UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Development and implementation of a manufacturing process for web based thermoplastic composites

Autor:
Diez Achiaga, Gonzalo

María Isabel Sánchez Bascones

Universität Augsburg

Valladolid, septiembre 2017.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Development and implementation of a manufacturing process for web based thermoplastic composites

ALUMNO: Gonzalo Diez Achiaga

FECHA: 15/09/2017

CENTRO: Universität Augsburg

TUTOR: Univ.-Prof. Dr.-Ing. Stefan Schlichter

RESUMEN:

El TFG se centra en el desarrollo y mejora de un proceso de fabricación para “web composites”. Una vez desarrollado el proceso, este fue automatizado, mediante la programación de un brazo robótico y distintos periféricos. Con el fin de alcanzar los objetivos propuestos, se realizó un estudio sobre la interacción entre el brazo robótico y la preforma de fibra de carbono.

El proceso de fabricación fue optimizado y automatizado mediante la programación del brazo robótico, hornos de infrarrojos y una prensa. Con el finde aumentar el grado de automatización global se diseñaron una serie de periféricos complementarios, con los que sería posible que el proceso fuera 100% automatizado. Durante el desarrollo de la tesis también se consigo incrementar la calidad de la superficie de las preformas de fibra de carbono.

El ciclo de fabricación fue reducido en 10,5 segundos, lo cual representaba una reducción del 61% consiguiendo así alcanzar los objetivos propuestos al inicio del TFG.

CINCO PALABRAS CLAVE:

Ingeniería de procesos, robótica, automatización, composites, fibra de carbono.

The work was submitted to the

Institut für Textiltechnik Augsburg gGmbH

Univ.-Prof. Dr.-Ing. Stefan Schlichter

Development and implementation of a manufacturing process for web based thermoplastic composites

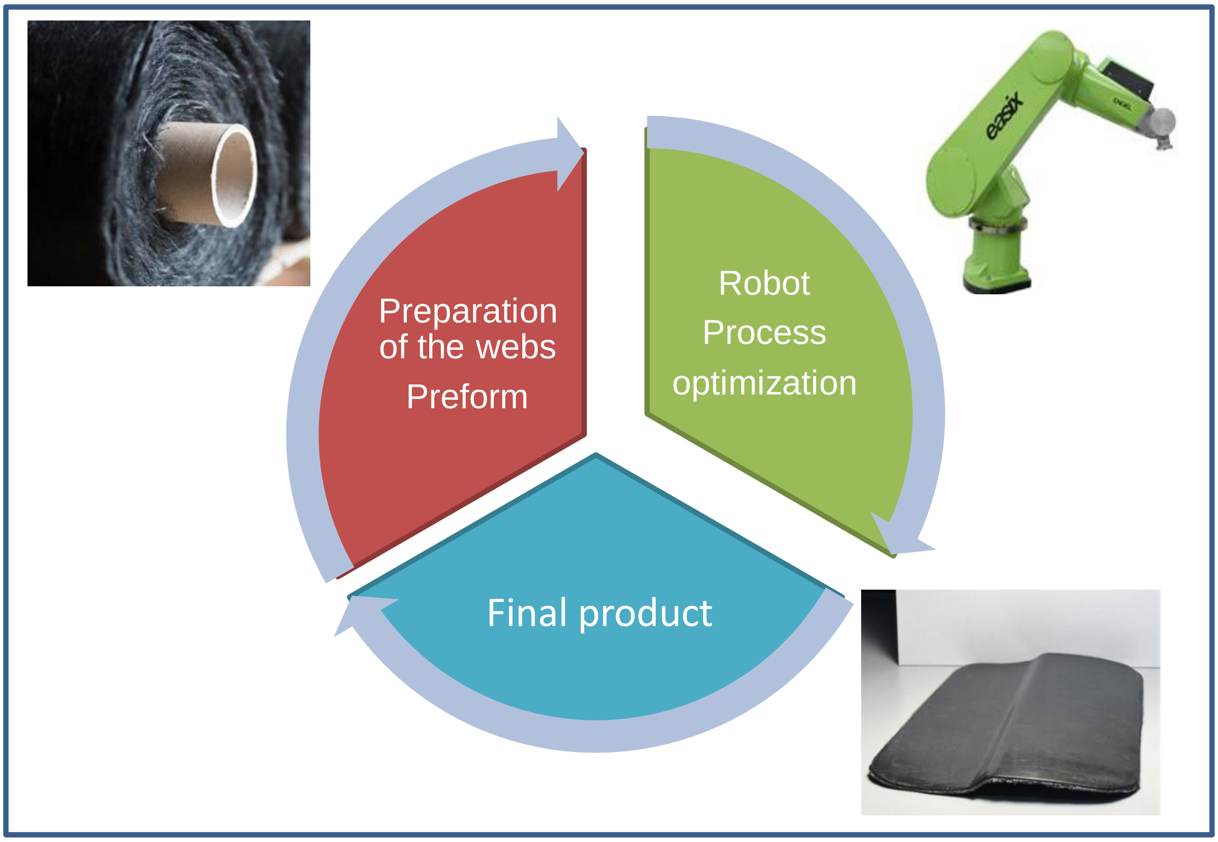
Presented as:	Bachelor Thesis
by:	Gonzalo Diez Achiaga
Matr.-No.	1528519

1st examiner: Univ.-Prof. Dr.-Ing. Stefan Schlichter

2nd examiner: Prof. Dr. Siegfried R. Horn

Supervisor:	Dr.-Ing. Philipp Abel

Augsburg, September 2017



2017

Bachelor Thesis

Development and implementation of a manufacturing process for web based thermoplastic composites

Gonzalo Diez Achiaga

Abstract

This thesis focuses on the development and improvement of the manufacturing process for a web based thermoplastic composite by an automatic process. In order to achieve the objectives an experiment studying the interaction between the preform and the robot gripper was realized.

Later the manufacturing process was optimized and automated using different robot programing and manufacturing process design. The optimization main achievement was reducing the process time by 10,5 seconds, which translated in 61% in cycle time reduction. This directly improve the surface quality of the final product.

Finally, after gathering all the information during the thesis it was decided to realize a product design, which will solve one of the last impediments towards full automation.

Keywords: Manufacturing Process, Robot, Composites, Carbon Fiber, Automation

Table of Contents

List of Figures

List of Tables

1 Introduction and Objectives

Composite recycling is still in development. It is necessary to mention that most products that contain composite components have a long service life and will not be available for recycling in some years by which the growth of the recycling industry does not resemble to the one of manufacturers.

Apart from the previously mentioned, there is another challenge that must be overcome. Not all the companies can work with recycled fibers (is necessary to align the recovery fibers), which is more complicated than working with new fibers. Furthermore, if similar composites are wish to those obtained with new fibers an almost perfect alignment is needed, which is a difficult task to accomplish.

Despite these disadvantages, the high value of carbon fiber makes new companies arise all over the world. This is the case of “Institut für Textiltechnik Augsburg” (ITA) that employs recycled carbon fibers in combination with various thermoplastic matrix producing different types of non-woven composites.

The Fig. 1.1 is a representation of the process commented previously

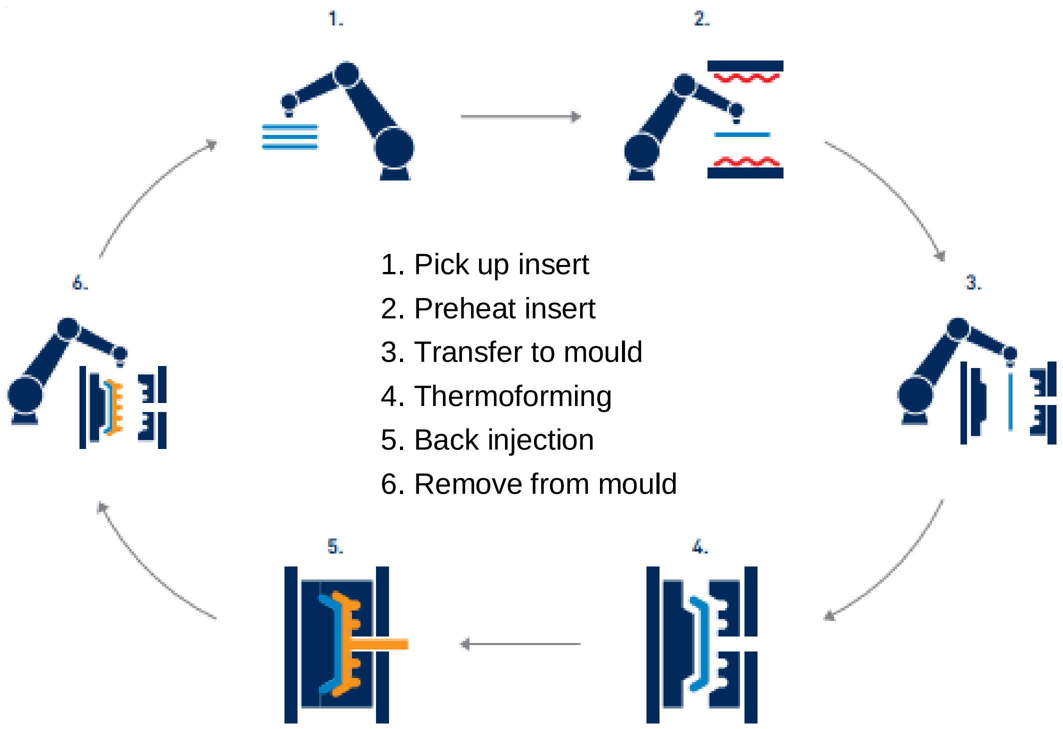


Fig. 1.1: Manufacturing process diagram. [Kra17]

The “ITA” has also implemented a production process of web based carbon fiber reinforced composites in its headquarters in Augsburg. It is a process that combines the thermoforming and subsequent compression with plastic injection. This process results in the production of final parts with mechanical characteristics comparable to those of metals.

The main objective of this thesis is the improvement of the manufacturing process and the quality of the final product. In order to achieve this, an optimization of the process has been carry out.

Before the optimization, several studies and experiments took place, their main goal was to set up the bases for the optimization.

The first experiment establishes the boundaries of the needles gripper used by the robot and the load capacity of the preform.

Once the boundaries were established, the optimization process was performed, the objectives during this phase of the thesis were the reduction of the cycle time, improve the surface quality of the final product and the increase in the automation grade of the process including the commercial viability of it.

The last part of the thesis consists on the design of a peripheral which would greatly improve the automation of the process and increase the manufacturing rate of the machine.

This thesis that is presently exposed would have no meaning if it is not for two other thesis which have been carried out by my colleagues in parallel. Each segment of the process has been approached particularly by every author.

Miguel has focused on the preparation of preforms and his subsequent reduction of times, Gonzalo in the optimization of the robot’s cycle and Elias in the surface quality of the parts resulting from the process. Miguel and Gonzalo thesis are detailed in Bibliography with the references [Gar17] and [Die17] respectively.

But before focusing on each part it is necessary to have an idea of the general process. This process is encompassed in another larger process in which the treatment of recycled carbon fiber is present and its subsequent conversion into rolls of non-woven textile. This large process includes every practice from the recycling of carbon fibers to the production of final parts with a defined functionality.

In the image below a schematic representation of the distributions commented previously can be appreciated. On the left, a flowchart of the different segments treated by each author is displayed and on the right, a sector diagram of the whole process from carbon recycling to the production of parts is presented.

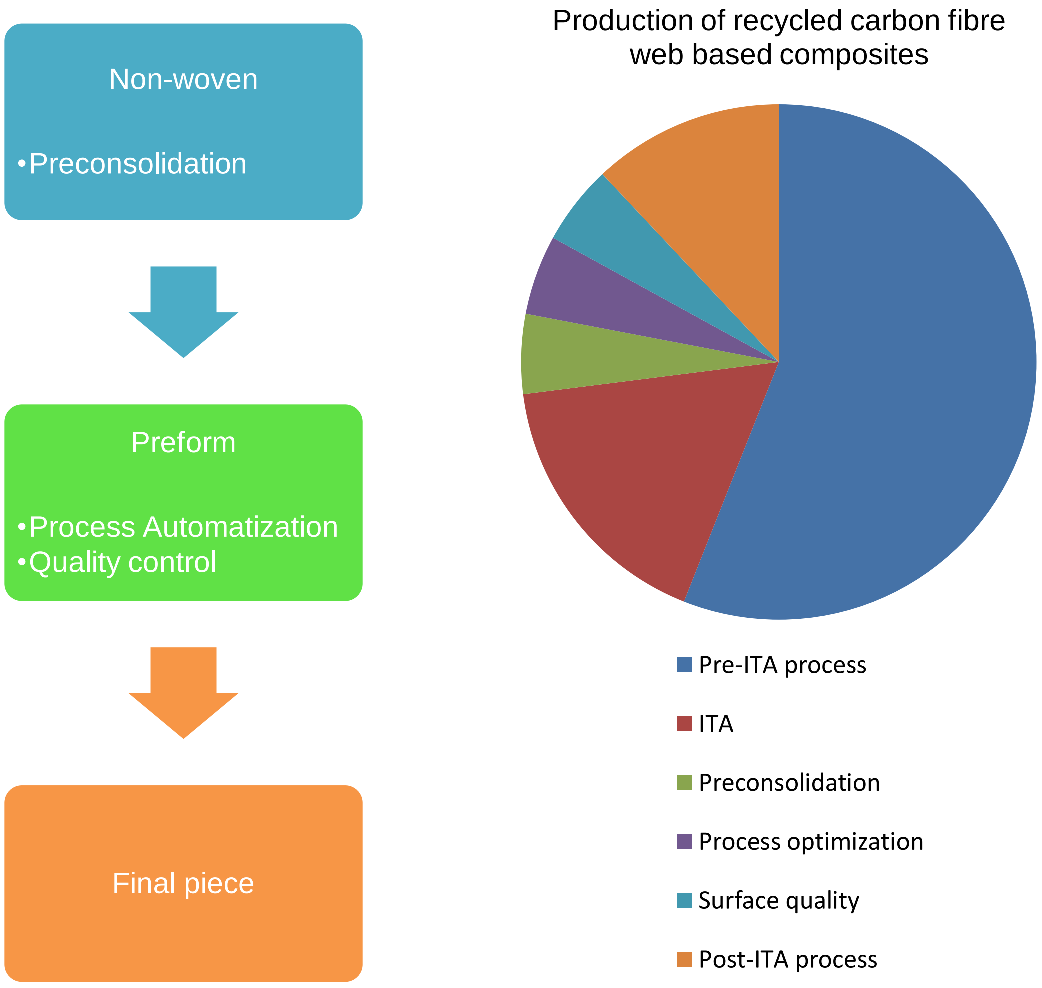


Fig. 1.2: Descriptive flowchart and sector diagram of the process.

2 State of the art

2.1 Introduction to composites materials

Composite material is a combination of two or more materials giving the resultant material better properties than those of the individual components by themselves. The materials retain their chemical, physical, and mechanical properties separated, this contrast to the metallic alloys. [M02]

Each composite ha two constituents and these are a reinforcement and a matrix. The main advantages of composite materials are their higher strength, higher stiffness lower density compared with bulk materials that form the composite. This allows for a weight reduction and higher mechanical properties in the final product.

The strength and stiffness is provided by the reinforcing these is because in most cases, the reinforcement is harder, stronger, and stiffer than the matrix.

The reinforcement in most cases is a fiber or a particulate. The Particulate composites have the benefit that are less expensive but the disadvantage that are weaker and less stiff that the continues fiber.

Composite mechanical properties can be tailored specifically to each design application. These are three of most used reinforcing materials: glass, aramid, and carbon, which may be continuous or discontinuous.

Composites matrix materials are chosen and designed to protect the fibers from the environment, maintain the fiber orientation, transfer the load to the fibers, and to separate the fibers away from themselves. There are many different types of matrix materials from polymeric to ceramic to metallic. Each type of matrix is chosen based upon its specific properties and how the matrix reacts with the reinforcement.

2.2 Carbon Fiber

Carbon fibers are the second most widely used reinforcing material with growing popularity.

The Carbon Fiber main characteristics are high tensile strength 4300 MPa, high modulus-to-density ratio 2457 KN*m/Kg/1.75g/cm, other characteristics are Young’s modulus in the direction of the basal planes is about 1000 GPa, while in the perpendicular is 35 GPa. less important features are low linear thermal expansion, high fatigue strength, and a high thermal conductivity. [H96]

The high-performance carbon fiber composites are used in areas where high strength and stiffness is required but more important is the light weight of the final product.

The much lower cost fiberglass composites are used in less demanding applications where the weight that's not have such a critical role.

Some of the most used applications include aerospace, transportation, construction, marine goods, sporting goods, and more recently infrastructure, with construction and transportation being the largest.

In areas where low weight is most important carbon fiber is highly use and there is no better example of this than in military aircraft where low weight is the most critical factor for various reasons like performance, payload and efficiency, composites are often use in 20 to 40 percent of the airframe weight.

Basically, there are carbon fibers of about 90% carbon, less than 7% nitrogen, less than 1% oxygen and less than 0.3% hydrogen. In diameter, they are between 5 and 10 microns.

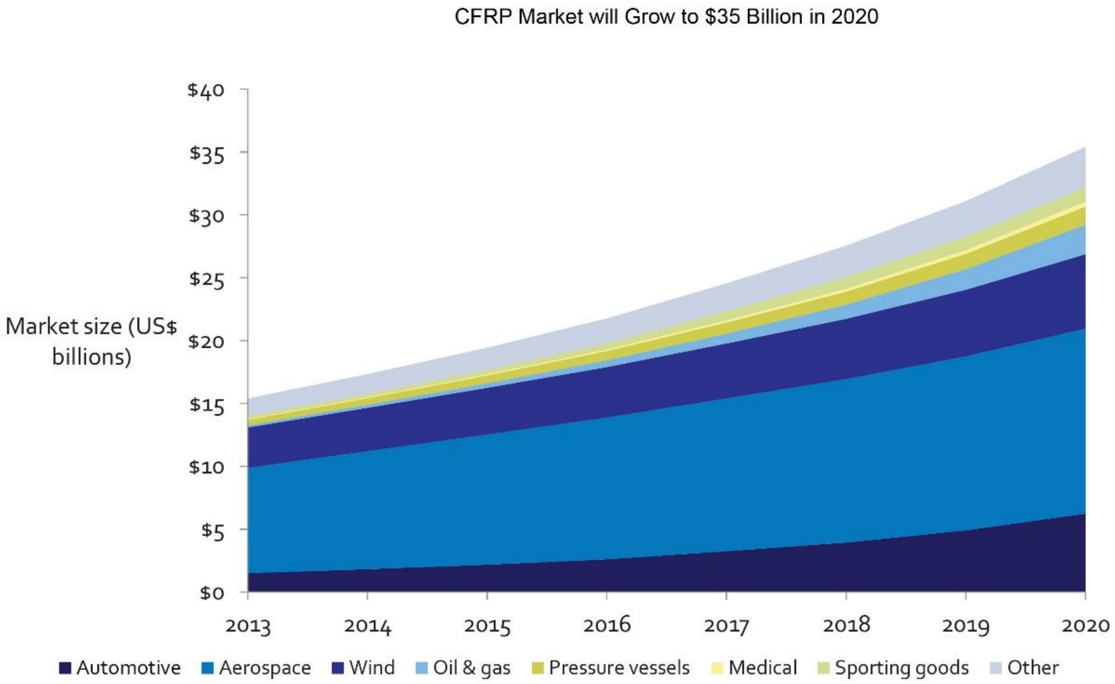


Fig. 2.1: CFRP market grow from 2013 to 2020.

2.2.1 Carbon Fiber structure

The carbon fiber is made of filaments, each of this filament are a thin tube with a diameter of 5.8 µm and it is made almost exclusively of carbon. The atoms are join in crystals that are parallel align with the longitudinal axis of the fiber. The first generations of fibers had a diameter of 7.8 µm. Later diameters of 5 µm were achieved.

Due to the alignment of the crystal the fiber has a very high strength compared to its volume. A few thousand carbon fibers are interlaced to form a thread, which can be use by itself or sew to form a web.

The carbon fiber has 5 times the strength of the steel, with the same resistance and it is lighter than the aluminum.

In addition to this particular feature, the following properties can be highlighted: [www09]

- High strength (Specific strength of 0.7-2.7 GPa).
- High rigidity (106-407 GPa of Young Modulus).
- Low density (1.5-1.7 g/cc).
- High resistance to vibrations
- Good behavior to fatigue (1600 MPa).
- Good electrical conductivity (Electrical resistivity of 1.5-7·10-4 ohm cm).
- Good thermal conductivity (24 W/mK).
- Low thermal expansion coefficient (-1 to +8 Inch / inch degree F).
- High temperature resistance (Fire resistance and non-flammable).
- Chemical stability
- They resist sea conditions
- Non-poisonous, biologically inert and X-Ray permeable.

The atomic structured of the carbon fiber is like the graphite, it consists in carbon atoms layers laid in a regular hexagonal pattern. The main different between the graphite and the carbon fiber is the way the layers are join.

The graphite is a crystal structure in where the layers are piled up parallel to each other in a regular manner. The intermolecular forces between the layers are considerable soft, this gives the graphite its soft and fragile characteristics.

The carbon fiber is an Amorphous material: the carbon atom layers are laid in a random and in a press together disposition. This layup is the responsible for its high strength.

The carbon fiber has a density of 1.750 kg/m3. When the carbon fiber is heat up the filaments becomes grosser and shorter. [AVK14]

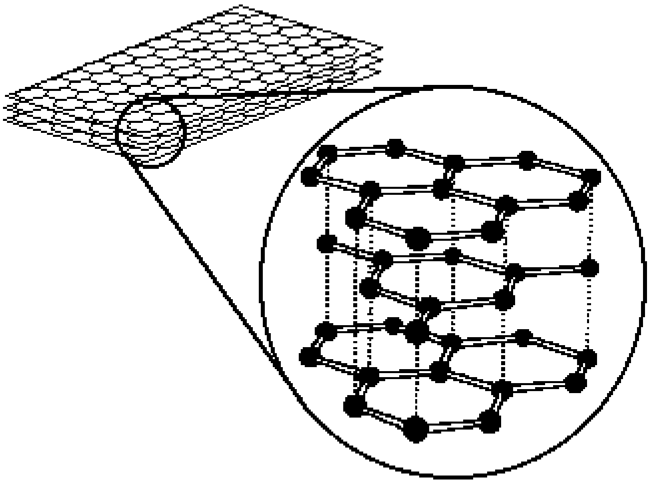


Fig. 2.1: Carbon fiber structure. [CR14]

2.2.2 Carbon Fiber manufacturing process

Carbon fiber is made of organic polymers, which consist of long strings of molecules held together by carbon atoms.

About 90% of carbon fibers are manufactured with a process call polyacrylonitrile, it is commonly known as PAN. There are others manufacturing process, but these processes account for about 10% of the carbon fiber manufactured.

The main different in the manufacturing of the carbon fiber is the combination on the raw material they use. Each company, produces their own combination and it is keep from the public in order not give advantage to their competitors.

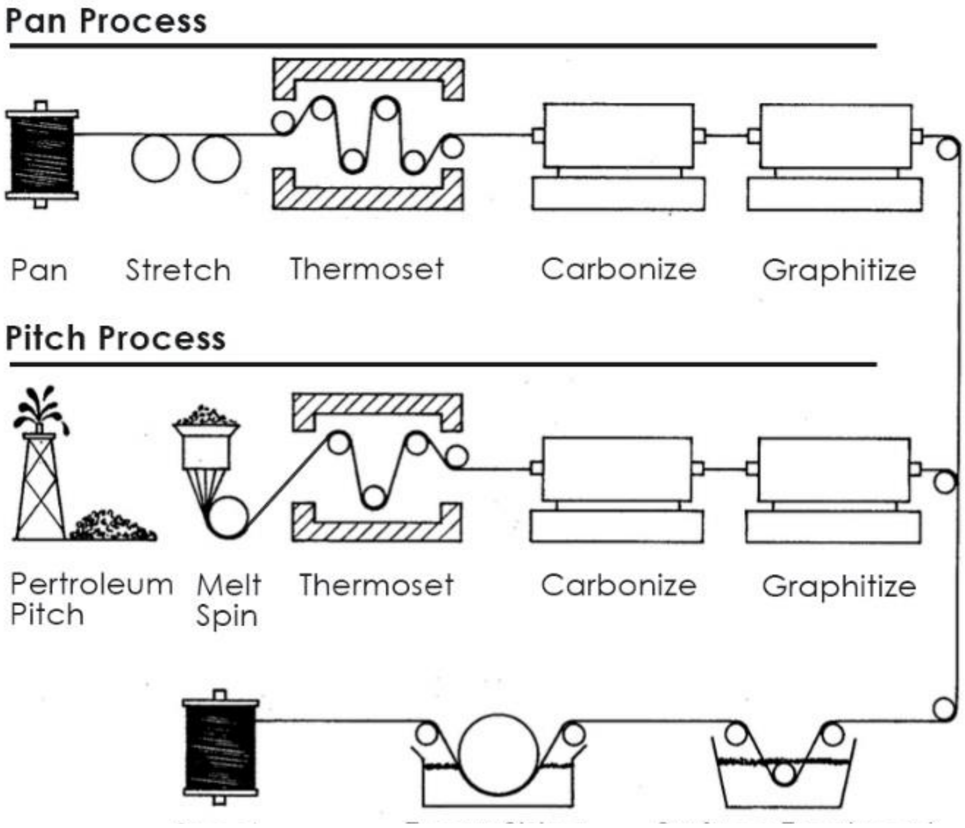


Fig. 2.2: PAN manufacturing process. [ED17]

<u>PAN Manufacturing</u>

The PAN process accounts for the 90% of the carbon fiber production. [Ehr11]

There are five steps in the PAN process, these are:

- Spinning: The PAN is mixed with other ingredients and then made into fibers, these fibers are washed and stretched.
- Stabilizing: In this step, the carbon fiber is chemically altered in order to stabilize the bonding.

- Carbonizing: Once the fibers are stabilized, they are heated to very high temperature, this creates very tight bonded of carbon crystals.
- Treating the Surface: After the carbonizing step, the fibers surface does not have the properties need to bond well with the epoxies and other materials used in composite materials. The surface then is slightly oxidized giving it the necessaries properties to bond with the other materials.
- Sizing: The final step in the PAN manufacturing gives the fibers a coating to protect them from damage during winding or weaving. The coated fibers are wound onto cylinders called bobbins then these bobbins are loaded into a spinning machine, where the fibers are twisted into various sizes yarns.

Recycling Carbon fiber

There has been a notable increase in the use of carbon fiber this is due to the numerous advantages properties of the CFRPs. During the past decade, the global demand has risen steadily, it has gone from 16.000 to 55.000 tonnes/year and the forecast is that it will reach 140.000 tonnes/year by 2020. [Wit13].

As the use of CFRP increase so has been the carbon composite waste. The waste is divided in manufacturing waste that accounts for 40% of all carbon fiber reinforced plastic (CFRP) waste and the end-of-life products that account for 60%.

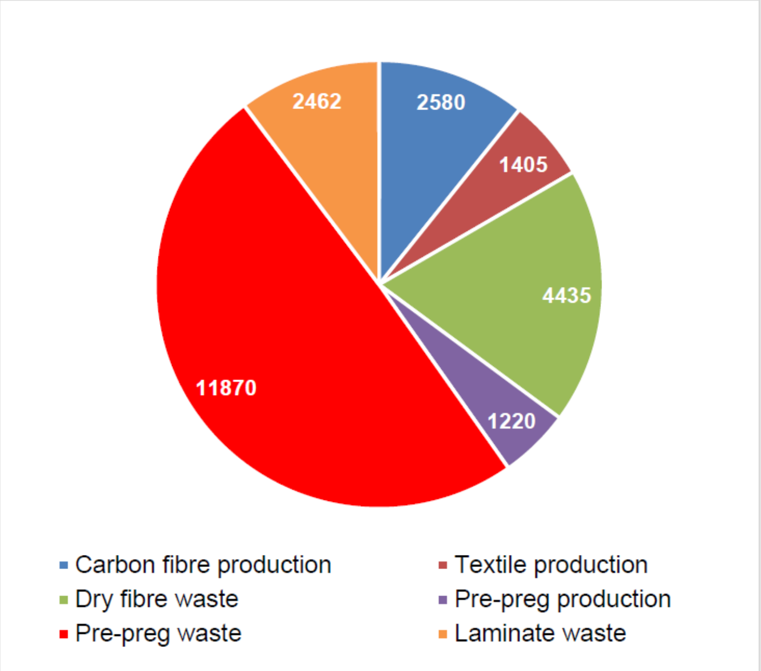


Fig. 2.3: Carbon fiber consumption. [Ste16]

When carbon fiber is recycled three main technical challenges are faced:

- First, the carbon fiber composites use carbon fibers, these fibers are woven together and mixed with thermosetting polymers (usually epoxy resin), which hardens to produce a solid part. Thermosetting polymers, unlike thermoplastic polymers, cannot be melted down or remolded. Thus, recovering CFRPs requires physical removal of the polymer. [Pic06].

- Second, the composite parts are often molded with metallic inserts, cardboard honeycomb core, or hybrid composites [PP11]. Removing these parts consists of additional time-consuming steps to the recycling process.
- Third, there is great variability amongst carbon fiber waste products. Identifying and sorting different compositions together can be done somewhat easily with manufacturing waste, but is extremely difficult for end of life products where different kinds of CFRPs are often mixed together

Mechanical Recycling

The mechanical process consists in crushing or cutting CFRPs down into sizes that comprised between 50 µm and 10 mm. This small fibers or powders that is created is then used as filler reinforcements in new composites.

This is a very simple solution and therefore the recycle carbon fiber that is obtain from the CFRP waste can only be use in a very specific limited non-structural application.

Chemical Recycling

Chemical recycling has the best quality results, but is has an environmental downside. The most conventional process for chemical recycling is low-temperature solvolysis. This process uses reactive solvents to break down the chemical bonds of the polymer matrix to separate it from the carbon fiber.

Thermal Recycling through Pyrolysis

The process used for thermal recycling is called pyrolysis, this process has some highly advantages compared to the mechanical and chemical recycling it is more economical and respectful to the environment.

The pyrolysis process consists of heating CFRP waste between 450°C and 700°C in the near absence of oxygen, which decomposes the polymer matrix into gaseous form [PP11]. At the end of the process, the carbon fibers are recovered with good mechanical properties and tensile strength between 4 and 20% less than VCF [Mor12]. These recycled fibers, as in chemical recycling, can be re-manufactured into new structural composites.

The pyrolysis process consists of heating CFRP waste between 450°C and 700°C in the near absence of oxygen, which decomposes the polymer matrix into gaseous form [PP11]. At the end of the process, the carbon fibers are recovered with good mechanical properties and tensile strength between 4 and 20% less than VCF [Mor12]. These recycled fibers, as in chemical recycling, can be re-manufactured into new structural composites.

2.3 Matrix

The matrix is the material where the reinforcement is enclosed, it is entirely continuous. The matrix determines the resistance of the polymer matrix composite these properties the properties that are determine include impact resistance, water absorption, chemical attack, and high-temperature behavior.

The two main functions of the matrix are, preserving the fibers with the correct orientation and position and protect them from the environments and it diverse elements [Chu04] In the case of polymer and metal composites, the matrix transfers the loads and tension to the fibers through shear loading. [Cam10]. The most used matrices are polymer matrices, carbon. Other matrices are metal and ceramic matrices and carbon/carbon composites. [Cam10]

2.3.1 Polymer Plastics

Polymers have low strength and stiffness [Cam10], but by combining polymers with fibers it is possible to receive higher strength and stiffness than the polymer itself has [Joh13]. Due to high strength and low density, are fiber-reinforced polymers the most dominate among polymer structural materials [Chu04].

The two main types of Polymers depending on the matrix are, thermoset or thermoplastic.

The most use matrix today is the Thermosetting especially the epoxy, in last year the thermoplastics are developing rapidly and gaining market share to the Thermosetting [Chu04].

<u>Thermoset</u>

The material has good mechanical properties when operating in hot and moist environments, it is easy to process and have good adhesion to many fibers, and the material cost is low [Cam10] Thermosetting plastics are not possible to reshape, it is a rigid cross-linked material that at high temperatures degrade rather than melt [Chu04]

- Polyester: The polyester resins have a limited operating temperature and their tensile strength is lower compared to the other resins.
- Epoxy: Is the most used matrix for carbon fibers, this is due to its unique combination of mechanical properties, corrosion resistance, dimensionally stable, good adhesion and on top of that it is relatively inexpensive
- Vinyl ester: Its main advantage is its low cost and its simple production, the mechanical properties exhibit by the vinyl ester are superior to the polyester.
- Polyimide: It is becoming increasingly important due to its good performance in high temperature applications. The Polyimide is more expensive than epoxies.

- Phenolic resins: Phenolic resins were more used before than today, polyesters and epoxies have in large parts replaced the material

Thermoplastic

The thermoplastics are possible to reshape after they are being reheated to high temperatures. This process can only be repeated a limited number of times, when the plastic is reheated several times the resin can start degrading. Thermoplastic composites are used in high performance applications because of its good resistance to impact loading. This material has been gaining importance because of greater ductility and processing speed. [Cam10]

- Polyetheretherketone (PEEK): This composite consists in a lightweight core separating two thin layers of composite, Sandwich-structured composites (Drechsler, et al., 2009). The material is commonly used in automotive, truck.
- Polyetherimide (PEI): PEI can resist higher impact loading and withstand high interlaminar fracture.
- Polyphelylene sulphide (PPS): PPS is used in electrical insulation, specialty membranes, and gaskets. PPS have superior fire resistance. PPS is used where fire resistance and electrical insulation are critical factors.
- Polyamide (PA): The PA can operate up to temperature of performance nylon, is used in a wide range of automotive 200 ºC with good performance. It is for parts such as interior, gears, bearings, housings, air ducts etc. The material tends to absorb moisture from the air, which affects the mechanical and electrical properties [V11].

2.4 Nonwoven

Definition by EDANA, (The European Disposables and Nonwovens Association) and INDA, (North America’s Association of the Nonwoven Fabrics Industry)

EDANA: “a nonwoven is a manufactured sheet, web or batt of directionally or randomly orientated fibers, bonded by friction, and/or cohesion and/or adhesion”,

INDA, “is a sheet or web structures bonded together by entangling fibers or filaments, by various mechanical, thermal and/or chemical processes. These are made directly from separate fibers or from molten plastic or plastic film.”

The proposed definition by EDANA and INDA to the International Standardization Organization is:

“A nonwoven is a sheet of fibers, continuous filaments, or chopped yarns of any nature or origin, that have been formed into a web by any means, and bonded together by any means, with the exception of weaving or knitting”.

Nonwovens are engineered fabrics made from fibers, these fabrics can be a limited life, single-use fabric or a very durable fabric.

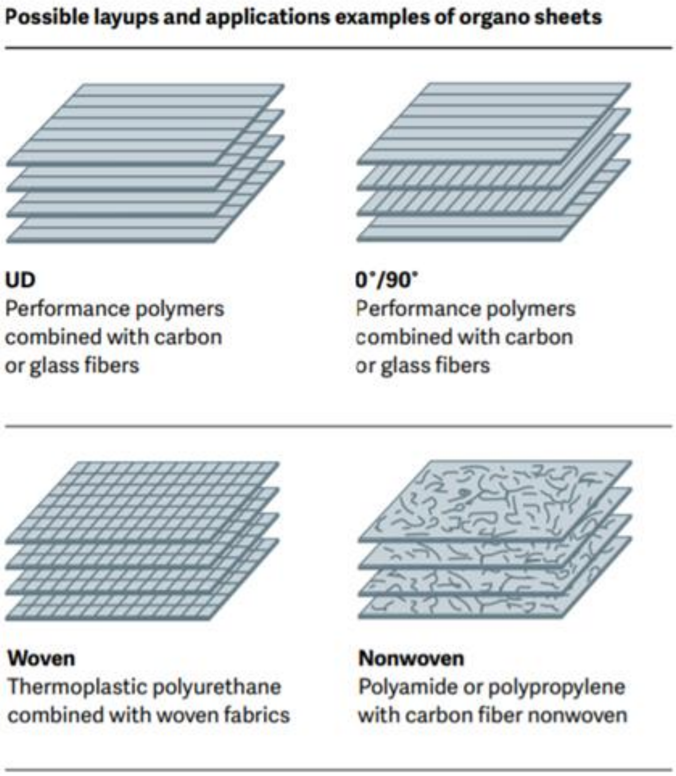


Fig. 2.4: Layups and applications examples of organic sheets. [SGL17]

This high-tech unique fabric has some characteristics that allow them to be use in a wide range of applications are: absorbency, liquid repellency, resilience, stretch, softness, strength, flame retardancy, wash ability, cushioning, filtering, bacterial barrier and sterility.

Having such a wide range of applications the nonwoven can be combined to create specific fabric for very specifics jobs, all this while maintaining a good ratio between the product life and the cost.

2.4.1 Nonwoven manufacturing

The nonwoven can be divided in three main categories drylaid, wetlaid and polymer-laid, the drylaid materials have their origins in textiles, the wetlaid materials have theirs in papermaking, and the polymer-laid products in polymer extrusion and plastics.

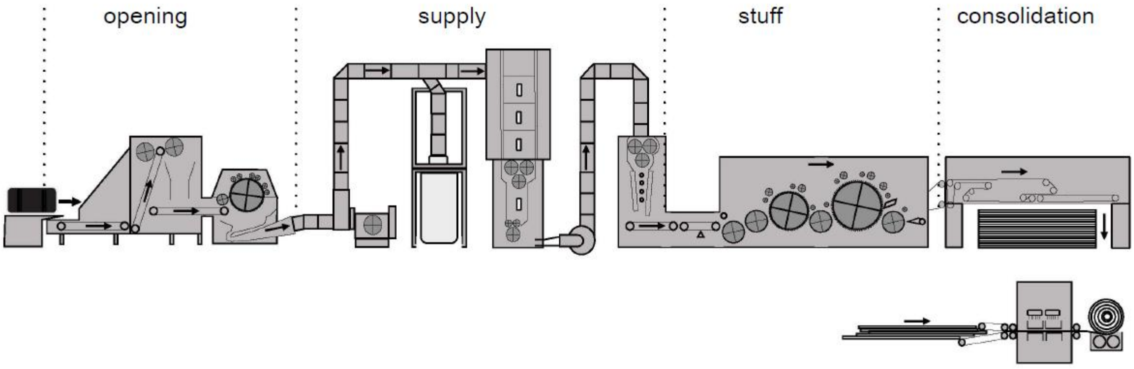


Fig. 2.5: Diagram of Dilo system for nonwoven production. [Mar17]

Carding this is a mechanical process in which the bales of fibers are open. Then these fibers are combine into a web by a carding machine. When the web is being carded the fibers can be parallel-laid or random-laid. When the fibers are parallel-laid carded the resulting web has good tensile strength, low elongation and low tear strength in the machine direction but low properties in the in the cross direction.

Airlaying, using this process a randomly oriented web is form. The process starts feeding the fibers, in some cases very short, into an air stream, Then the fibers are randomly laid by a moving belt or perforated drum.

Airlaid webs have a lower density, a greater softness and an absence of laminar structure compared with carded webs. This method also expands the range fibers and fibers blends that can be used.

Bonding

The webs created using airlaying and carding method have little strength in their unbonded form, therefore the web must strengthen.

This process is call bonding and it is a crucial part of the production of nonwovens. Depending in the type of bond strengthen that is apply to the web different functional properties are obtain.

There are three basic types of bonding, chemical, thermal and mechanical.

Finishing Treatment

This different method can be farther personalized to meet the customers' demands by using different chemical substances before or after the binding, also different mechanical process can be used to the nonwoven after the binding.

2.5 Component production of carbon fiber

The development of inexpensive and fast manufacturing processes has been and is an objective. Highly complex components with very short cycle times are already known for injection processes. However, until now only short-fiber reinforced thermoplastics have been used in serial applications. The main objective is to achieve short cycle times with continuous-fiber reinforcements, whose mechanical properties are better.

Therefore, the following processes for continuous fiber reinforced components are considered.

2.5.1 Thermoforming of organic sheets.

Organic sheets are continuous fiber-reinforced, semi-finished products, embedded in a thermoplastic matrix. One of the most used matrix is polyamide, apart from other advantages, especially allows a very good adhesion to fibers. First, the organic sheet is heated to give shape by thermoforming. Subsequently, this product is heated to a temperature close to the fusion point of the matrix and immediately afterwards, is placed in a mold and is compressed into shape. Here, it must be ensured that there are no dislocations of the fiber layers. The entire cycle can last about 60 seconds conceivable for the quick processing potential of thermoplastics. [RAR12]

“Organic sheets” a possible alternative to aluminum and steel. News release LANXESS

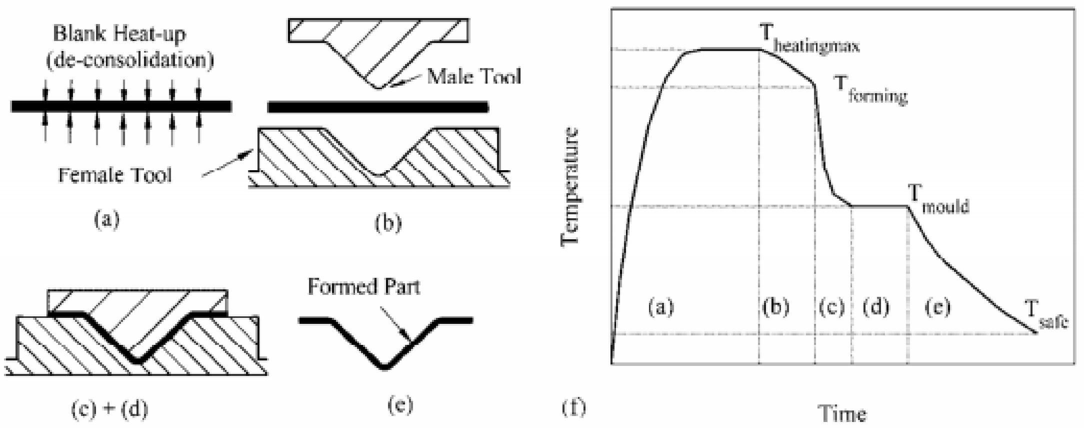


Fig. 2.6: Thermoforming process stages for composites. [RAR12]

Fig. 2.6 characterizes the process in terms of physical shape change and thermal variation of the blank during the complete process [RAR12].

2.5.2 Resin Transfer molding

It is the process of producing composites in a mechanically closed rigid mold. Dry reinforcement (glass fiber, carbon fiber, aramid, etc.), is positioned between the two sides of the mold, and this is closed using mechanical forces (hydraulic press, bolts or vacuum). [RT17]

A thermosetting resin is injected, often by the central part of the mold, directly in the reinforcement fiber bundle. The mold is filled by the effect of the hydraulic pressure generated by the injection machine. The mold has normally outputs at the corners, allowing air from the inside to escape and being replaced by the resin.

Vacuum resin transfer molding (VRTM) is a variant of RTM which principal difference is that makes use of the atmospheric pressure as help to close the mold, in contrast to the heavy locking systems used in RTM. [VI17]

2.5.3 Thermoforming and injection molding

It is a process that combines the thermoforming and subsequent compression with plastic injection. This is a process used by the “Institut für Textiltechnik Augsburg” (ITA) with an Engel machine. [Kra17]

In an automated cell, individual organic sheets are pre-heated by an infrared oven, inserted into an injection mold by means of a robot with hydraulic needles. It is then compressed and back-injected with ribs. In Fig. 2.8 it can be seen a diagram illustrating this process.

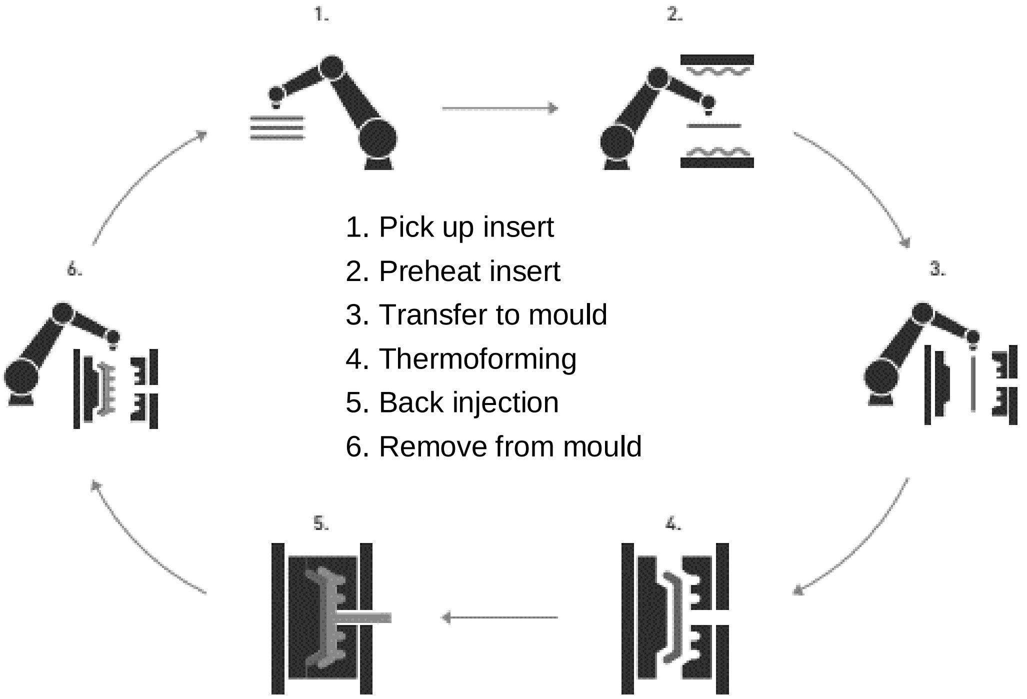


Fig. 2.7: Thermoforming process with injection molding. [Kra17]

The use of injection molding also makes it possible to work in thermoplastic with long fiber reinforcement and thus to achieve components with greater strength. The high pressure with which the melt is initiated, permits that possible imperfections in the composite sheet can be filled.

Hybrid thermoforming-injection process attracts auto industry interest. Article from PLASTICS TODAY, community for plastic professionals. [PT12]

3 Production process

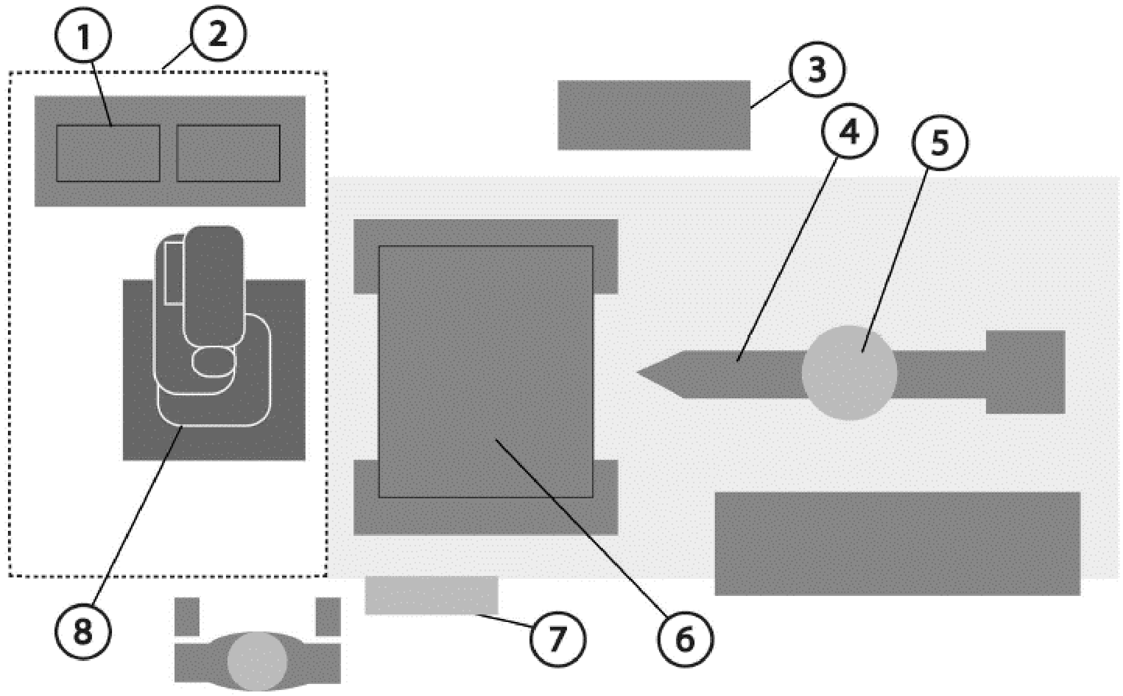
As it was mentioned in paragraph before the production process of parts consists of several steps. In the first place, preforms, which are the raw material for the process, are obtained. This preforms consist of the union of different layers of nonwoven. This union is possible by submitting the layers to heat and pressure with a stamping machine.

Later, these preforms are heated to the melting point of the matrix in an induction furnace. When they reach the melting temperature, a robot transports them to the mold holding them by the top via a needle group.

Then the mold is closed and the press allows the preform to get the mold's shape. At this time, the injection unit injects plastic on the low side of the mold culminating the thermoforming and injection molding entire process.

Finally, the press opens allowing collecting the final composite piece and ending a process cycle.

The process described above is schematically represented in Figure 3.1:



1- Infrared oven

2- Protection zone

3- Tempering unit

4- Injection unit

5- Filling hopper

6- Hydraulic closing unit

7- Tool control panel

8- Robot

Fig. 3.1: Top view of the manufacturing process. [Ege17]

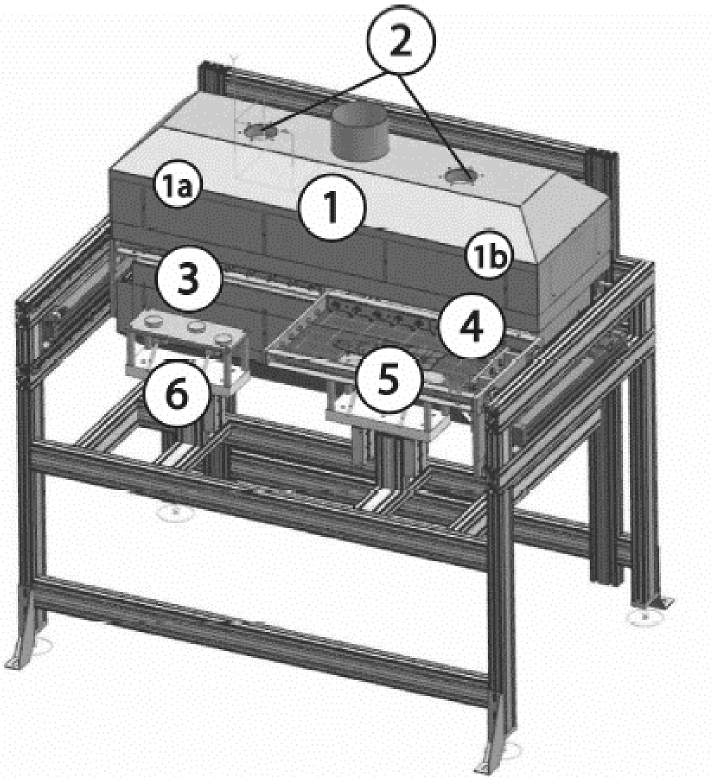
3.1 Infrared oven

This is an element of great importance because it provides the necessary heat to melt the preform before introducing it into the mold.

The handling system leaves the preform on a tray. Then the tray retracts back into the oven where the fusion of the thermoplastic material takes place. After that the tray extends out of the oven and the preform is seized by the handling system and placed in the mold.

The temperature of the oven is a parameter that influences in the superficial quality of the final piece and therefore, will be dealt with in detail further on.

Figure 3.2 shows the oven employed in the experiments and its principal components.



1) Infrared oven
    a) Left oven
    b) Right oven
2) Pyrometer
3) Sliding table 1 (retracted)
4) Sliding table 2 (extended)
5) Organic sheet receptor
6) Holding device

Fig. 3.2: Infrared oven and its components. [EnM16]

3.2 Handling system

The handling system is Stäubli robot of the company Stäubli AG, Pfäffikon, Switzerland with an Engel control software for operating. This robot consists of six axes controlled by servomotors. The acquisition-head is driven by a pneumatic system with compressed air.

Figure 3.3 illustrates the robot and the movements that can perform.

At the top a head is fitted which is responsible for holding the workpiece when the robot is transporting it.

As will be seen later, the handling system has relevance in the thesis since it affects the surface quality of the workpiece.

A group of needles is responsible for providing the stability during movement, getting inside the piece with a certain angle to avoid the gravity effect.

Fig. 3.3: Stäubli robot and its rotation axes. [EnM16]

The needle gripper commented previously is shown in Fig. 3.4.

Fig. 3.4: Needle gripper in detail.

There is a second pneumatic circuit which work as a vacuum ejector, since they are used to remove the pressed piece from the mold. This second holding unit is required because once the molding process has finished, the final piece is below the melting temperature of the array and the needles cannot penetrate it.

One of the process operations is to heat the mold surface, this is accomplished with two inductions plates that are place over the robot head. In Fig. 3.5 the robot head can be seen with the black induction plates.

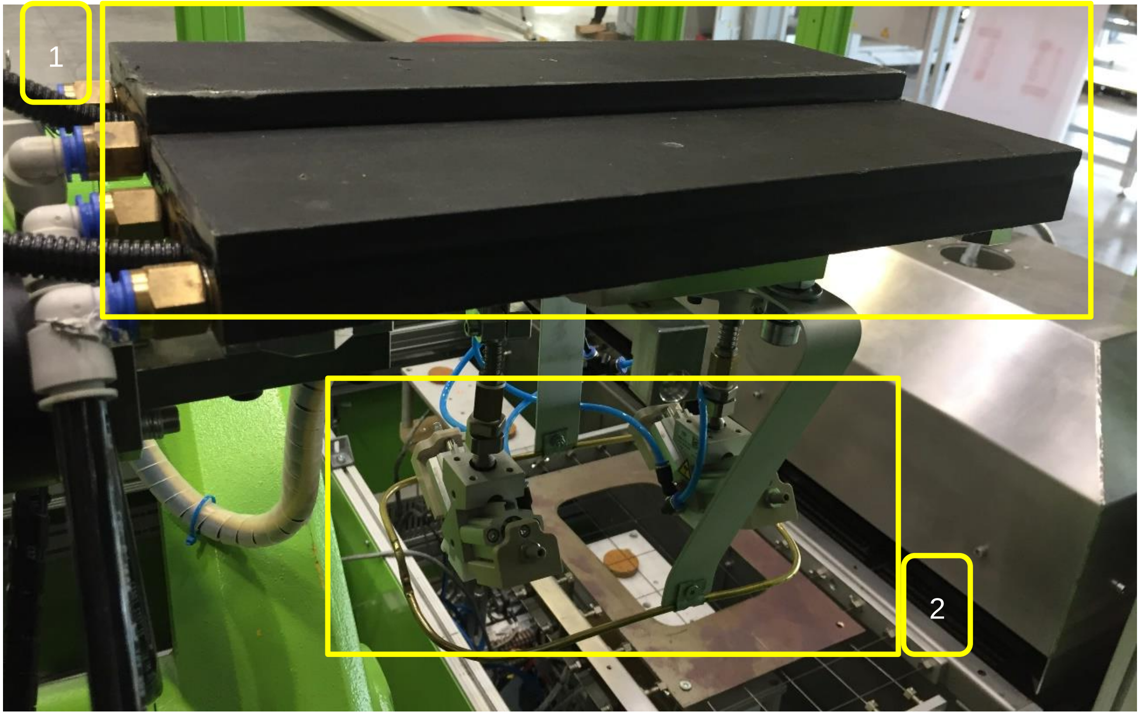


Fig. 3.5: Robot head with needle grippers (2) and induction plates (1).

3.3 Pressing unit

The pressing unit is responsible for the injection molding process. It ensures a tight sealing of lower and upper parts of the mold, holding the injection pressure and providing the final piece the desired shape.

The upper and lower mold halves can be heated separately. This is necessary to prevent a quickly cooling of the molten preform and to allow a good impregnation of the web with the molten thermoplastic during the compression phase.

In Fig. 3.6 the clamping unit is represented. Down to the left is the pressing half on the right the injection half. Up in the middle resides the heating tool.

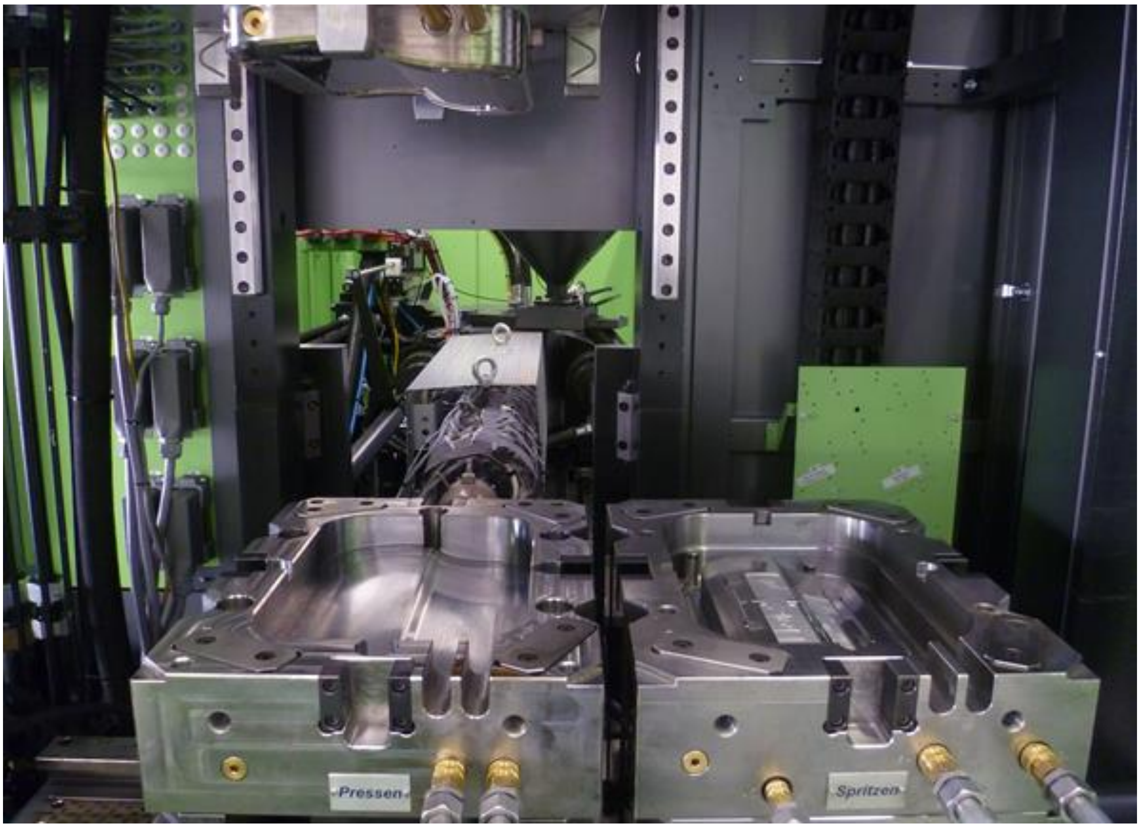


Fig. 3.6: Pressing unit opened with molds.

3.4 Table peripheral and preform machine

One of the implementations that will be carry out in this thesis will be a perform machine that will feed the robot with PF in order to make the process autonomous, doing this the process will not have to stop after each cycle to put a new PF on the oven. In Fig. 3.7 and Fig. 3.8 the positions where the machine will place the PF can be seen and where the PF will be taken from by the robot.

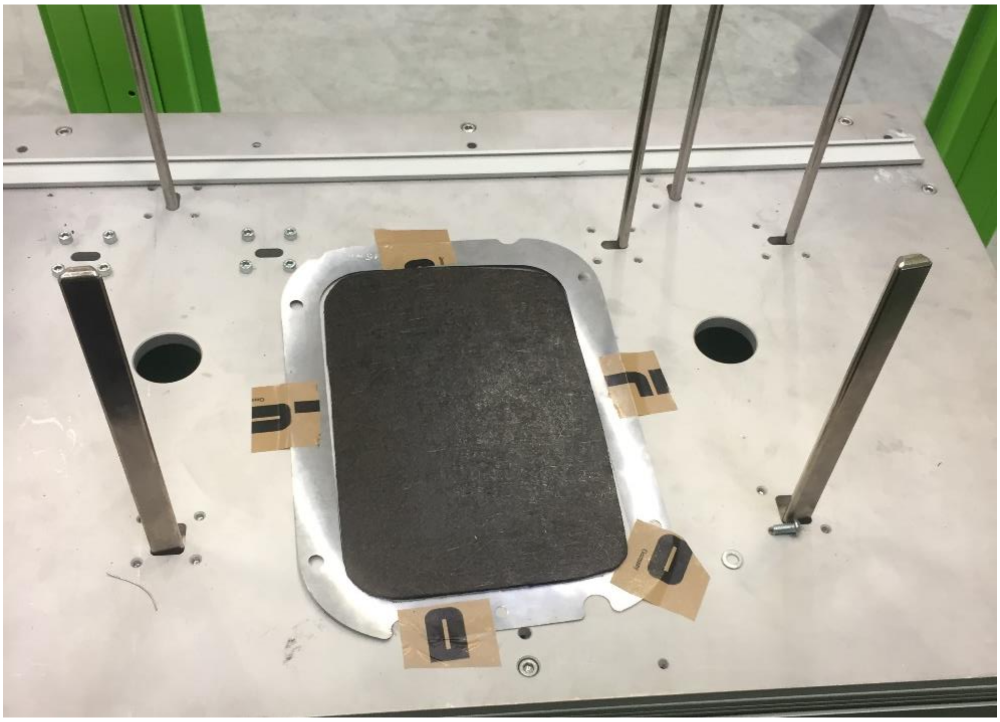


Fig. 3.7: Preform on the table were the machine will be

Fig. 3.8: Area where the machine will place the preform.

4 Preform and gripper interaction experiment

4.1 Robotic gripper with needles experiment

4.1.1 Abstract

Few studies have investigated the control of grip force when manipulating an object with a small mass using a precision grip.

Grip-load force coordination was examined with a scale and one griper which was being operated by a human. The scale had a top capacity of 5 kg which made this the maximum load that could be put on the preform. The load was put on the non-woven preform using weigh of different size so they could be arranged in different positions to see what kind of changes this will introduce in the overall result.

Additional measurements of grip-force-dependent on the length of the needles and the contact area of the griper with the pre-form, as well as a test of weight discrimination, were also performed. For each needle position, the static grip force was applied in parallel with load force while holding the object of a mass under 5 kg.

In the experiment was also measured the difference between the load the griper could hold up when the preform was being lifting and when the preform was being hold still.

The proportion of safety margin in the static grip force and normalized moment-to-moment variability of the static grip force were also elevated towards the lower end of the object mass for both needle position. These findings indicate that the strategy of grip force control for holding objects with an extremely short needle length differs from that with length of 5mm or more.

The elevated grip force variability associated with the air pressure that forces the grippers to close, and anticipated inertial force on the held object due to acceleration of the arm and hand, could also have contributed to the cost function.

4.1.2 Introduction

This experiment is related to the thesis Effects of Processing Parameters on the Surface Quality of Web Based Thermo-Plastic Composites Manufactured in an Automated Process is doing on how much do the holes created by the needles influence the surface quality of the performance.

Before this experiment there was no knowledge of how much force the gripper could handle and how much influence the length the needles were introduce in the preform had in the holding capabilities of the grippers.

Because of the experiment was done by hand the force used to close the grippers was different with the force used by the robot since the robot use compress air to close them. This was considered in the experiment but due to the absent of specific instruments to measure the force applied by the robot, another approach was taken to compare both techniques the method used to measure how far the needles were introduce by the robot and how far could they be introduced manually.

The most important part of the experiment is the robotic gripper used to hold the preform textile, there is a wide range of grippers a robot can use to manipulate materials.

End of arm tooling (EOAT) is one of the most important parts of the robot. It is the part that basically acts like the robot's hands. These robot grippers serve as the physical interface between the robot arm and the work piece.

There are four main types of robotic grippers: vacuum grippers, pneumatic grippers, hydraulic grippers and servo-electric grippers. Manufacturers choose grippers based on the applications and type of material they use.

Vacuum Grippers: The vacuum gripper has been the standard EOAT in manufacturing because of its high level of flexibility. This type of robot gripper uses a rubber or polyurethane suction cup to pick up items. Some vacuum grippers use a closed-cell foam rubber layer, rather than suction cups, to complete the application.

Pneumatic Grippers: The pneumatic gripper is popular due to its compact size and light weight. It can easily be incorporated into tight spaces, which can be helpful in the manufacturing industry. Pneumatic robot grippers can either be opened or closed.

Hydraulic Grippers: The hydraulic gripper provides the most strength and is often used for applications that require significant amounts of force. These robotic grippers generate their strength from pumps that can provide up to 2000psi. Although they are strong, hydraulic grippers are messier than other grippers due to the oil used in the pumps. They also may need more maintenance due the gripper being damaged because of the force used during the application.

Servo-Electric Grippers: The servo-electric gripper appears more and more in industrial settings, due to the fact that it is easy to control. Electronic motors control the movement of the gripper jaws. These grippers are highly flexible and allow for different material tolerances when handling parts. Servo-electric grippers are also cost effective because they are clean and have no air lines. [GP17]

Due to the requirements of the work, the applications and type of material, a different type of gripper was chosen, the best solution was to use a needle gripper.

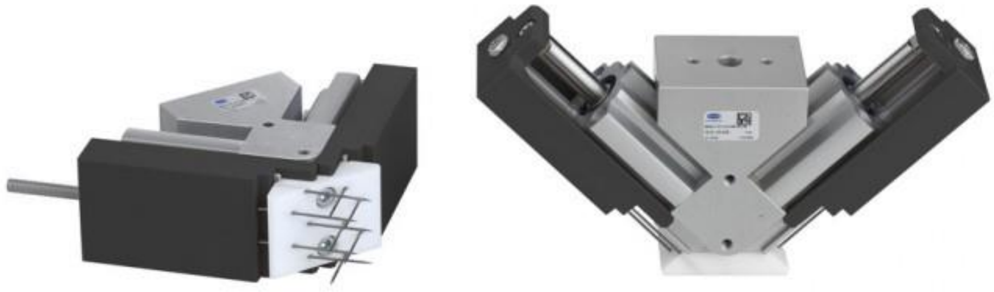


Fig. 4.1: Needle gripper in detail. [SCH1]

Needle grippers provide the option of reliable gripping of workpieces which are difficult to handle non-rigid and highly porous materials such as composite textiles, fleece, filter materials, insulation and foam materials etc. Intersecting needles ensure an optimal holding force. These special grippers are particularly suitable, for example, for textiles, fiber composite materials or fleeces.

4.1.3 Materials and Methods

In the realization of the experiment four different types of non-woven preforms were used, weight from different sizes and shapes, different needles lengths and a scale, etc.. In the following page, the material and the methods used in the realization of the experiment will be explain in this chapter.

During the fulfillment of this experiment four different preform were used, the only difference between the preform, was the number of the layers of material they were made of.

For these first experiments, non-woven webs composed of 40% CF 60% PA and 680 g/m^2 of density was used.

Tab. 4.1: Experiment resume.

Experiment	PF sheets (number)	Thickness (mm)	Weigh PF (gr)
1	2	3	14
2	4	5	41
3	8	7	93
4	12	8-10	140

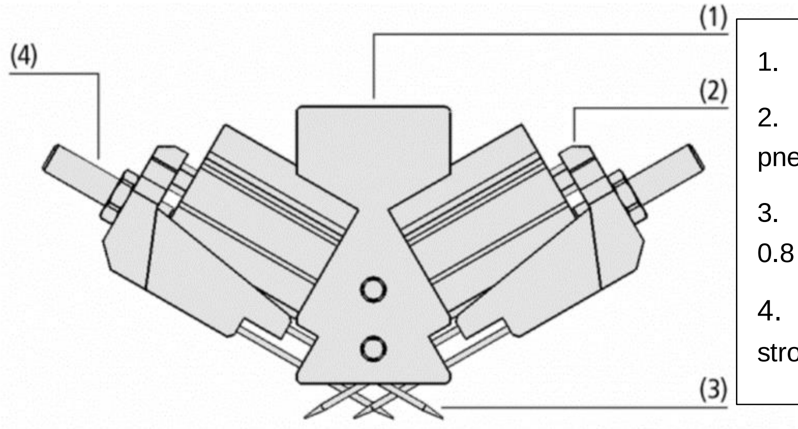
Fig. 4.2: Needle grippers handling a textile preform. [SCH1]

Benefits:

- High holding force, even for flexible, non-rigid workpieces.
- Handling of small workpieces possible.
- Very short cycle times.
- Individual adjustment for different workpiece thicknesses, sizes and shapes.
- Saves pneumatic tubes and connectors; ensures synchronous movement of needles.
- Specifics of the scale: model and capabilities.

Tab. 4.2: Needle characteristics.

	Number of needles	Length	Angle	Diameter	Material
Needles	10 (5 in each side)	15 mm	30º	0.8 mm - 1.2 mm	Aluminum



1. Robust aluminum housing.
2. Drive via double-acting pneumatic cylinders.
3. 10 needles with diameter 0.8 mm or 1.2 mm.
4. Continuously variable stroke adjustment

Fig. 4.3: Needle gripper parts definition. [SCH1]

Method:
In the fulfillment of this experiment a scale to measure how much force could the grippers handle was used.
First, the load put on the preform is measured this was done with the scale which could measure up to 5000 gr, and how much force was applied on it, the force varies depending where were the mass place.

Before starting the experiment, the grippers and the preform needed to be join by the needles as the robot will do later on the process, this was done by applying manual force to the end needles and closing them.

To make the situation as realistic as possible the needles needed to be introduce the same distance as the robot will introduce them but that they don’t go all the way through.

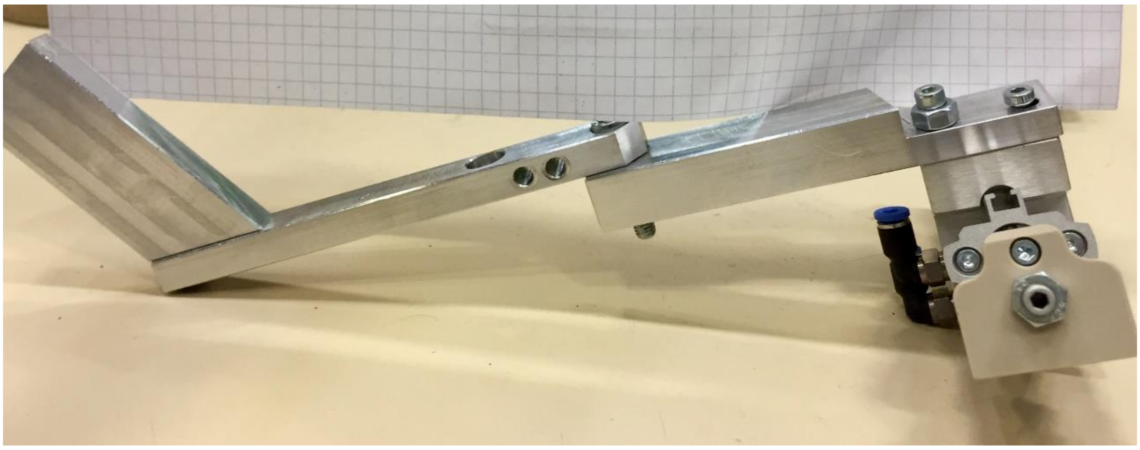


Fig. 4.4: Gripper holding structure use in the experiment

The needle length is not the same as the thickness of the PF, the needles go in in an angle so if the thickness is 3 mm the needles will need to be introduce 10 mm to go all the way trough.

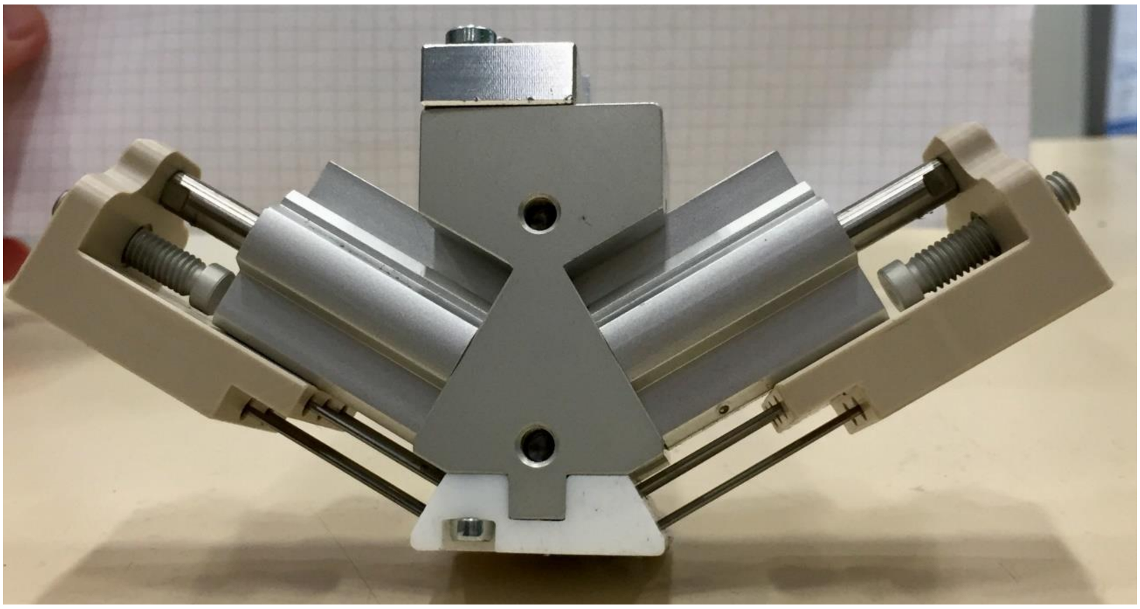


Fig. 4.5: Gripper head

If the needles go all the way through, a problem emerges, because when the preform are placed in the mold the needles will scratch the surface of the mold damaging it and creating serious problems in the quality of the final product.

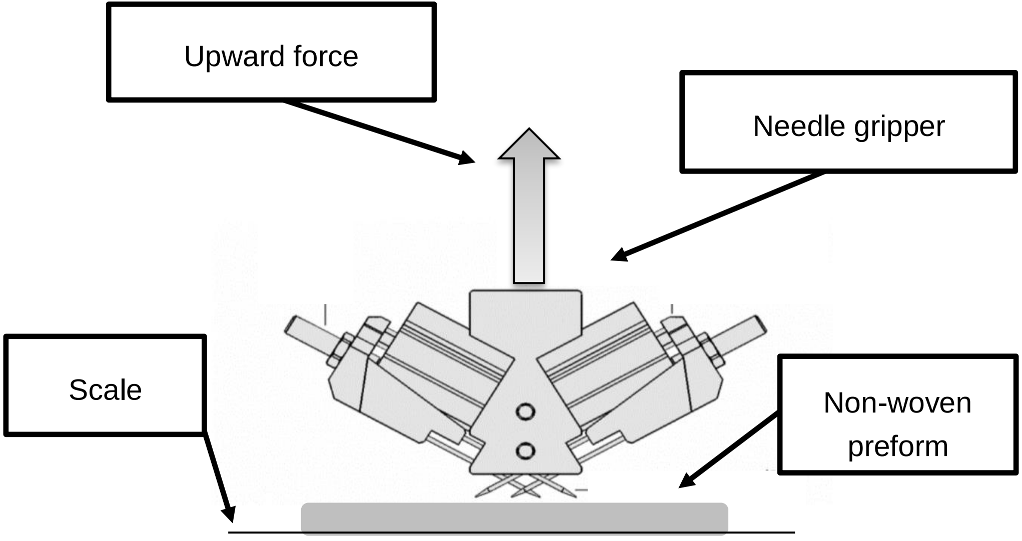


Fig. 4.6: Experiment execution diagram

When everything is joined, as can be seen on Fig.4.7 they are laid on the scale and it is rest to 0, meaning that the scale only measured the loads that are going to be add later.

Once the whole experiment is prepared the load is added to the preform, as stated before the scale can only measure till 5000 gr but the weight of the grippers and the preform has to be taken into account, that means that only 4500 gr of load can be added.

After the weighs are on the preform an upward force starts to be apply by hand, this force is applied without acceleration, the aim of this experimental is not trying to figure out how much acceleration can the preform handle just the force generated by the weights.

If the preform is lift from the scale then it is assured that the preform can handle that load. Then the experiment is repeated for the next load until the max load is found.

When a specific weigh that can not be handled by the preform is find then the experiment advances to the second part and then the process is repeated but this time with a needle length of 5mm. This is done in order to create data that might help in future experiment in which the needle length that has to be introduce is less than the maximum length it can be introduce.

During the experiment, there have been some cases in where the load and the position of the grippers have had to be changed to achieve the real result. This is happened after several repetitions; the last experiments of each round are the least reliable because the preform has already been performed several times and the fiber don’t hold as good as they should.

Summary of the experiment:

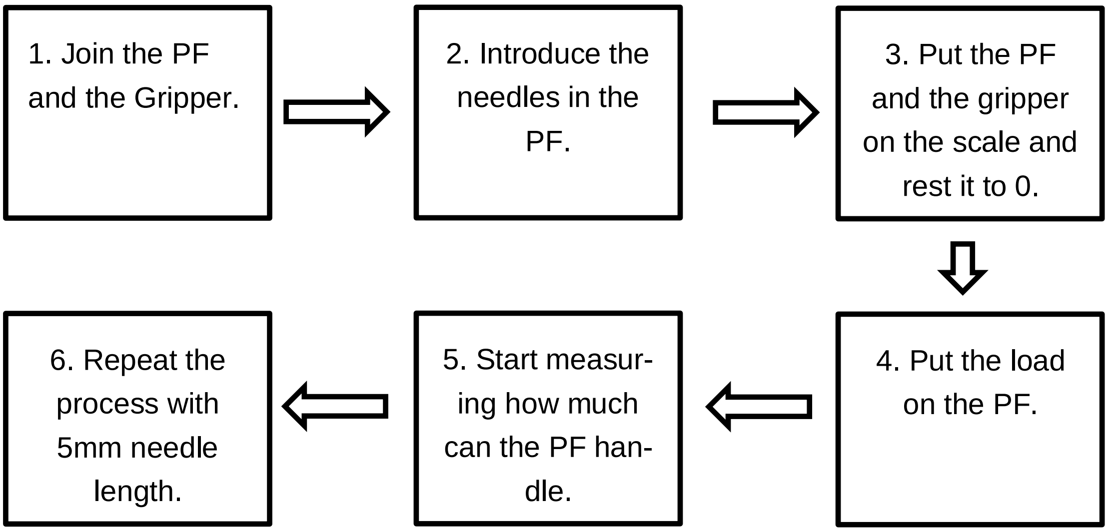


Fig. 4.7: Experiment steps diagram

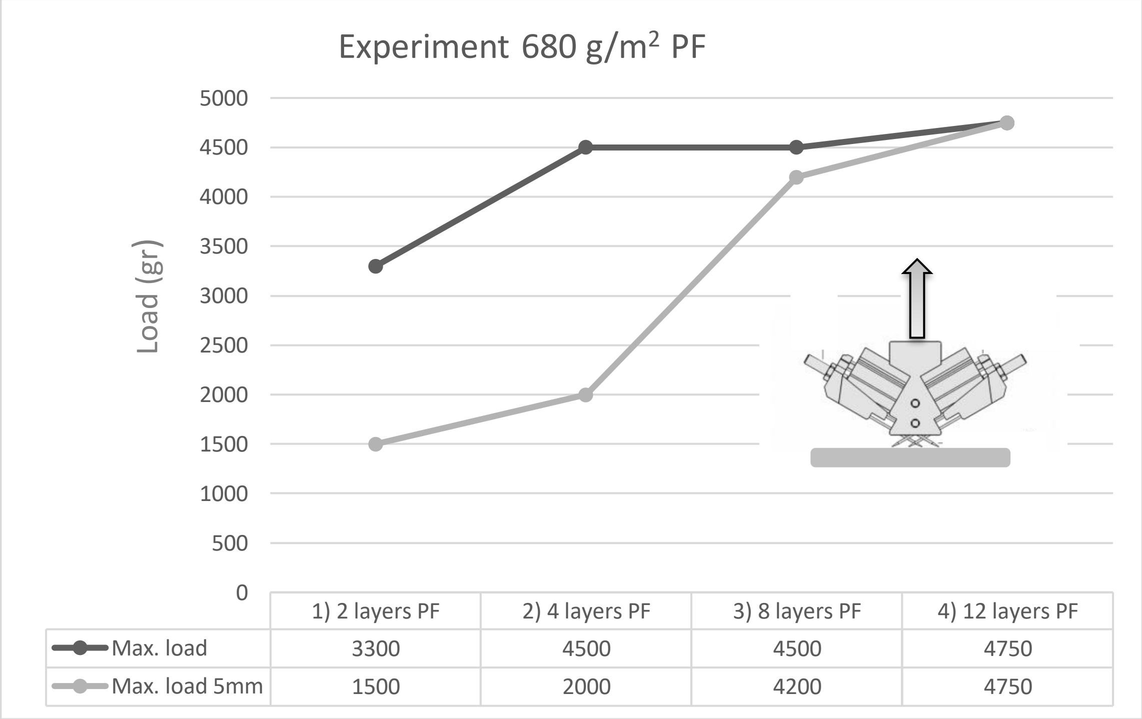
4.1.4 Results and conclusions

This experiment was performed with 1 gripper, the robot has two grippers so the results should be multiplied by a factor of two to get how much load can the robot gripper handle.

Tab. 4.3: Resume experiment results.

Experiment	Max. load	Max. load 5 mm
1) 2 layers	3300 gr	1500 gr
2) 4 layers	4500 gr	2000 gr
3) 8 layers	> 4500 gr	4200 gr
4) 12 layers	> 4750 gr	4750 gr

Tab. 4.4: Graph of the experiment results.



	1) 2 layers PF	2) 4 layers PF	3) 8 layers PF	4) 12 layers PF
Max. load	3300	4500	4500	4750
Max. load 5mm	1500	2000	4200	4750

As can be seen on the results of the experiments in the experiment 4 the max load and the max load for 5 mm is the same, this is because there was not any more weight to put on the PF but after reviewing the data it could be affirm that the 12-layer PF could hold considerably more weight.

All the experiment has been done with one needle gripper, the robot has 2 so the load the robot will be able to manipulate will double the result shown in the experiments. After reviewing the results, it can be confirmed that the gripper could operate with the 5 mm setup in most of the process that will be carry out by the robot.

Using the 5 mm set up the damage caused to the non-woven performed by the needles will be substantially less.

From now on the robot will be working with the 5mm setup, this will improve the quality of the surface of the PF. In the following chapters will explain more in detail this subject.

4.1.5 Experiment data explanation

In this section, the criteria for the experiments is going to be explain, in order to make easier for the reader, the criteria have been divided in 4 categories:

The criteria used in the experiment has been summarize in Tab. 4.5.The max load hold by the preform was valid when the preform holded perfectly and in any other of the three cases the result was not valid. The reason there are four categories is to offer a more detail explanation on why the preform did not hold, in case, the experiment wanted to be reproduce.

For the 5 mm experiment setup the same criteria was follow.

Tab. 4.5: Experiment results explanation

Observation	Explanation
Does not hold	The grippers detach when the force upwards is apply.
Holds but does not lift the PF	The PF were able to be lift a couple of mm off the ground but then it detaches.
Holds and lifts but not sudden movements	The PF can be lift but it is not stable and the first sudden movement makes the PF and the Gripper separate.
Holds perfectly	The PF holds extremely well and capable of performing movements without any inconvenient.

5 Process optimization

The process with which was started, was simple and slow, it was designed as a proof of concept for the process, meaning that the process was only able to perform the minimum to meet the requirements of the part production.

The process optimization aims to achieve two main goals, improve the surface quality of the final product and make the process more commercially viable. These two objectives are very wide that's why I am going to work in collaboration with one of my colleges. My part is going to be focus in the programming of the robot, this will consist in writing a program sophisticated enough to meet the requirements needed to achieve both goals

The second part of the process, improving the quality of the surface will be executed by college, he will gather data about some of the process factors that influence the surface of the PF, this will be done by designing a very flexible process where most of the factors can modify to see which one's influences and which one don't.

The creation of the flexible process and the results thrown by it will be explain section 5.2. Making the process commercially viable implies that a more complex program with more peripherals has to be written and this will be explained in section 5.4.

A diagram of the process is represented on Fig. 5.1, this diagram will later be expanded to match the function of the more complex process

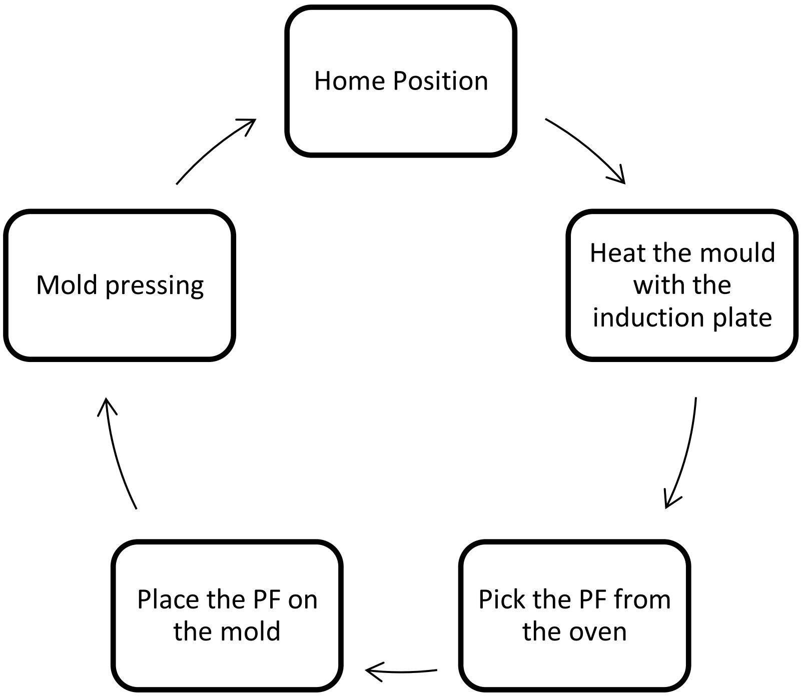


Fig. 5.1: The four main actions the robot does in the process.

5.1 Variables for the process

There are many factors that influence the final surface of the piece; some of them are fixed parameters in the process, that is, parameters that cannot be modified as the material of the mold, the atmosphere or the needle group in charge of holding the piece during its way through the productive process. Others, however, can be modified and it is in them on which the attention will be focus. Some of these are furnace and mold temperatures, the composition of the web, the introduction of polyamide or not, the process employed for obtaining the preform, etc.

1. Temperature: Temperature is one of the most important parameters of the process as it is present in the oven and the molds. In experiments the temperature varies both in the oven and in the mold. This parameter is also present in the refrigeration flow of induction plates which has a value between 20ºC and 21ºC.
2. Pressure: This is another parameter with great importance as it is present in the press, the robot, the furnace and the refrigeration flow of the induction plates. The overall set of the machine has compressed air ducts that allow the opening and closing of the oven as well as the movements of robot and needle grippers respectively.
3. Time: This parameter is present in the cycle time of the robot, the heating time in the oven, the time that the induction plates act and the compression time of the press.

   The heating time in the oven remains constant in all the process and is 80 seconds whereas the time the induction plates act varies between 20 and 60 seconds.

5.2 Flexible process

As it has been stated before the aim of this process is not to be neither fast nor efficient, the aim of the process is to perform and experiment where it can be study which factors improve the quality of the surface and which one make it worse.

The main factors being work with are the time of the process, the material, the pressure and the temperature of the oven and the temperature of the induction plates, because there is not an available way to measure the temperature of this last one it is going to be measure by energy and time.

The density of the materials was 680 g/m^2 for non-woven webs composed of 40% CF 60% PA and 212 g/m^2 for webs composed of 40% CF 60% PE.

With the temperature of the material being the most important factor [Bar17], it is of critical importance to maintain it as stable as possible, these means that the time it takes from the material to go from the oven to the press should be the minimum as possible. Because during the transport of the PF from the oven to the mold the PF cools down, In Fig. 5.2 a breakdown of the time each operation takes has been done, doing that it can easily be seen which operation takes the most time and center our effort in optimizing that part of the process.

It is only measure the time it takes the robot to realize the movements, it is not being take into account the time the robot spends in each position realizing different task, like heating up the mold. Taking all this into account the process time is 90 seconds.

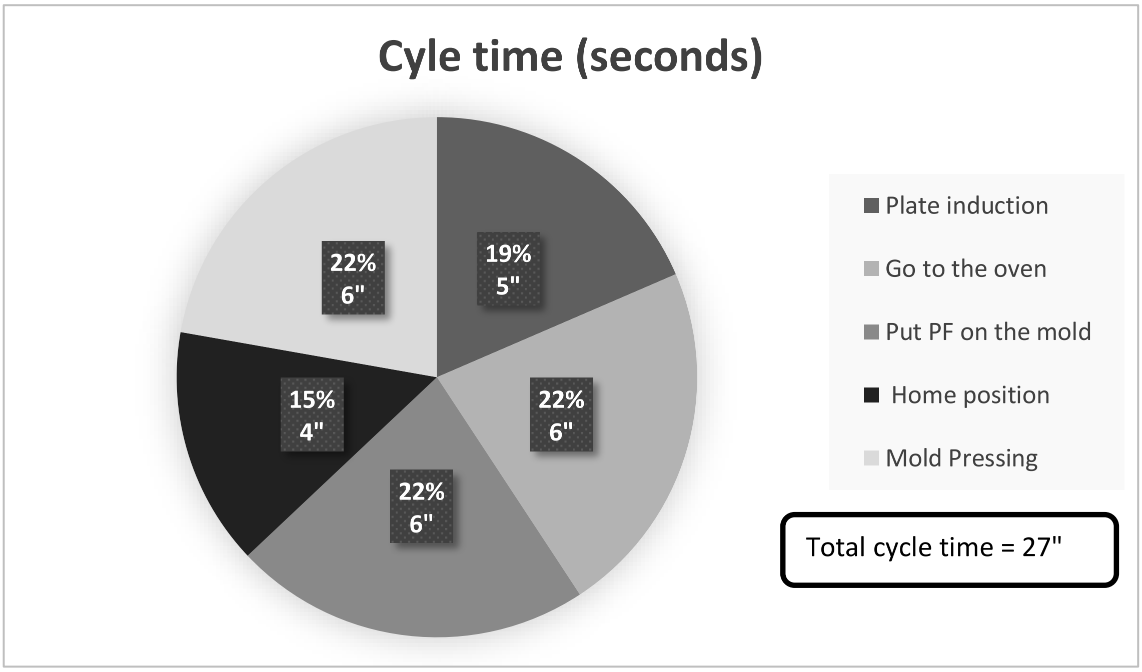


Fig. 5.2: Cycle time breakdown percentage points.

5.3 Optimized process

For the design of this process, has been use all the factors gather in the previous experiment that gave the best results on the surface of the PF and the process time breakdown.

Key factor of the optimized process as seen in Fig.5.3.

- Reduction of the process time by 10,5 seconds.
- Process 61% faster.
- Improve quality of the final product.
- Higher level of automation.
- Better surface quality of the final product.

When we take into account all the heating time the whole process takes about 97 seconds so reducing 10,5 seconds from the process might not seem like much, but it has to be taken into account that mostly the more critical process is being optimize, this means that the process being optimize are those which affect directly on the surface quality of the final product and on the commercial ability of the process.

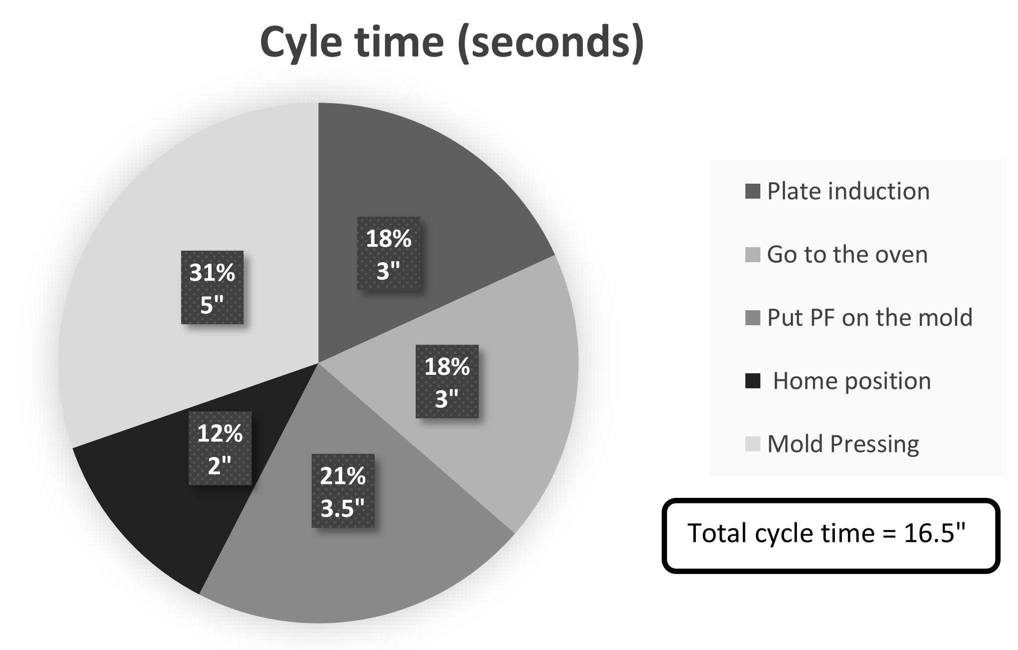


Fig. 5.3: Cycle time optimize process break down for the optimal process.

The optimization of the process was accomplish using a series of programming tools that were at our disposal. This is shown in Tab. 5.1

Tab. 5.1: Program symbol explanation.[EnM16]

	LIN positioning
	PTP positioning
	PTP with overgrinding
	LIN with overgrinding

	Open grippers
	Close grippers
	Activate/deactivate pneumatic for the oven

The program is divided in five sections: Heat the mold with the induction plates, pick PF 1, put PF on the mold and mold pressing as seen on the fig below.

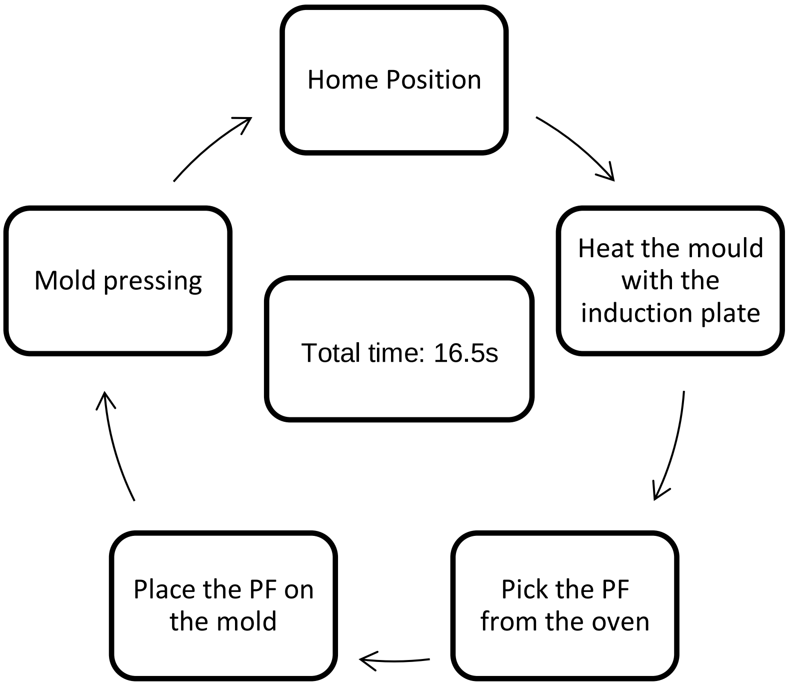


Fig. 5.4: Basic optimized process.

The more useful tool in the optimization of the program was the PTP positioning with the overgrinding option. The robot can be given two types of order for positioning, LIN and PTP as shown in Fig. 5.5

LIN: the robot goes from point 1 to point 3 following a straight line with the head of the robot

PTP: the robot goes from point 1 to 3 following the most comfortable path for the robot, this is usually not the sorter path but it is usually the faster. this position can not be use in narrow spaces where the danger of crashing is high this is due that the robot movements are unpredictable.

Overgrinding, this option can be apply to PTP and LIN movements and it means that the robot does not need to arrive to the point three exactly, here you can give the robot a tolerance. This allow the robot to link several movements together without having to stop after each move. The robots show a very fluent and fast movements when use with this option.

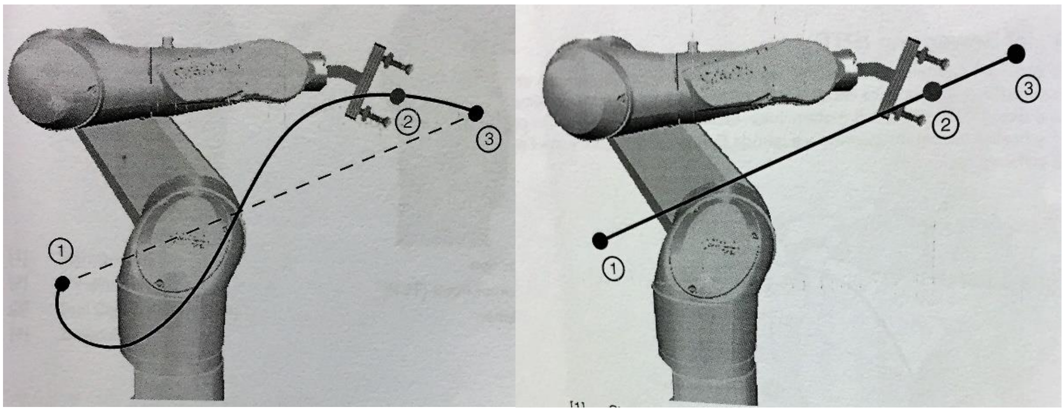


Fig. 5.5: PTP movement (left) LIN movement (right). [EnM16]

In the following paragraphs, it is going to be explain in detail how each movement was optimized. (The complete program programming can be seen on the appendix)

Heat mold with induction plates Fig. 9.1.

The robot always starts the program in home position, first the robot goes inside the mold and it waits there until for a specific “z” time and then it get closer to the mold and heats it up during “y” seconds, “z” and “y” time is calculated with the equation: x-y=z being “x” the time the PF need to be in the oven, “y” amount of time the induction pates needs to heat the mold and “z” is the time the robot is waiting inside the mold without heating. This is done this way because the time the PF need to be heat up is the deferent from the time the mold needs to be heat up.

Pick the PF from the oven Fig. 9.3

The function of this sequence is to pick the PF from oven one and go to home position, from there the robot will introduce the PF to the mold.

Place the PF in the mold Fig. 9.4.

Being this movement the most important it has been done using PTP positioning and overriding making the movement very smooth and reducing the time by almost 3 seconds. After dropping the PF the robots goes back home.

Mold pressing Fig. 9.5 Fig. 9.6

Fig. 9.5: Mold pressing program sequence.

In this sequence, the press is program instead of the robot, this sequence is done in parallel with another movement of the robot, doing this a lot of time is safe, because as it can be seen on Fig.5.3 pressing the PF is the most consuming task in the program

5.4 Alternative process

The overall aim is to make the process as viable for the industry as possible this means that apart of making the best PF possible the whole process should also be automated as much as possible. A complete automated process will need to be able to operate without humans, to achieve this two more peripheral had to be introduce.

First, a place for the PF machine will be need, there the robot could pick the PF that later will place on the oven and on the mold 5.4.1.Second, a way to remove the PF from the mold and place them on a stack will need to be find, this will be explained in 5.4.3.Last, the second oven that is on the machine has to be implemented, the goal of the oven is to heat the needles before they are used to pick the PF and place it on the mold.

5.4.1 Adding the preform machine

The first problem is feeding the robot with a large supply of PF so no human has to stop the process every cycle, by adding a PF machine into the process. This sequence is the longest of the whole program this is because it involves three independent robot movement.

First the robot goes from home to the table, this movements is done with PTP positioning and overgrind making it very fluent and fast. Second movement consist in taking the PF from the table and taking it to the oven, picking the PF is done with LIN because of the narrow space the robot is operating in, when the robot goes to the oven is done with the PTP. Last the robot lays the PF on the oven with LIN positioning

The programing sequence can be seen on Fig. 5.6, adding the PF machine will add 7 seconds to the overall process.

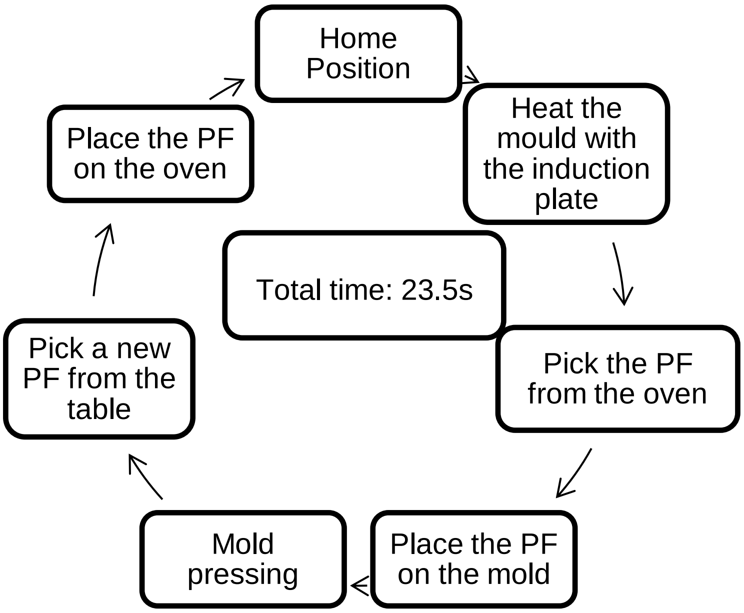


Fig. 5.6: Process cycle with PF machine.

5.4.2 Adding the second oven

After the first trials, it has been observed a few marks on the surface of the preform made by the needle of the gripper. The hypothesis, is that the marks are cause by the temperature difference between the needles and the heated web.

In order to fix this problem, the needles are going to be heated to see if this makes a difference in the marks. The second oven will be used to heat the needles. The robot before picking the process PF, goes to the second oven and introduce the needles in mock PF, that it is only use for this purpose, the robot stays in that position for 5 seconds to increase the temperature of the needles and then it moves to the next sequence.

The programming sequence can be seen on Fig. 5.7.

Using the second oven to heat the needles will add 8 second to the overall process.

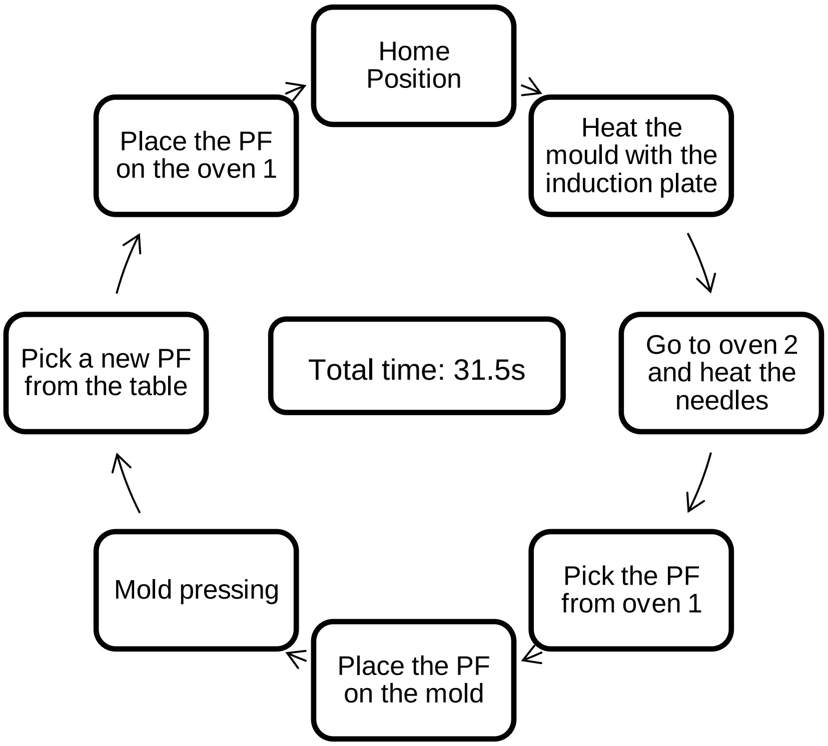


Fig. 5.7: Process cycle with PF machine and second oven

5.4.3 Further improvements.

After adding all the improvements that were at our disposal, the process is not full autonomous yet, it is still missing one vital function and that is removing the final PF from the mold.

The theory is very straight forward, the final part should be retrieve from the mold using vacuum grippers and then place that is next to the robot. Trying to implement this part of the process, some problems appear, the biggest being that only one vacuum gripper could be use and it was not strong enough to pick the final part from the mold, but this could be achieve using two vacuum grippers.

Once this function is implement in the program, the process will be almost 100% autonomous, the only human intervention needed will be to load the PF to the machine that was discuss in section 5.4.1. Then this machine will feed the PF to the robot who will run the program nonstop until the machines runs out of PF.

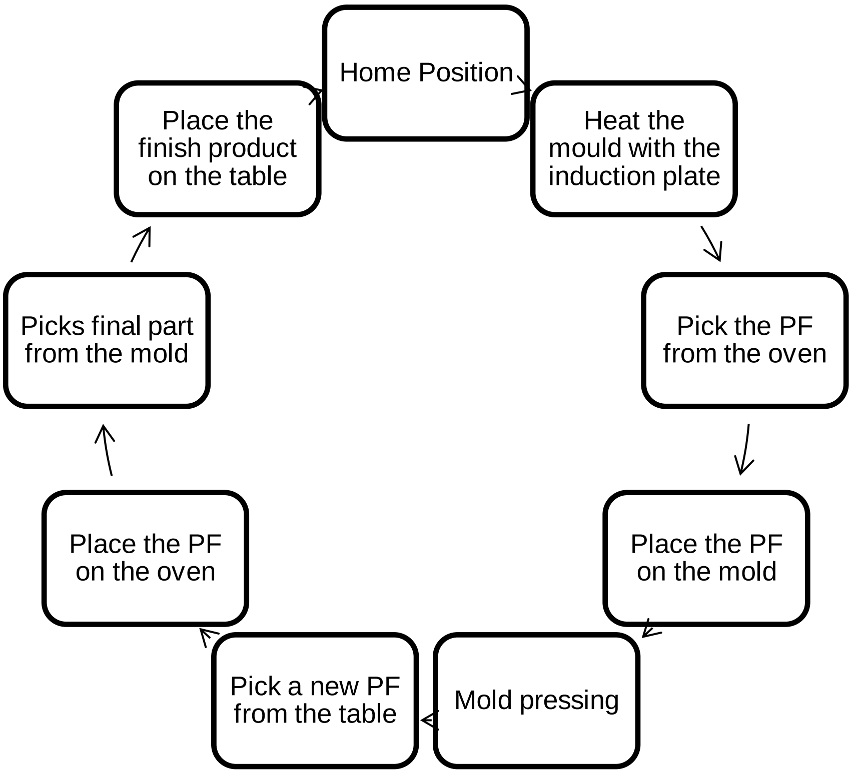


Fig. 5.8: Complete process cycle.

5.5 Improvements in the process

Benefits of the new process:

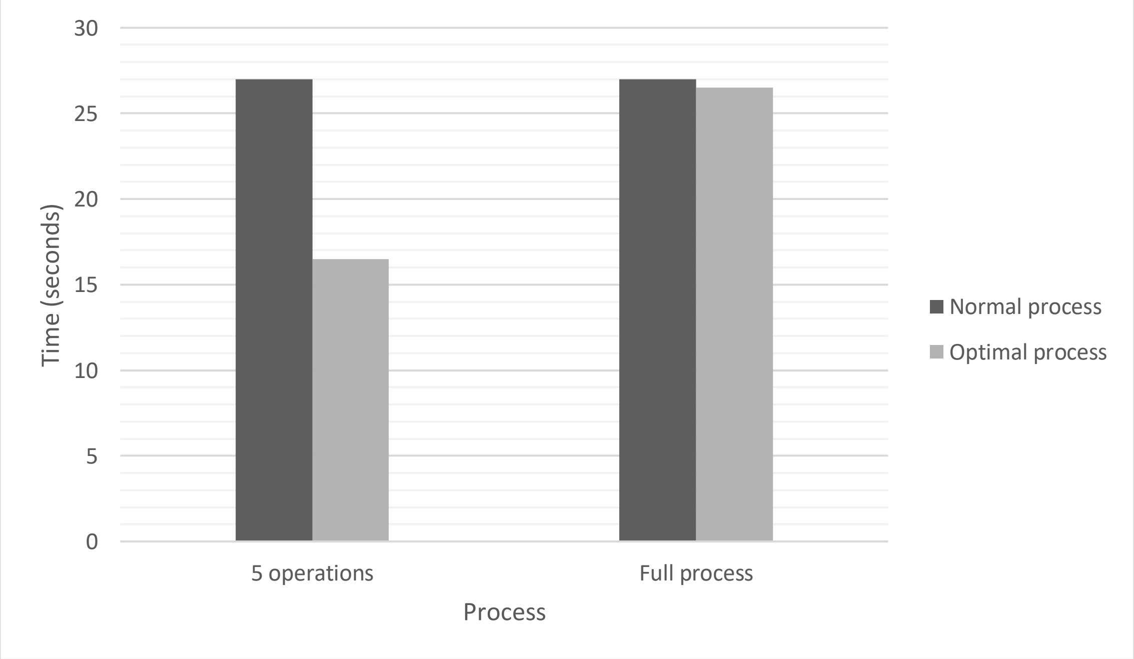
- Shorter manufacturing cycle time.
- Improves the final product quality
- Higher level of automation

With these improvements, the process needs to be made more reliable and easier to implement in the industry, because the process is optimized the temperatures and the times are constant throughout the manufacturing process and therefore the final product is more consistent. Because of the addition of more peripherals the gap to full automation has close.

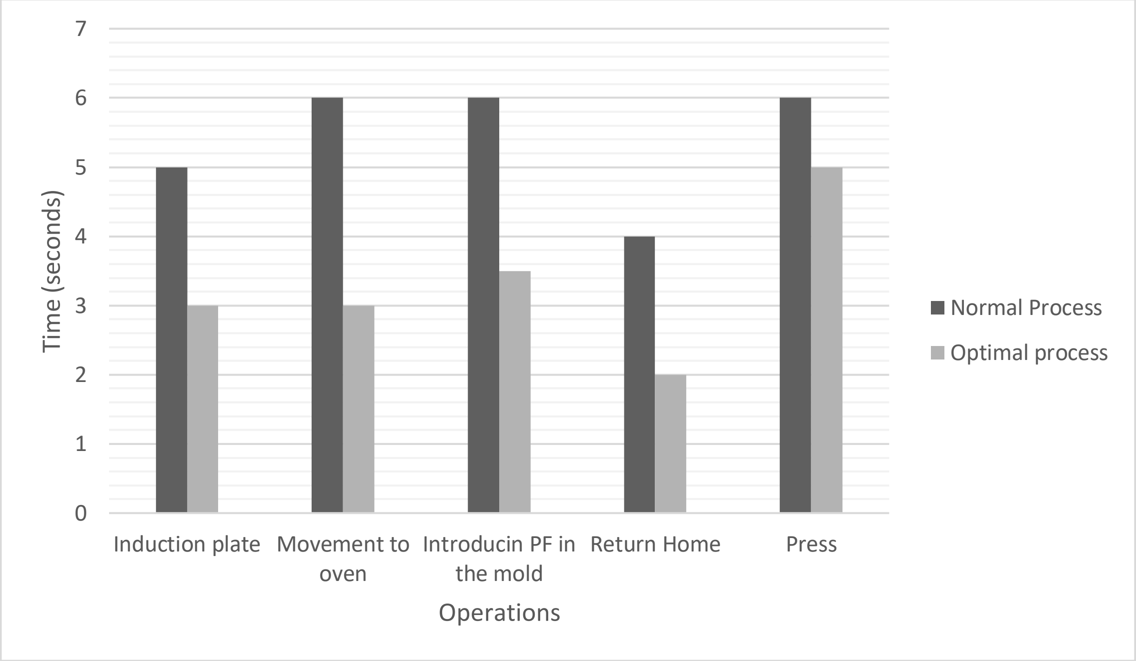
The process cycle time has been reduced by 10.5 seconds making the cycle 61% shorter, this high reduction in time combine with the automation makes the process very efficient.

In the last paragraph, the same five operations for both programs are being compare, the optimal process is longer due to the introduction of the second oven and the table. The full process is 31,5 second when once all the operations are added together, but because when the process is optimized the robot does not have to wait for the press to close, it can do additional operations in this case getting a new PF from the machine, so 5 seconds of the process need to be subtract. This takes the cycle time to 26,5 seconds, which is 0,5 seconds shorter than the normal process started with.

Tab. 5.2: Process time graph comparison



Tab. 5.3: Operations times graph comparison



5.6 Best final product

After applying all the modifications that have been realize during this thesis a final product with a Ra of 2.97 µm on the most conflict area has been produce, where the needles are introduce. This result have been evaluated in [Bar17].

These extraordinary results were achieved thanks to the optimized, specially the reduce in the cycle time, the second oven and the needles gripper with the 5 mm setup. All of these modifications combine greatly improve the preform surface quality.

Tab. 5.4: Specifications of the best final product made.

Web	Material	Tª oven and duration	Time induction plates	Polyamide (layers)	2º oven	Tª upper mould	Ra needle zone (µm)
5	**PA**	**250ºC 80 s**	**40 s**	**Two**	**Yes**	**125ºC**	**2,97**

Fig. 5.9: Best final product piece.

6 Product design

The aim of the work in this section is to design a machine that supplies the robot with a large amount of preform, this way an autonomous process could be simulate. The necessity for the implementation of a machine that could feed the robot with sufficient preform appear at the begging of the manufacturing process design. This section aims to solve this necessity, studying which designs would be better to implement in the manufacturing process.

The design process is conducted in accordance with the VDI guideline 221st the "Preform supply machine" function is accordingly placed in the functional structure. For the adaptive behavior of the machine, the invention method provides solutions to TRIZ. Three concepts are derived from the standing corresponds knit structures of the morphological box and evaluated. [PBF07]

TRIZ "theory of the resolution of invention-related tasks" translation of the Russian acronym TRIZ - a theory, whose purpose is to clearly define the act of invention.

These tools include, among others, a matrix of 39 generic engineering parameters and 40 inventive principles that can solve technical problems by formulating them in the form of contradictions opposing two parameters of the studied technical system.

TRIZ presents a systematic approach for understanding and defining challenging problems: difficult problems require an inventive solution, and TRIZ provides a range of strategies and tools for finding these inventive solutions. [WKZ]

6.1 Instruments of development methodology

This chapter describes the design process is presented based on the VDI guideline 2221 in his theory. The VDI 2221 describes a basic approach to the design and development of technical products. In Fig. 6.1 This cross-sectoral approach plan is presented, which is divided into seven basic working steps. Be-tween the seven steps the respective operating results as list of requirements, functional structure, principle solutions, etc. are shown. [PBF07]

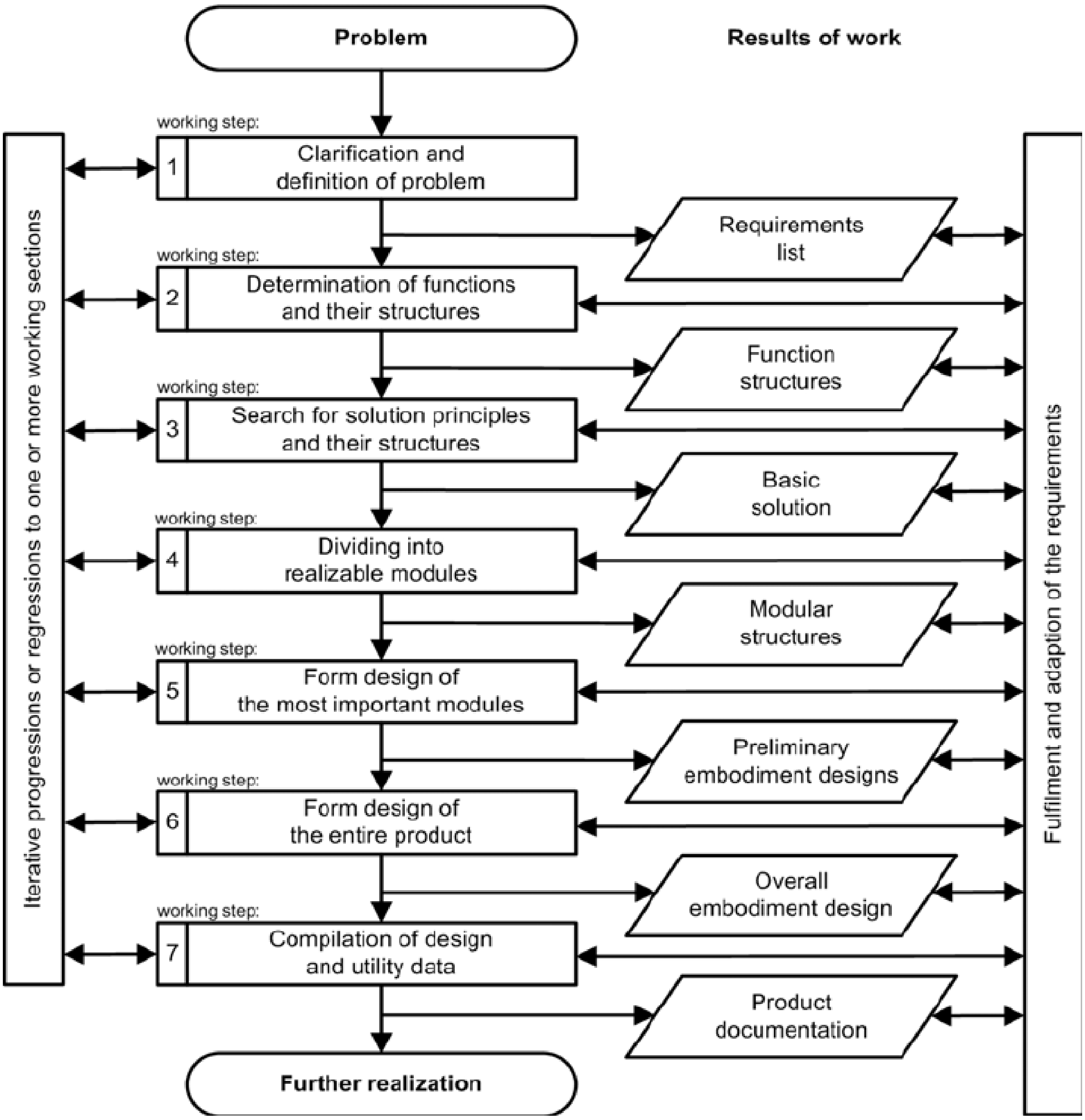


Fig. 6.1: VDI-procedure of development and design (VDI 2221, 1993).

6.2 Request list

The request list is according to the VDI 2221, the first step and will be developed at the start with the customer and the manufacturer. There are all requirements permanently documented, so that a binding basis between the parties [PBF07]. Points that are not in the list of requirements, need not be considered for the design.

1. Geometry: This request is the result of the area where the machine will be operating. The working area will be the table place inside the robot working are, it has to be taken into account that the robot will be the one interacting with the machine so it needs space to operate.
2. Dynamics: The speed of the machine should be regulated so it can coordinate with the robot in order to provide the PF at the pace that is need.
3. Energy: This request area affects the energy flow of the design. The module shall not require exceptional demands on the power supply. The construction must be adapted to the connections of the existing infrastructure of the ITA. This includes pneumatic and electrical connections
4. Materials: For the construction of commercial materials must be used that are not flammable and do not react with the production material
5. Production: The tools and installations available in the ITA should be use in the manufacturing of the machine.
6. Use: The module must be designed for a service life of over 5 years and a continuous operation of at least 24 hours withstand.
7. Reliability: The machine will be implemented in an autonomous process so it has to be able to reproduce the same result over and over with extreme accuracy for long periods of time.
8. Precision: This requirement is one of the most important, because the precision of this machine determines the precision of the whole process.
9. Safety: The machine will be load by a person but after that it will interact only with the robot and no human will be close to the machine while it is running, so the only safety requirements will be on the loading phase.
10. Cost: the design must be made with the objective of develop a cost-effective solution. The running costs and the maintenance have to be reduced as much as possible.

Tab. 6.1: Request list is according to the VDI 2221.

request list				
Project: controllable module for feeding individuals PF to the robot				
Company: ITA Editor:Gonzalo Diez Achiaga		Project no. 1	24-08-2017	
D/R	No.	Demands (D), request (R)	Specifics	source
	1	Geometry		
D	1.1	Width of the module	mm	
D	1.2	Height of the module	mm	
D	1.3	Length of the working area	mm	
	2	Dynamics		
D	2.1	Speed of the process must not be affected	seg	
D	2.2	PF laying cadence	PF/seg	
R	2.3	Prcocess cylcel time	seg	
	3	Energy		
R	3.1	Driving electrically or pneumatically		
D	3.2	Compressed air connection	< 7bar	
D	3.3	Power connection	400 V / 3 phase	
	4	Materials		
D	4.1	Use commercially available materials		
R	4.2	Do not use combustible materials		
D	4.3	Material must not react with fibers		
	5	Production		
R	5.1	Producing the components with common manufacturing process		
D	5.2	Use of standard components		
D	5.3	Use of commercially available parts		
	6	Use		

D	6.1	Lifespan	>5 years	
request list				
Project: controllable module for feeding individuals PF to the robot				
Company: ITA Editor:Gonzalo Diez Achiaga		Project no. 1	24-08-2017	
D/R	No.	Demands (D), request (R)	Specifics	source
D	6.2	Continuous use	Up tp 24 hours a day	
	7	Reliability		
R	7.1	Continuous cycles without calibration	Up to 1000	
D	7.2	Automatic quality control integrated bar		
	8	Precision		
D	8.1	Placement precision	+-1mm	
R	8.2	Self-calibrating		
	9	Safety		
D	9.1	Safe to load PF		
D	9.2	Provide emergency shutdown		
D	9.3	Construction according to the applicable security guidelines		
	10	Cost		
R	10.1	Cost-effective solution		
R	10.2	Low running costs		
R	10.3	Low repair cost		
R	10.4	Low implementation costs		

6.3 Functional structure

The main goal of the design is to provide the robot with sufficient preform webs. This includes a loading process of the preform textile in the supply machine, the machines later have to be able to put a preform on a specific place on a surface, from where the robot will pick it up and proceed with the process.

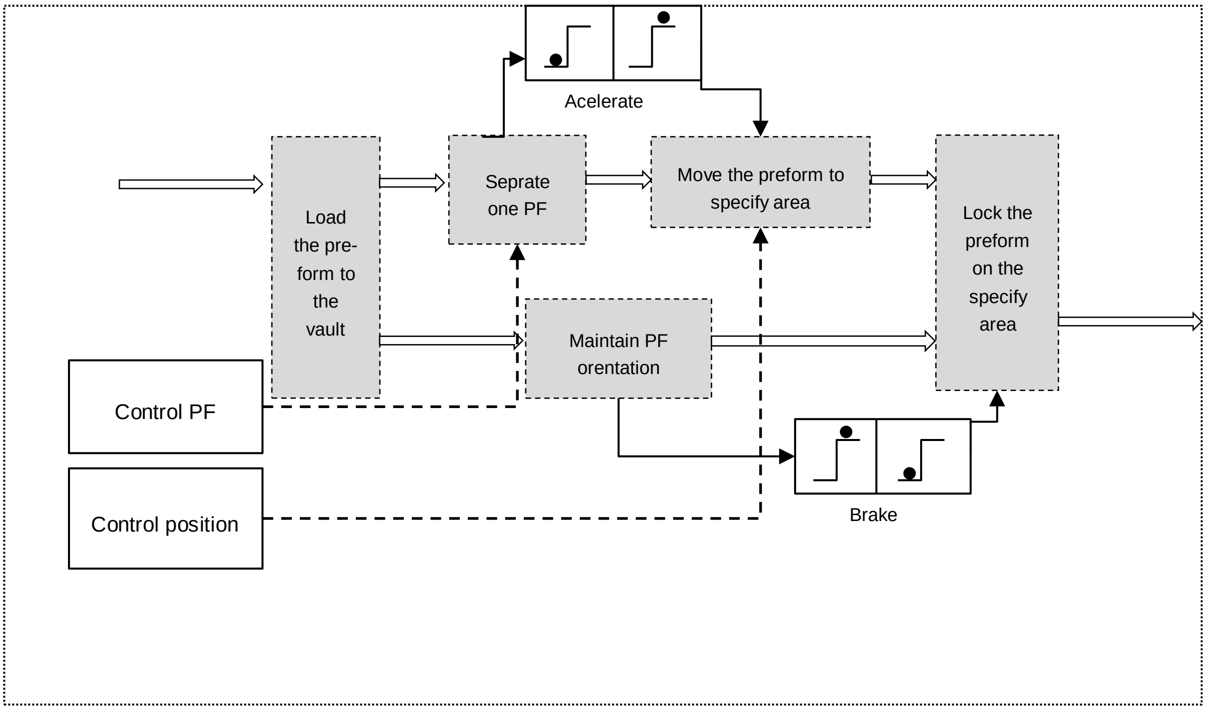


Fig. 6.2: Complete functional structure

6.4 Concepts designs

After analyzing the complete functional structure and the requirement list, four concepts that solve all the problems have developed.

During the development of the concepts a distinction has been made between concepts that require the creation of a machine or a structure to solve the problem and the ones that require the robot head modification and the program code.

Concepts 1 and 2 require developing a machine in order to work in the other hand concepts 3 and 4 only require small sensor that could be easily integrated in the robot head and modifying the robot code, this last task may present a bigger challenge.

6.4.1 Slide concept 1

The first concept realizes the adaptive behavior by the principle of separation or segmentation. The purpose of this concept is to separate one web from the stack of webs and then lay it on top of the table so the robot can pick it up. Once the robot has pick the web, a signal will be send to the machine so another web is laid on the table.

The preform will be load in the PF container, then the push mechanism will send one PF through the small opening to the PF release gate, which will detect that there is just one PF, and as soon this is confirm the gate will open letting the PF slide into the pickup area, where later it will be pick by the robot gripper.

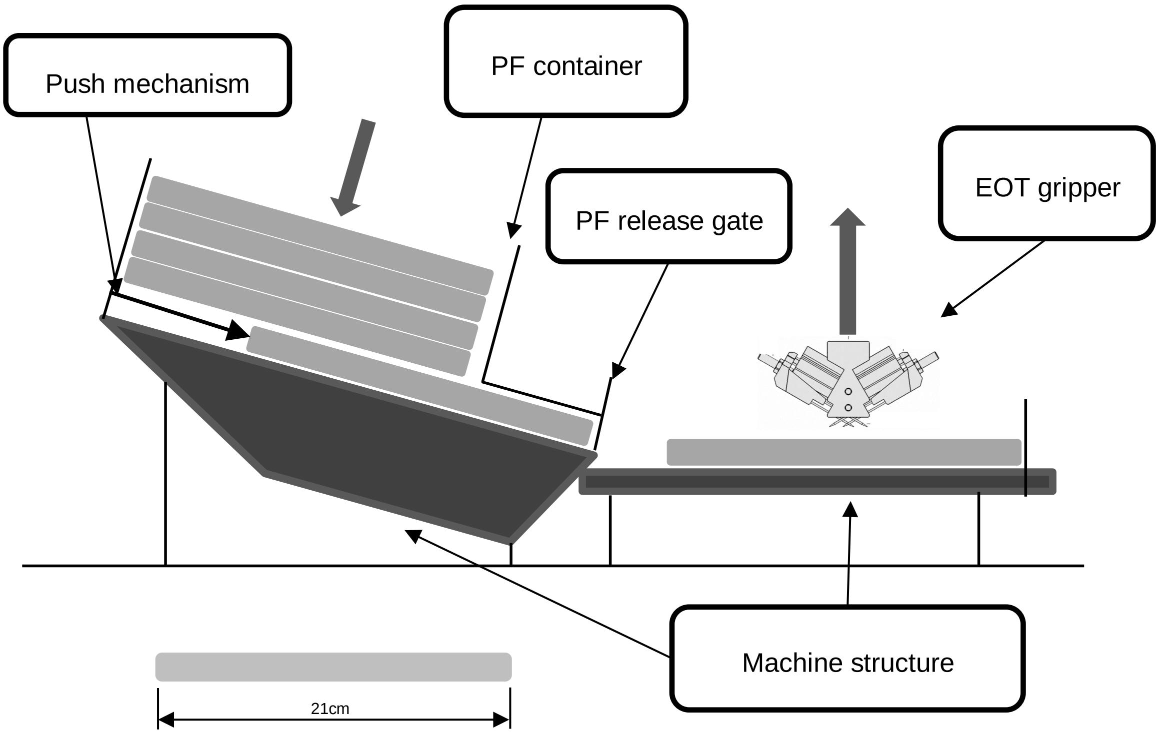


Fig. 6.3: Slide concept 1

6.4.2 Tray concept 2

The second concept work with the same principles as the first one but arrange in a different way. First the preform will be load into the PF container, the push mechanism will push the PF upwards until the PF release sensor is activated, when it sensor a PF on the pickup area.

Then, the robot will pick up one PF directly from the stack and once the PF has been taken by the robot the PF release sensor will send a signal to the push mechanism to adjust the height of the PF. Doing this the robot always picks the PF from the same position.

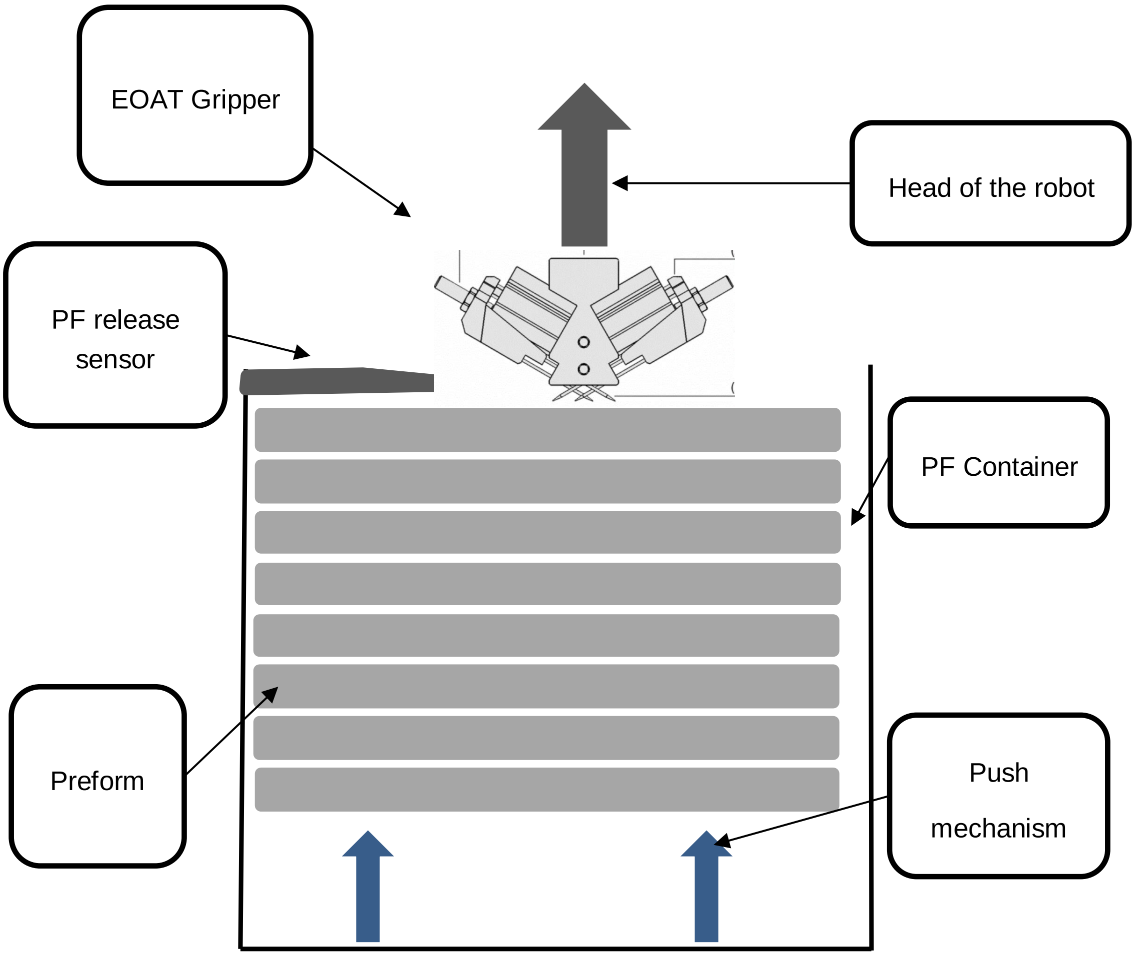


Fig. 6.4: Tray concept 2

6.4.3 Contact sensor concept 3

This concept only requires adding a slight modification in the robot head, a small contact sensor needs be added. This will work in the following way, the robot will approach the stack of PF and will lower itself to pick one, when it comes in contact with the first PF the spring will contract and the sensor will be activated, it then will send a signal to the robot to close the grippers and grab the PF.

The thickness of the PF nor the numbers of PF need to be introduce in the robot programing, the PF just need to be place in the correct position.

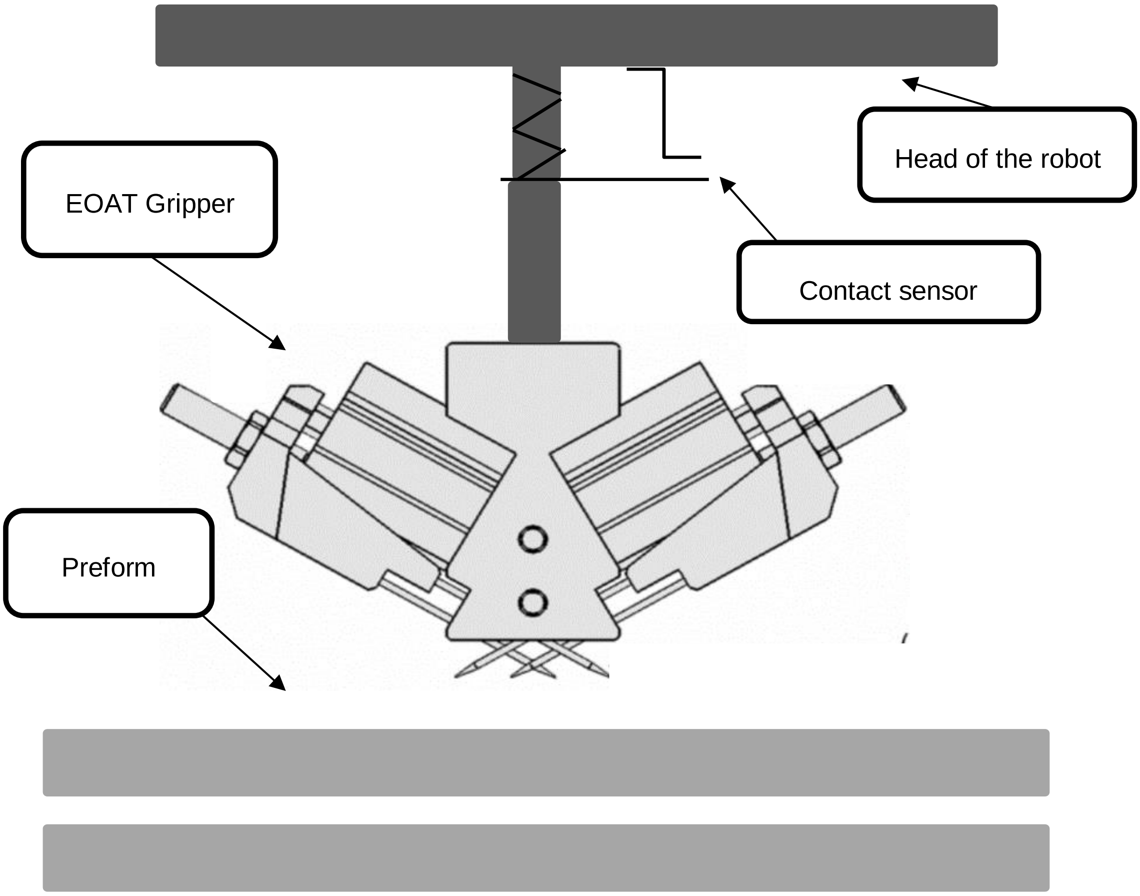


Fig. 6.5: Contact sensor concept 3

6.4.4 Proximity sensor concept 4

This concept works in a similar way as the concept 3 but instead of having a contact sensor it will have a proximity sensor and when the grippers is close enough to the PF the sensor will order the robot to close the needles and grab the PF.

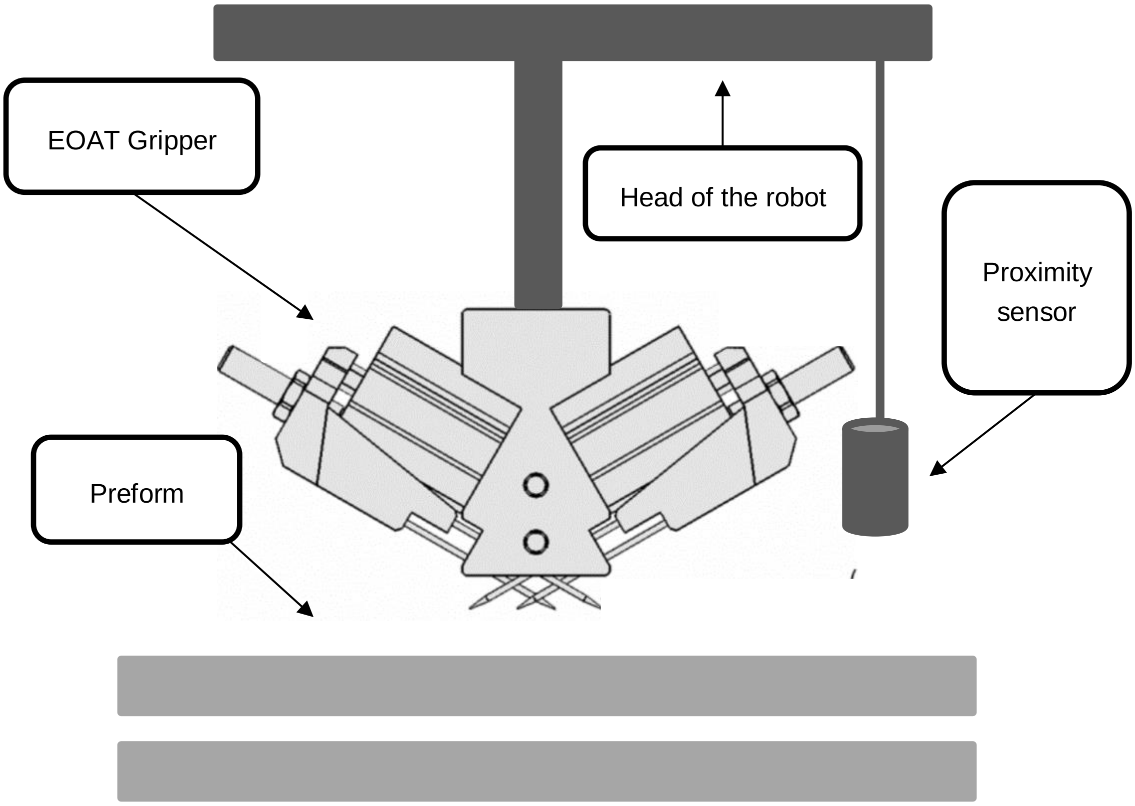


Fig. 6.6: Proximity sensor concept 4

6.5 Assessment of Concepts

To select the best solution concept, the evaluation criteria presented in Tab.6.1 was used, these criteria will let us evaluate the concepts in all critical areas.

Tab. 6.2: Evaluation criteria

1. SPEED • High production speed • Fast solving problems
2. INVESTMENT COSTS • Development costs • Tooling costs • Manufacturing costs
3. RUNNING COSTS • Energy consumption • Tools wear
4. MAINTENANCE • Durability of the designed components • Quick and easy removability
5. CONTROL • Central unit • Some kind of pressure sensor to know when the web has been pick up
6. SAFETY • Quick stop option or safe mode • Good isolation
7. EFFICIENCY • Low waste of energy • Recycling
8. Accuracy/Precision • Be able to lay the PF always on the same place • Easy to measure
9. Complexity • How hard is to implement

After stating which are the criteria where the concepts are going to compete. To compare them the Tab. 6.3 is use, where each criterion will be ranked using frequency, which reflects the importance of the criterion. In order to normalize this, the frequency is divided by the number of all combinations (19) and there is a normalized weighting factor for each evaluation criterion.

Tab. 6.3: Ranking table for the criterion

Evaluation criterion	1	2	3	4	5	6	7	8	9	Σ
Frequency	4	7	7	2	4	2	2	9	6	43
Weighting factor	0,09	0,16	0,16	0,05	0,09	0,05	0,05	0,21	0,14	1

The table shows the Accuracy evaluation criterion as the highest importance criteria with a frequency of 9. The investment cost and running price criterion being number 2 and 3 respectively have a great importance too.

After these results, it is clear that the focus is on the economic aspects which are the most important for the customers. However, the good precision and accuracy of the process play the most important role, because the outcome of the whole process depends on how well the robot picks the PF from the machine. The safety and control do not be so important because the present design is a prototype and the focus is on reaching a good quality product taking care of the costs and the final product will be place inside a secure area where no one will manipulate it while it is running.

Tab. 6.4: Rating scheme

Points	Importance	Significance when comparing
0	Unsatisfactory	Way below average
1	Just about acceptable	Below average
2	Sufficient	On average
3	Good	Above average
4	Ideal	Well above average

I

n the rating scheme (Tab. 6.3), the numerical values are fixed and each associated with one meaning. The guideline VDI 2225 uses a scale from 0 to 4, which cor-responds to "unsatisfactory" a scale of "ideal" [PBF07]. Often it is not possible to assign a value to a qualitative evaluation criterion. For this reason, the concepts are compared against each other. This means that the concepts are relatively compared with each other and not with an ideal solution. The comparison with an ideal solution would be an absolute comparison. The scale of importance when comparing thus changes to "well below average" to "well above average".

In Tab. 6.5 can be appreciate that the concept 4 has the highest score follow by concept 3 and 1, in last place is concept 2. This means that the modification of the robot head is a smarter approach in order to solve the problem, although another possibility could be y to implement concept 1 because of its proximity with concept 3. In other to see the strength and weakness of each process and how can they be improved a vulnerability analysis is going to be realize on section 6.6

Tab. 6.5: Cost-benefit analysis

No i.	**evaluation criterion**	Wt. Gi	**concept 1**		**concept 2**		**concept 3**		**concept 4**	
			wi, 1	wgi, 1	wi, 2	wgi, 3	wi, 2	wgi, 2	wi, 3	wgi, 3
1	Speed	0,09	1	0,09	3	0,27	4	0,36	4	0,36
2	Investment cost	0,16	2	0,32	2	0,32	4	0,64	4	0,64
3	Running price	0,16	3	0,48	2	0,32	3	0,48	4	0,64
4	Maintenance	0,05	3	0,15	2	0,1	3	0,15	4	0,2
5	Control	0,09	3	0,27	3	0,27	3	0,27	2	0,18
6	Safety	0,05	2	0,1	2	0,1	3	0,15	2	0,1
7	Efficiency	0,05	2	0,1	3	0,15	3	0,15	3	0,15
8	Accuracy	0,21	4	0,84	3	0,63	2	0,42	2	0,42
9	Complexity	0,14	2	0,28	3	0,42	1	0,14	1	0,14
	Total value = Σgiwi, j		**2,63**		**2,58**		**2,76**		**2,83**	

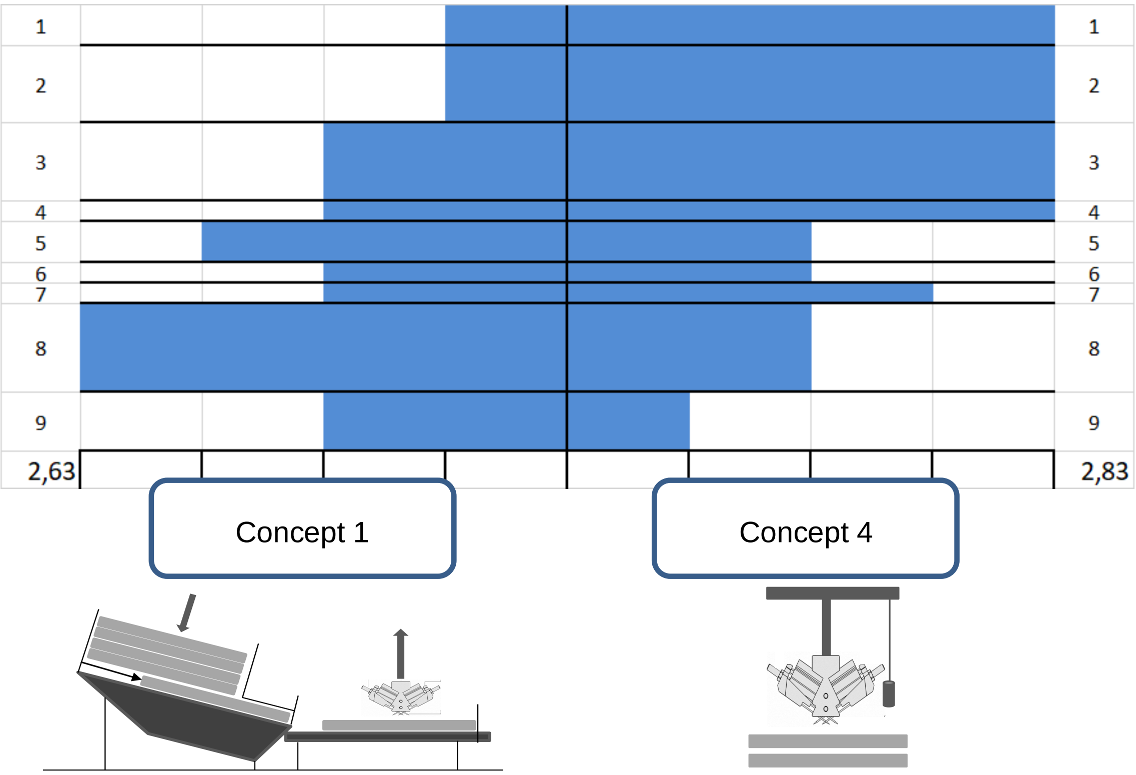
6.6 Vulnerability Analysis

Vulnerability analysis in this work is represented with the aid of a value profile. The concept with the highest score will be provided in each case the other two concepts for a direct comparison against. The two best concepts are going to compare the best concept of developing a machine, concept 1, with the best concept of modifying the robot, concept 4, this comparison will be on Tab. 6.6 then on Tab. 6.7 concepts 2 and 3 are comparing being the other two concepts of developing a machine and modifying the robot.

From Tab. 6.6, it appears that the concept 4 is not balanced overall. Concept 4 has 3 strong points but is rather weak in the others, what makes concept 4 the best one is that its strengths are in 3 very important areas, investment cost, running price and speed. Concept 1 has a strong point which is also the most import area, accuracy and precision.

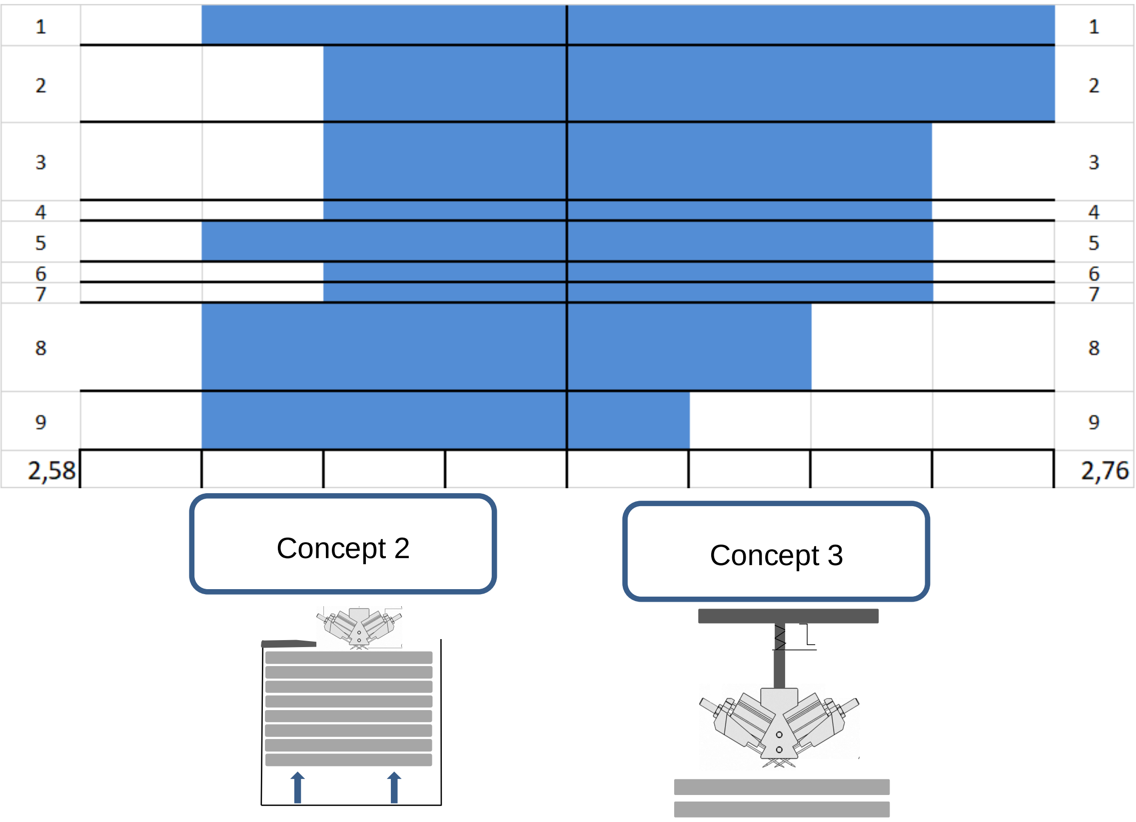
After analyzing the vulnerabilities, conclusion can be gather being it that a new concept should be made, these new concept is to add to concept 4 the strong points of concept 1, being those control and accuracy.

Tab. 6.6: Vulnerability Analysis Concept 1 and Concept 4



From Tab. 6.7, can be observe that the concept 2 is well balanced overall but it is balance with low scores. Concept 3 has 2 strong points and 5 medium score points, investment cost, and speed. On the other hand, Concept 2 has two strong point in accuracy and complexity which means that the best solution for this problem with this two concepts will be to implement criterion 8 and 9 from concept 2 in the concept 3 which will mount to an overall high score.

Tab. 6.7: Vulnerability Analysis Concept 2 and Concept 3



6.7 Concepts conclusions

After analysis all the concepts, the conclusion it has been arrived to is that the best solution will be to implement a new concept, which will be base in one of the concepts that modify the robot head instead of building a whole machine, specially concept four, that is the one which got the highest ranking.

In other to create a new better concept it will be necessary to implement some features from the other concepts into concept four.

To be more specific the features that will be kept from concept four will be criterion 1,2,3 and 4, speed, investment costs, running costs and maintenance respectably, then it will be needed to add the criterion from the other concepts where concept four is weak, like criterion 5 (control) and 8 (accuracy) from concept 1 and 9 (complexity) from concept 2.

If all of this is taken into account the concept that will be manufacture will be a hybrid between the head modification and a small machine.

Once a cost benefit analysis is done in this new concept the total score will not be the sum of the individuals score of each feature from the other concepts. This is due to the fact that once some features from other concepts are implemented, the value of some features of the original concept might be reduce. So a new cost benefit analysis comparing the five concepts should be done.

7 Summary, conclusions and outlook

7.1 Summary

The goal of this thesis is to improve the process of transforming non-woven web into a final product capable of being merchantable. In order to achieve this, several peripherals had to be add and do several experiments, which were closely related to the final product quality.

The thesis is divided in three sections. The three of them sum up to achieve the goal of the thesis.

The first sections focus on the robot needles grippers and which is the maximum load it can handle, the purpose of doing this experiment was to figure with which was the minimum length the grippers where effective to perform the process.

The second sections are center in the optimization of the process, in there it is explain which where the steps taking to reduce the cycle time and which peripherals where implemented to improve the process and the quality of the final product.

The third and last section focus on how to implement a new machine that feeds the robot with non-woven PF, this way the process could be made almost fully autonomous.

7.2 Conclusions

After gathering and studying all the results from the experiments and process improvements these are the four most important conclusions:

1. The needles grippers can perform perfectly with the 5 mm setup reducing the impact it has on the final product surface.
2. The cycle time reduction has been considerably, reducing more than 60% the basic cycle of the process. This has been extremely influential in the quality improvement of the surface. Making a shorter cycle, allows the preform to maintain the temperature therefore improving the final product quality.
3. The added peripherals, the second oven and the table have a great impact on the surface quality of the final product and on the grade of automation of the process.
4. The product design has thrown revealing result, being more viable and more versatile to implement a solution on the robot head, proximity sensor than manufacture a machine that feeds PF to the robot.

After putting all the improvements made during the thesis together, can be affirm that the manufacturing process has been really optimized, the final product surface has been improved, and that a number of peripherals have been implemented successfully and that all the objective set at the beginning of the thesis have been achieved.

7.3 Outlook

The results achieved by thesis are very promising because the cycle time has been reduced considerably and a few new peripherals have been added, making half the process fully autonomous.

There is a lot more to do to make the process commercially viable. First the machine that feed PF to the robot should be built and the program adjusted to work in a cooperative way. In the other hand, the robot head should be fit with two vacuum grippers that would retrieve the final product from the mold and will place it on a stack in the table.

Although the results thrown by the gripper experiment are quite satisfactory a study in the viability of using the vacuum grippers during the whole process should be made. Doing this the quality of the final product could be increase. This is due that the needles were the main factor that caused of most of the irregularities on the surface of the product.

8 Bibliography

[M02] Mazumdar, S.:
Composites Manufacturing: Materials, Product and Process Engineering
CRC Press (2002),

[Gar17] Garcia, M.:
Preconsolidation of hybrid textiles for the production of web based thermoplastic composites, University of Augsburg, Institut für Textiltechnik Augsburg GmbH, Bachelor thesis, 2017.

[H96] Hull, Derek.:
Introduction to Composite Materials
Cambridge University Press (1996).

[V11] Vaidya, U
Composites for Automotive, Truck and Mass Transit: Materials, Design
DEStech, Inc., Lancaster (2011).

[Ege17] Eager, E.:
Prozessentwicklung zur Fertigung von Prüfkörpern mittels Pressen von Kohlenstofffaser-Vliesen mit thermoplastischer Matrix, Augsburg, Universität Augsburg, Institut für Textiltechnik Augsburg GmbH, Bachelorarbeit, 2017.

[EnM16] Engel Austria GmbH (Ed.):
Operator Manual Machine IN 1050H/200
Schwertberg: Engel Austria GmbH, 2016, [Firmenschrift]

[PH10] Soo-Jin, P.; Gun-Young, H.:
Carbon Fibres, Springer Series in Materials Science
Springer (2010), S.200-230

[A05] Besednjak, A.:
Materiales compuestos. Procesos de fabricación de embarcaciones.
Iniciativa Digital Politecnica (2005)

[Ste16] Anthony Stevenson.
Recycling carbon fibre: state of the and future developments
ELG Carbon Fiber, England

[SCH1] www.schmalz.com

[WW09] http://www.performance-composites.com/carbonfibre/

[A16] Stevenson, Anthony.:

Recycling carbon fibres: state of the art and future developments

International Textile Conference (2016)

[SGG16] Job, S.; Leeke, G.; Oliveux, G.:

Recycling Report 2016, composites recycling: where are we now?

Composites UK (2016)

[Reg14] Regulation (EU) No 333/2014 of 11 March 2014 amending (EC) 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars.

[LVD00] Life Vehicle Directive 2000/53/EC

[McK12] McKinsey & Company

Lightweight, heavy impact: How carbon fibre and other lightweight materials will develop across industries and specifically in automotive.

http://www.mckinsey.com/

February 2012

[R99] Rotheiser, J.:

Joining of Plastics, Handbook for Designers and Engineers

Carl Hanser Verlag, Munich (1999).

[H14] Hanser, C.:

Composite materials, Carbon Fiber, Recovering Carbon Fibers

Kunststoffe international (2014)

[TR11] Trend Report, Engineering plastics

Kunststoffe international 10/2011

Carl Hanser Verlag, Munich

[RLL11] Raghavalu, D. P.; Logstrup, T.; Lystrup, A.:

Influence of moisture absorption on properties of fiber reinforced polyamide 6 composites.

26th Annual Technical Conference of the American Society for Composites

DEStech Publications (2011), Vol. 1,pp. 500-510

[SJ07] Russell, S.J.:

Handbook of nonwovens.

The textile industry, CRC Press, Cambridge England, 2007

[SGL17] SGL Group: Thermoplastic composite materials made from carbon and glass fibres

http://www.sglgroup.com/

Germany 03.2017

[ED17] EDANA: Nonwovens formation

http://www.edana.org/

Brussels 2017

[Mar17]: Marin, P.:

Erarbeiten von Anlagenparametern zur Erzeugung von Vliesstoffen unterschiedlicher Orientierung und deren Vergleich, Augsburg, Universität Augsburg, Institut für Textiltechnik Augsburg gGmbH, Bachelorarbeit, 2017

[RAR12] McCool, R.; Murphy, A.; Wilson, R.:

Thermoforming carbon fibre-reinforced thermoplastic composites

Part L: Journal of Materials: Design and Applications, Vol 226, Issue 2, 2012

[RT17] Resin Transfer Moulding (RTM) Process

http://www.moldedfiberglass.com/

Molded Fiber Glass Companies 2017

[VI17] Vacuum Infusion Moulding (VARTM) Processing

http://www.moldedfiberglass.com/

Molded Fiber Glass Companies 2017

[Kra17] Krauss Maffei: The perfect combination of thermoforming and injection molding

http://www.kraussmaffei.com/

Germany 2017

[PT12] Article in Plastics Today: Hybrid thermoforming-injection process attracts auto industry interest.

https://www.plasticstoday.com/

02.12.11

[Wit13] Carbon fibre reinforced composite waste: an environmental assessment of recycling, energy recovery and landfilling

R.A. Witik, R. Teuscher, V. Michaud, C. Ludwig, J.A. Manson2013

[Pic06] Recycling technologies for thermoset composite materials- current status

S.J. Pickering 2006

[PP11] Recycling carbon fibre reinforced polymers for structural applications: technology review and market outlook

S. Pimenta, S.T. Pinho Waste Manag.,(2011)

[Mor12] Near - and supercritical solvolysis of carbon fibre reinforced polymers (CFRPs) for recycling carbon fibers as a valuable resource: state of the art

Morin, A. Loppinet-serani, F. Cansell, C. Aymonier J. Supercrit. Fluids, 2012C

[Chu04] Self-sensing attained in carbon-fiber–polymer-matrix structural composites by using the interlaminar interface as a sensor

Shoukai Wang, Daniel P Kowalik and D D L Chung Published 4 May 2004

[Cam10] Comparison of the structures and peptide binding specificities of the BRCT domains of MDC1 and BRCA1

S.J. Campbell, R.A. Edwards, J.N.M. Glover Structure, 18 (2010),.

[PBF07] Pahl, G; Beitz, W; Feldhusen, J; Grote, K.-H .:

Pahl / Beitz Engineering Design. Basics of successful product development methods and applications

[Bar17] Elias Barbero Garcia

Effects of Processing Parameters on the Surface Quality of Web Based Thermo-Plastic Composites Manufactured in an Automated Process

Augsburg, Germany 2017

[GP17] https://www.robots.com/articles/viewing/grippers-for-robots

[WKZ] https://en.wikipedia.org/wiki/TRIZ

9 Attachments

9.1 Needle gripper experiment data

2 layers

First experiment, it is going to be use a preform of 2 layers meaning that the web is made of two different preform joins together by heat and pressure, which is achieved in a heating press.

Tab. 9.1: Material and specifics:

Material	Quantity	??	Specifics	Other information
Web preform	3	2 layers	14 gr 3 mm thick	
Gripper	1	10 needles	460 gr	
Needles	10	-	15 mm long 0.8 mm - 1.2 mm	Manual Length 10 mm Robot length 9 mm*
Weights	>5	-	Up to 4500 gr	
Scale	1	-	Measures up to 5000 gr	

*How far the needles go inside the PF.

Tab. 9.2: Results 10mm needle length:

a	Load	Result	PF	Observations
1	4000gr	Not conclusive	Extreme Deformation	The gripper hold can not be measure if, as soon as it is pull up, the PF deforms and the load drops to the ground.
2	3600gr	Gripper holds	Severe Deformation	If the load is near the Gravity Center the PF doesn’t bend but as the load is move outward the PF bend and the loads are dropped.

3	3300gr	Gripper holds	Median Defor-mation	If the load is near the Gravity Center the PF doesn't bend but as the load is move outward the PF bend and the loads are dropped.

Tab. 9.3: Results 5mm needle length:

b	Load	Result	PF	Observations
1	3300gr	Gripper Don't hold	Median Defor-mation	Does not hold
2	2400gr	Gripper don't hold	No Defor-mation	Holds but does not lift the PF
3	1850gr	Gripper don't hold	No Defor-mation	Holds and lifts but not sudden movements
4	1700gr	Gripper hold	No Defor-mation	Holds and lifts but not sudden movements
5	1500gr	Gripper holds	No Defor-mation	Holds perfectly
6	1200gr	Gripper holds	No Defor-mation	Holds perfectly

4 layers

Tab. 9.4: Material and specifics 4 layers:

Material	Quantity	??	Specifics	Other information
Web preform	3	4 layers	41 gr 5 mm thick	
Gripper	1	10 needles	460 gr	
Needles	10	-	15 mm long 0.8 mm - 1.2 mm	Manual Length 8 mm* Robot length 8 mm
Weights	>5	-	Up to 4500 gr	
Scale	1	-	Measures up to 5000 gr	

*How far the needles go inside the PF.

Tab. 9.5: Results 10mm needle length:

a	Load	Result	PF	Observations
1	4000gr	Gripper holds	No Deformation	Holds perfectly
2	4200gr	Gripper holds	No Deformation	Holds perfectly
3	4500gr	Gripper holds	Minimum Deformation	Holds perfectly

Tab. 9.6: Results 5mm needle length:

b	Load	Result	PF	Observations
1	4000gr	Gripper Don’t hold	No Deformation	Does not hold
2	2400gr	Gripper don’t hold	No Deformation	Holds but does not lift the PF
3	2000gr	Gripper don’t hold	No Deformation	Holds and lifts but not sudden movements
4	1850gr	Gripper hold	No Deformation	Holds and lifts but not sudden movements

Tab. 9.7: Results with 5mm needles and new PF.

c	Load	Result	PF	Observations
1	2200gr	Gripper holds	No Deformation	Holds and lifts but not sudden movements
2	2400gr	Gripper holds	No Deformation	Holds and lifts but not sudden movements

8 layers

Tab. 9.8: Material and specifics:

Material	Quantity	Material Information	Specifics	Other information
Web preform	3	8 layers	93 gr 7mm thick	
Gripper	1	10 needles	460gr	
Needles	10	-	15mm long 0.8 mm - 1.2 mm	Manual Length 7mm* Robot length 7mm
Weights	>5	-	Up to 4500gr	
Scale	1	-	Measures up to 5000gr	

*How far the needles go inside the PF.

Tab. 9.9: Results 7mm needle length:

a	Load	Result	PF	Observations
1	4000gr	Gripper holds	No Deformation	Holds perfectly
2	4200gr	Gripper holds	No Deformation	Holds perfectly
3	4500gr	Gripper holds	No Deformation	Holds perfectly

Results 5mm needle length:

Tab. 9.10: Results 5mm needle length:

b	Load	Result	PF	Observations
1	4400gr	Gripper Don’t hold	No Deformation	Does not hold
2	4200gr	Gripper don’t hold	No Deformation	Holds but does not lift the PF
3	4000gr	Gripper hold	No Deformation	Holds and lifts but not sudden movements

Tab. 9.11: Results with 5mm needles and new PF.

c	Load	Result	PF	Observations
1	4400gr	Gripper Don’t hold	No Deformation	Does not hold
2	4200gr	Gripper don’t hold	No Deformation	Holds but does not lift the PF
3	4200gr	Gripper hold	No Deformation	Holds and lifts but not sudden movements

12 layers

Tab. 9.12: Material and specifics:

Material	Quantity	??	Specifics	Other information
Web preform	3	12 layers	140 gr 8-10mm thick	
Gripper	1	10 needles	460gr	
Needles	10	-	15mm long 0.8 mm - 1.2 mm	Manual Length 6mm* Robot length 6mm
Weights	>5	-	Up to 4500gr	
Scale	1	-	Measures up to 5000gr	

*How far the needles go inside the PF.

Tab. 9.13: Results 6mm needle length:

a	Load	Result	PF	Observations
1	4000gr	Gripper holds	No Deformation	Holds perfectly
2	4200gr	Gripper holds	No Deformation	Holds perfectly
3	4500gr	Gripper holds	No Deformation	Holds perfectly
4	4750gr	Gripper holds	No Deformation	Holds perfectly

Tab. 9.14: Results 5mm needle length:

b	Load	Result	PF	Observations
1	4000gr	Gripper hold	No Deformation	Holds perfectly
2	4200gr	Gripper don't hold	No Deformation	Holds perfectly
3	4500gr	Gripper don't hold	No Deformation	Holds perfectly

From the last part of the experiment can be observe that the PF holds firmly all the load was put on it, even with the needle length of 5mm it holds up to 4500gr.

Now a different approach is going to be taken and more load is going to added to the PF, doing this the scale can not be use in the same way as were used before, in this case load is going to be add.

Tab. 9.15: Results with 5mm needles and new PF.

c	Load	Result	PF	Observations
1	4750gr	Gripper don't hold	No Deformation	Does not hold
2	4600gr	Gripper don't hold	No Deformation	Does not hold
3*	4750gr	Gripper hold	No Deformation	Holds and lifts but not sudden movements
4*	4600gr	Gripper hold	No Deformation	Holds perfectly

*For the experiments c.3 and c.4 a new PF is use just to make sure that the results from the experiment c.1 and c.2 are reliable and they are not being misleading by the fatigue in the PF. The load has also been relocated putting it closer to the GC.

9.2 Process programing and automation

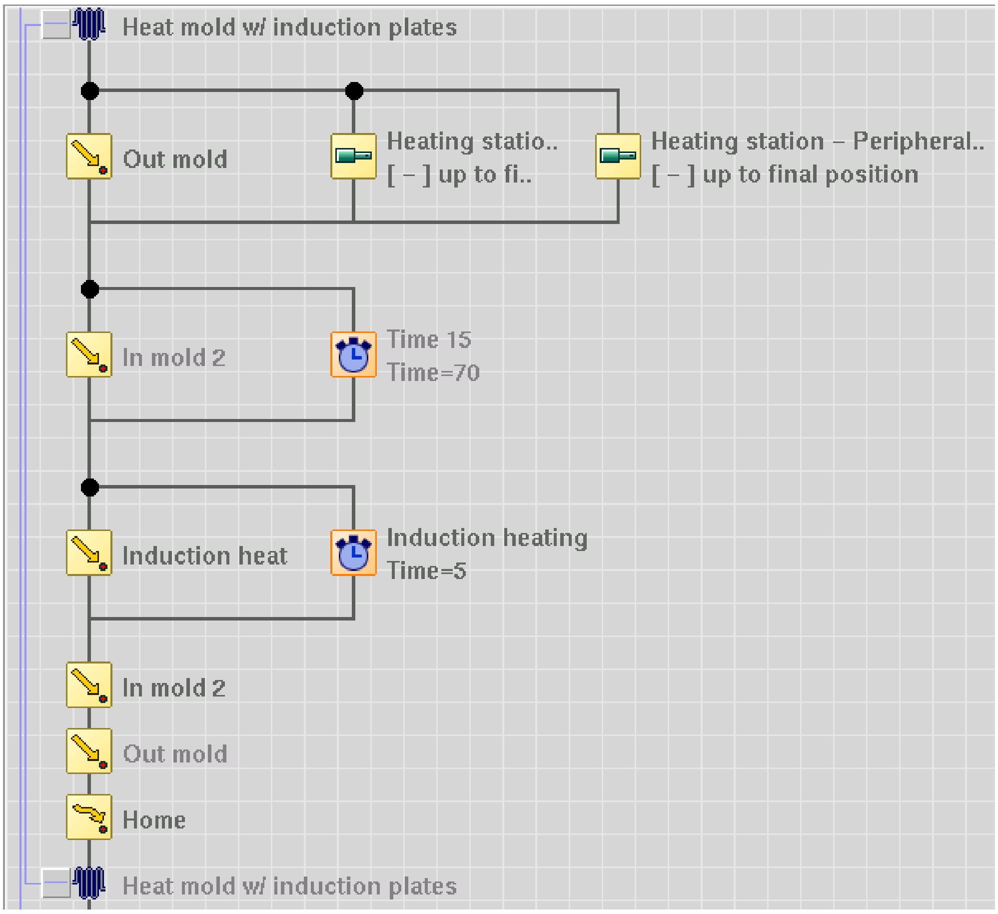
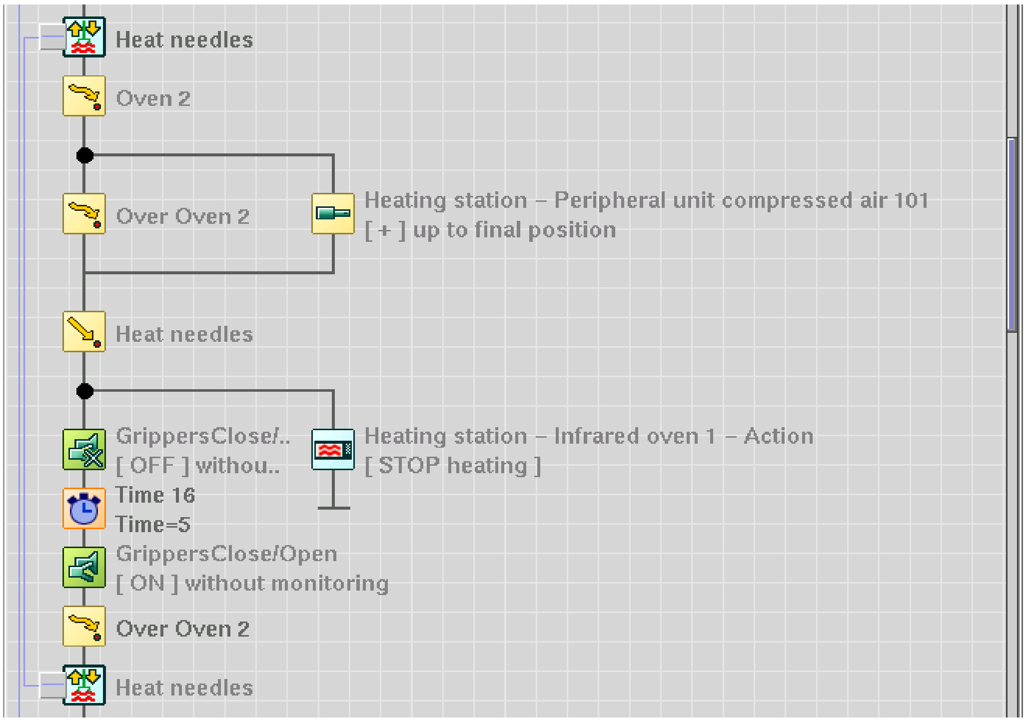


Fig. 9.1: Heat mold with induction plates program sequence.



Heat needles

Oven 2

Over Oven 2

Heating station – Peripheral unit compressed air 101
[+] up to final position

Heat needles

GrippersClose/..
[OFF] withou..

Heating station – Infrared oven 1 – Action
[STOP heating]

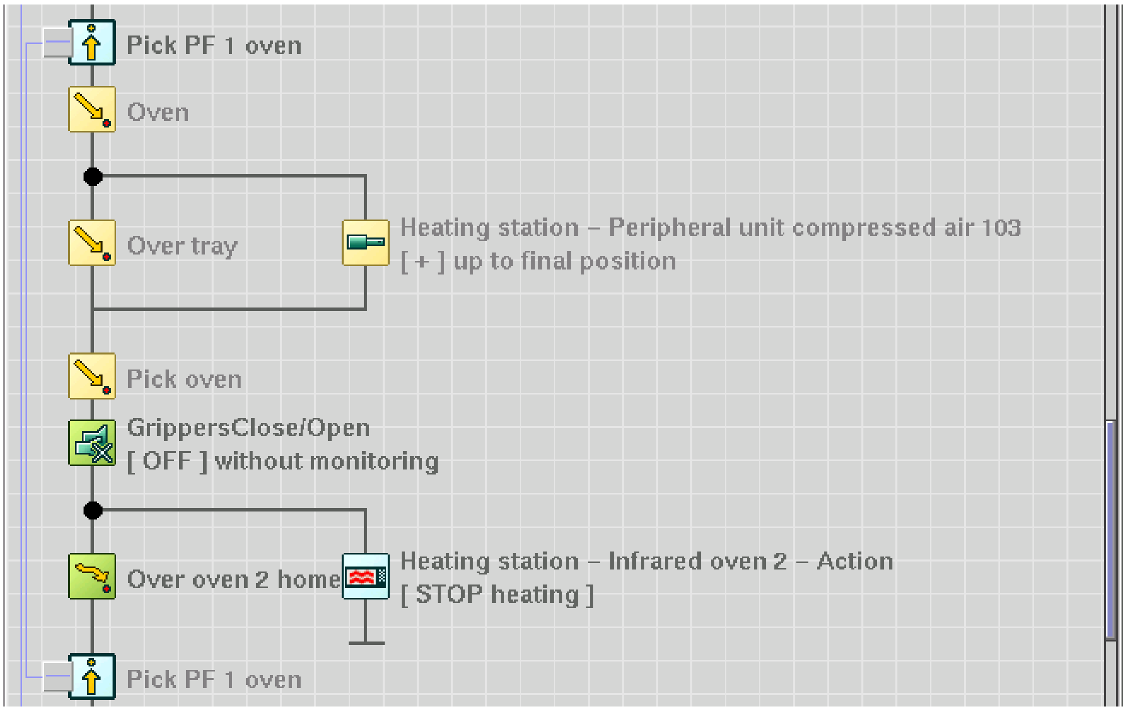
Time 16
Time=5

GrippersClose/Open
[ON] without monitoring

Over Oven 2

Heat needles

Fig. 9.2: Heating the needles program sequence.



Pick PF 1 oven

Oven

Over tray

Heating station – Peripheral unit compressed air 103
[+] up to final position

Pick oven

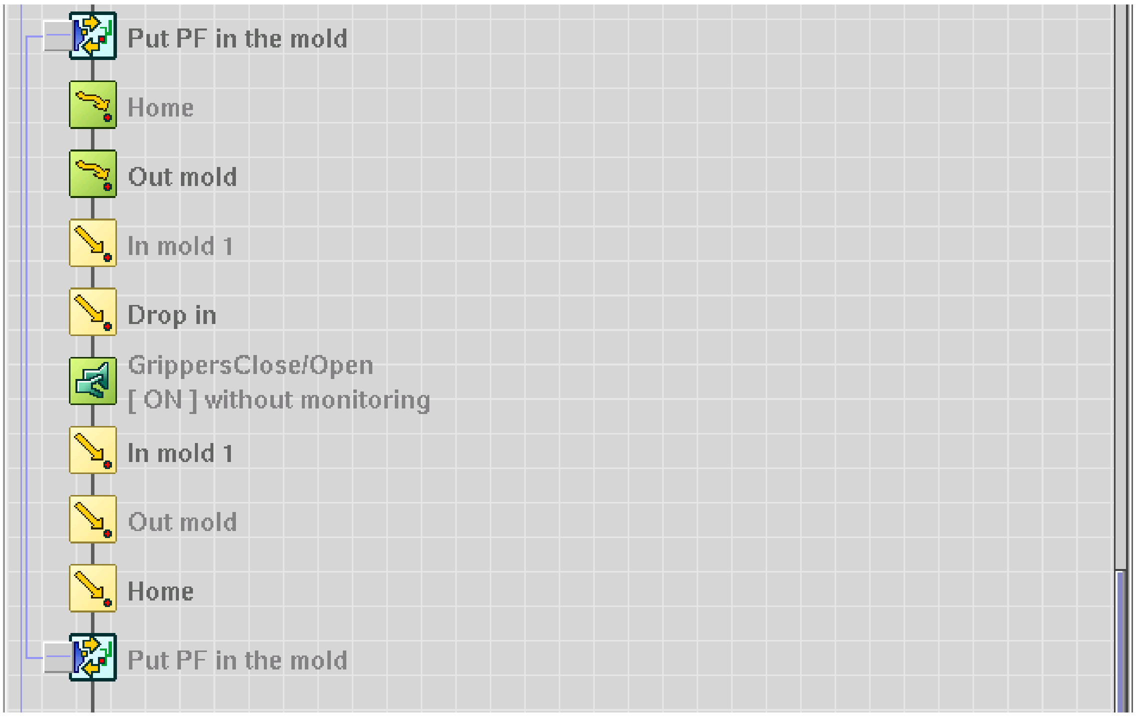
GrippersClose/Open
[OFF] without monitoring

Over oven 2 home

Heating station – Infrared oven 2 – Action
[STOP heating]

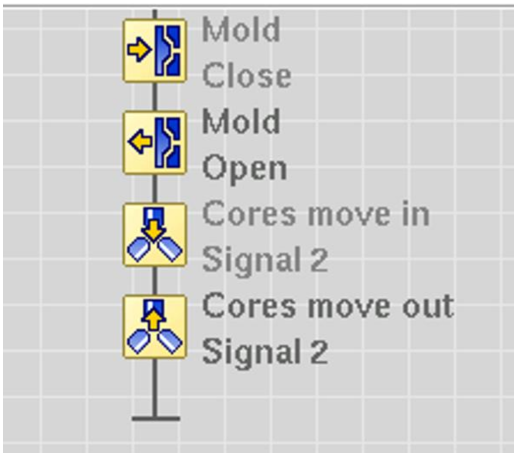
Pick PF 1 oven

Fig. 9.3: Pick PF from the oven 1 program sequence.



Put PF in the mold
Home
Out mold
In mold 1
Drop in
GrippersClose/Open
[ON] without monitoring
In mold 1
Out mold
Home
Put PF in the mold

Fig. 9.4: Place the PF in the mold sequence



Mold
Close
Mold
Open
Cores move in
Signal 2
Cores move out
Signal 2

Fig. 9.5: Mold pressing program sequence.

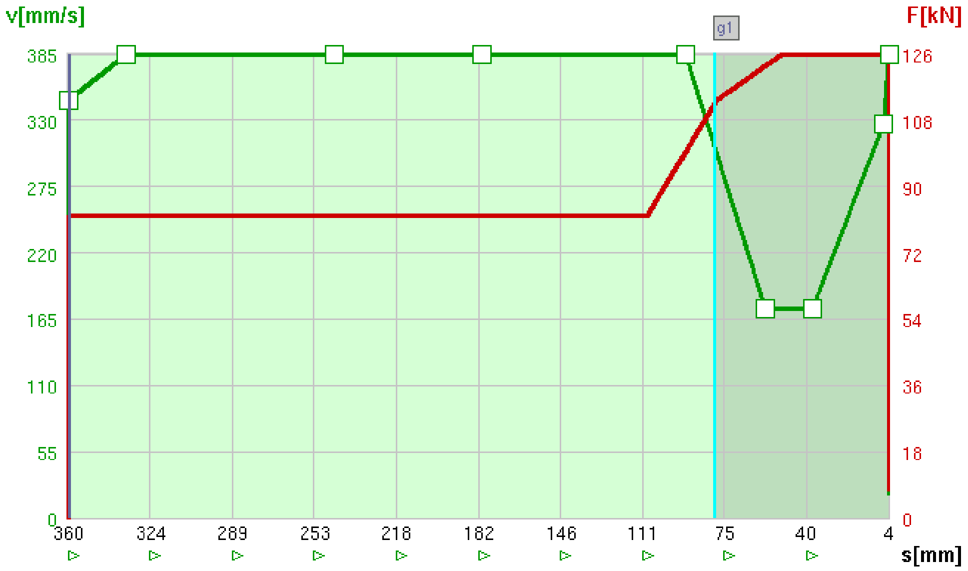


Fig. 9.6: Press speed and force graph

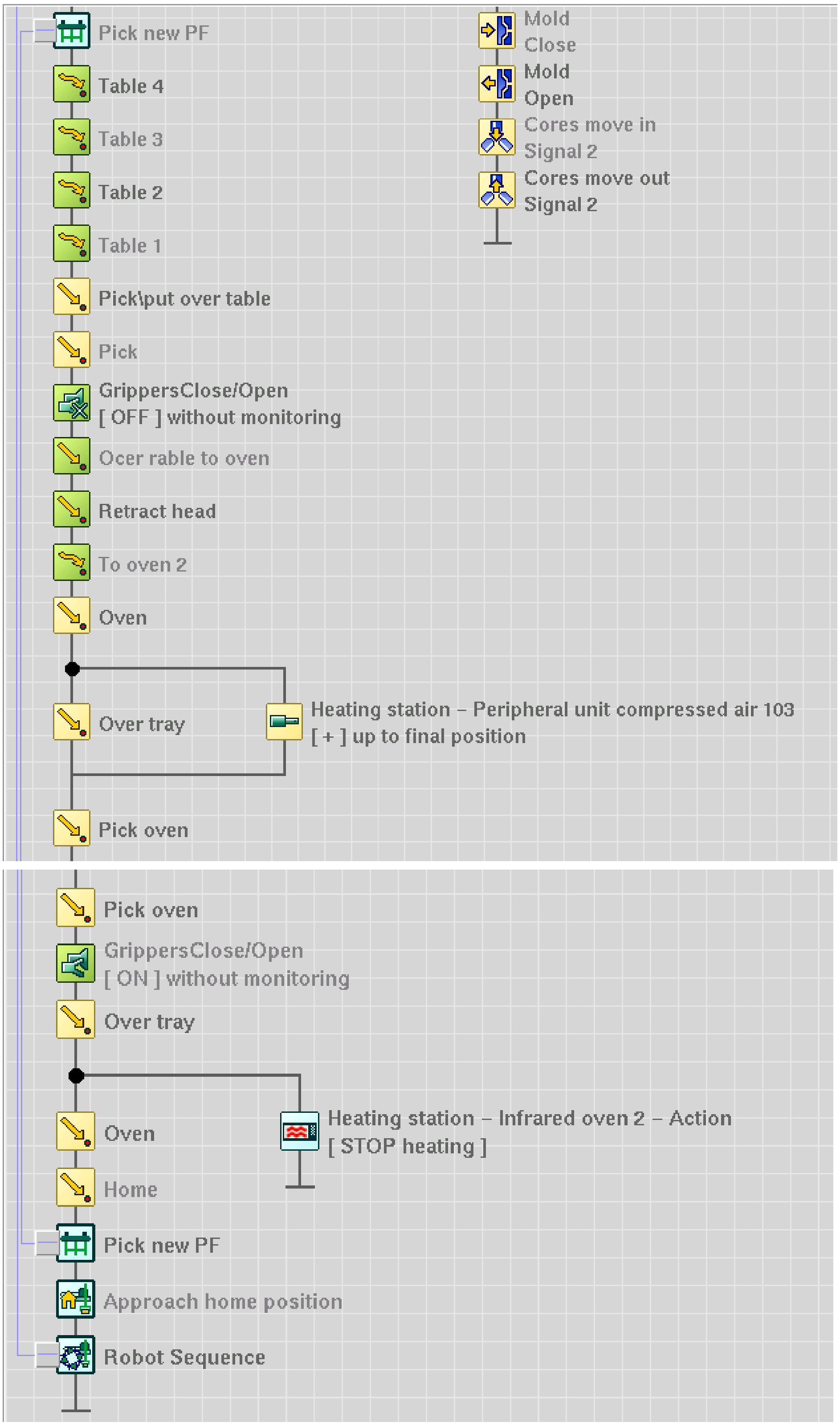


Fig. 9.7: Picking new PF and lay it on the oven

10 Statement of academic honesty

I hereby declare to the best of my knowledge that this thesis contains no material previously published or written by any other person. The work submitted in this thesis is the product of my own original research, except where I have duly acknowledged the work of others.

City, Date	Signature