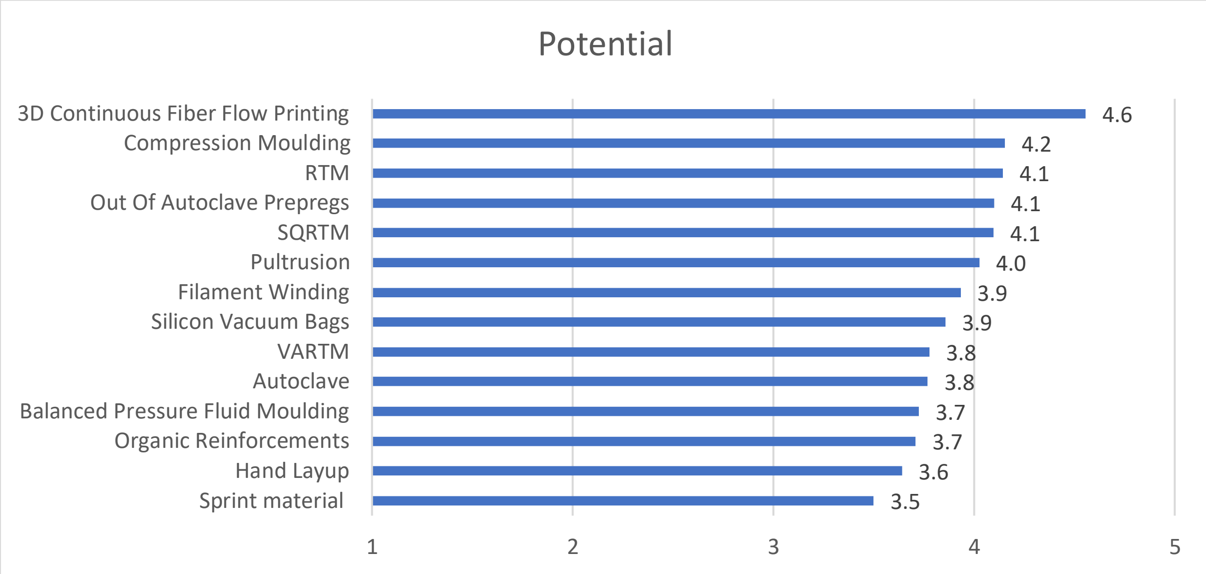
9. Processes and materials comparison

The tables below show the comparison of all the above mentioned procedures in the composite industry according to the selected criteria (Familiarity, Potential, Labour Costs, Equipment Costst, Tooling Costs, The possibility of automation).



Comparing to the Sprint material which is the least known (less than 30% of people know and use the material), Hand Layup is one of the most well-known and common processes in the composite industry. More than 90% of people of our respondents know and use this process.

From an economic and regional development point of view, the regions of Southwest and Southcentral Bulgaria, Zasavje, Kuressaare, Saxony, Zagreb capital region in Croatia differ in almost all aspects. Still, the core aspect remains the same, and it is the constant need for re-skilling and up-skilling of the manual labour force. The regions involved have a strong base in industry and manufacturing. Except for Saxony, all had problems adjusting to the labour market. The majority of involved regions in the last decade changed the industrial sectors, but the transition was, in most cases, somewhat chaotic and painful. Our respondents are mostly familiar with Out of Autoclave Pregpregs, Compression Moulding, Filament Winding, SQRTM, Pultrusion, Autoclave and VARTM, but their familiarity differs between the partner countries. The other processes / materials are dispersed depending on the industry using the processes.



Our respondents are unanimous that 3D Continuous Fiber Flow Printing has the highest potential, although is a fairly new process in the composite industry. The process is already used in some of the industrial environments and it is considered as process with extraordinary potential. The process of 3D printing of composites is very similar to the process of 3D printing of plastic. The only difference is in the filler material, which is reinforced with reinforcing fibers.

Sprint material has the least potential, but is also one of the least known materials in the composite industry.

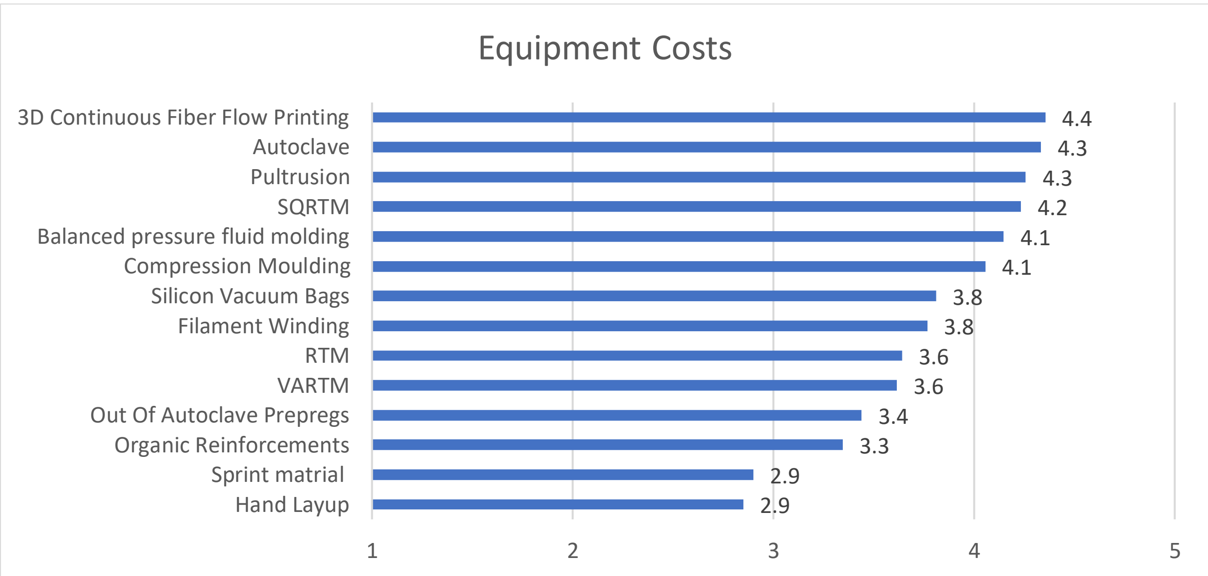
If a processes, techique and material has achieved less than an average 3.9 points, we can estimate that its use in the composite industry production process will decrease in the future. The lower the overall score, the faster the use of the process or material will decline.

Processes, techniques and materials that have scored more than 3.9 points (SQRTM, Out of Autoclave Pregpregs, RTM, Compression Moulding, 3D Continuous Fiber Flow Printing) will gain in popularity in the future. The higher the overall score, the faster and to a greater extent the process will establish itself in the composite industry.

For processes, techniques and materials rated with an medium (average) rating, we anticipate that they will remain at their current level (Filament Winding, Silicon Vacuum Bags).

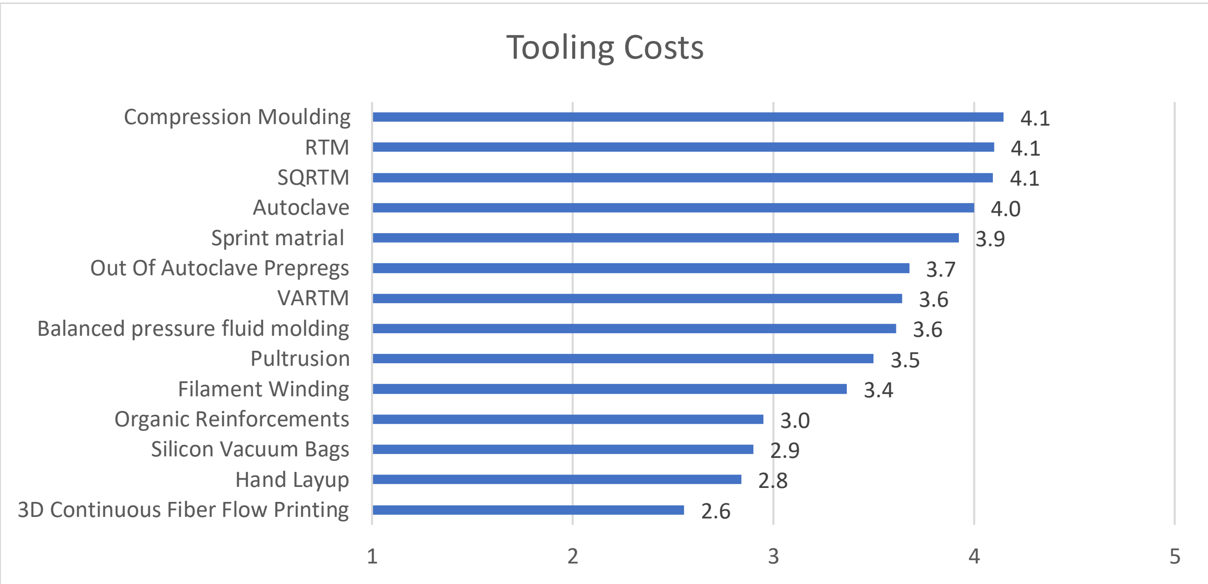
Our respondents agree that the Hand Layup is the process with the highest labor costs. This is reasonable, since with Hand Layup, all phases of the process are carried out manually, which requires a large and skilled workforce, which in turn means high labor costs. Additionally, due to manual labor, the cycles between composite parts are also long, which makes the process unfavorable for mass production.

On the other hand, the process with the most potential - 3D Continuous Fiber Flow Printing- takes extremely little time to finish. Most of the products are ready for use immediately after the end of manufacturing process without any finishing touches. There is no manual work during the process itself. As a result, the labor cost of making composite part using this process are also extremely low.



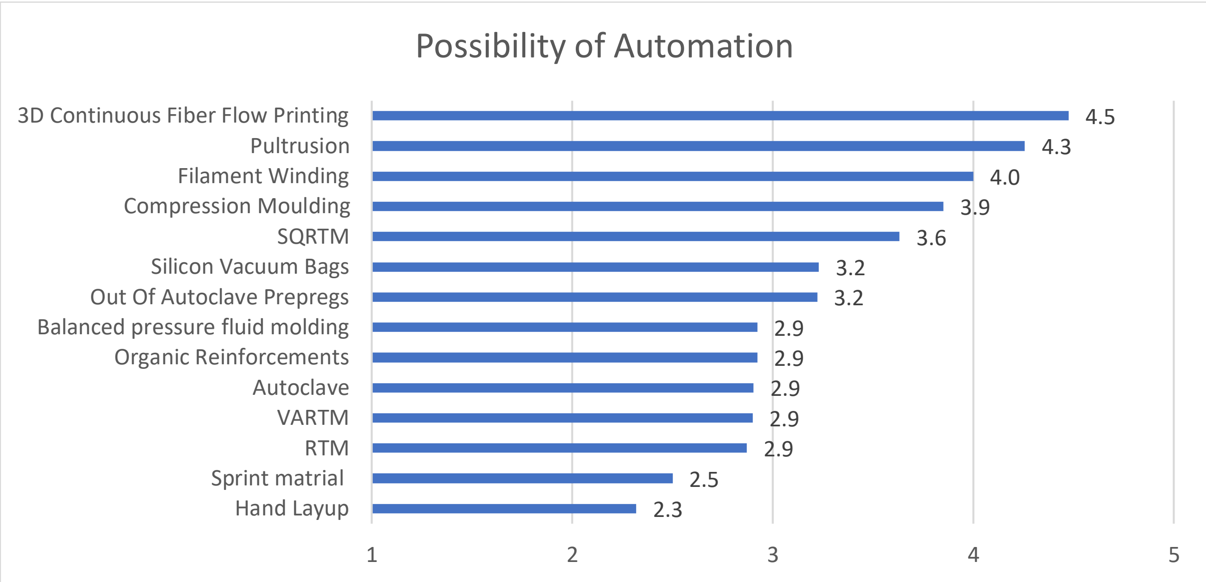
Equipment costs encompass the cost of purchasing and maintaining various equipment required to carry out the process, technique or use the raw material to produce composite parts. In the scope of equipment costs we mean personal protective equipment for the workforce, small equipment such as knives, brushes, scissors, and larger equipment such as vacuum pumps, autoclaves, resin injection equipment, a winding machine, tools and fabric cutting machines (either manual or CNC), tools and machines for final trimming of composite parts, robotic hands for manipulation, and other costs incurred in the working process.

The biggest drawback of Hand Layup are high labor costs. On the other hand, the cost of equipment and tooling is low compared to other processes. We do not need expensive and special equipment to process materials using Hand Layup. It can be performed using small hand tools and basic equipment. Also, the tools do not represent a high cost, as they are not very loaded in the process and do not need to have special properties, which reduces the cost of their manufacture. This is the reasoning why Hand Layup is assessed favourably by our respondents. On the other hand, 3D Continuous Fiber Flow Printing is still in its infancy. As a result, equipment is currently expensive. In the future, it is anticipated that equipment will become cheaper with mass use.



In the scope of Tooling costs, we took into account the costs associated with the purchase, manufacture and maintenance of tools required for a particular process or technique. By the phrase Tooling costs, we have in mind patterns, moulds, jigs and other equipment that is part specific and can not be transferred to make another completely different part. For example, patterns and moulds are usually part specific. In some cases, it is possible to make different versions of the same part using only one mould. But this still counts as tooling. To simplify, the difference between equipment and tooling is that with the equipment you can work on multiple different parts while tooling is used to produce only one part (or very similar versions of this part).

Our respondents assessed the lowest production costs using 3D Continuous Fiber Flow printing process, as no molds or other dedicated tools are required to make the composite parts. On the other hand, processes like Compression Moulding, RTM and SQRTM were evaluated as the ones with High Tooling Costs.



At this point, we also assessed whether a process/techinque or part of a process could be automated, and if so, to which scope. This means that an employee is partially or completely removed from the production process using this process/technique.

Our respondents evaluated the possibilities of automatin according to the evaluation criteria listed in the Chapter 2.4.

Hand Layup is the process where the possibility of automating is low. The process can be partially automated, but not fully. On the other end, making composites using 3D Continuous Fiber Flow printing process is fully automatic. Processes/Materials like the Sprint material, RTM, VARTM, Autoclave, and using Organic Reinforcements can be partially automated. Unfortunately, the main steps of these processess can only be performed manually.

The other processes differ on the scale/level of possible automaticity, where most of the main processes can be easily automated, but there are some tasks that employees still perform manually.

10. Conclusion

The composite industry is characterised by a high added value. It mostly employs workers performing accurate, high-quality manual labour. It is one of the few industries still valuing manual labour fabricating aircraft, boats, sports equipment, wind power turbine blades and even bathtubs from fibre materials.

Composites are the material of the future. They solve problems, raise performance levels and enable the development of new innovations in markets such as transportation, construction, corrosion-resistance, marine, infrastructure, consumer products, electrics, aerospace, appliances, and business equipment. Despite the fact that the composite market employs hundreds of thousands of workers across Europe and is making about 70 million EUR each day it has gone under the radar of the educational system. This is due to the fact that for decades the productions techniques/processess were closely guarded secrets. As a result, there is a total disconnect between the industry and education. This is why the partners of the CompoWIN project (http://www.compohub.eu) believe that composite industry will evolve in the future as the need for composites to replace other materials is high. The need for skilled labor will also increase. Production workers will need to be educated. Knowledge of manual processes will certainly be necessary and desirable, but other knowledge will be added to the existing knowledge, such as knowledge of working with machines, CNC programming, CNC device management and similar technical knowledge.

For the needs of creating the PTFC, the partners performed an analysis of the technological processes in the partner countries. Based on this analysis, we have identified processes that are interesting from the production point of view in terms of automatization potential and the cost of mass production, and are therefore expected to be most used in the future. On the basis of our research for the PTFC, it will be possible to prepare educational programs for existing and future workers in composite production industry, and to direct the company's strategy in the right direction using suitable technologies that have the greatest potential.

Developing skills and exploiting the potential of both the existing composite industry and related industries, could act as a sustainable catalyst for diversifying regional economies (i.e. post-coal economy of the Zasavje region, the low-technology manufacturing industries in Southwest Bulgaria, the 3dprinting and design sector of Croatia, etc.). Additionally, the newly developed training methodologies and the achieved exchange of expertise and knowledge will be beneficial for countries such as Bulgaria and Croatia, where the composite industry and the relevant training offers are quite underdeveloped.

The partners believe that CompoWIN is a self-sustained project. The industry will organically grow and adapt the contents and material according to their needs ensuring sustainability in the post-project period. It will provide a fast, economical, and goal-oriented course and, furthermore, define and develop a new/upgraded occupational standard and Catalogue of the “Composite Fabricator” (influencing also the future development of the National Occupational

Qualifications). This will assure that skills and qualification can be more easily recognized, within and across national borders, as well as in the labour market.