Metropolia

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Mould Design for Composite Body Structures

Helsinki Metropolia University of Applied Sciences
Bachelor of Engineering

Automotive and Transport Engineering

Thesis

29.8.2012

Abstract

Author(s) Title Number of Pages Date	Aki Maksimainen Mould Design for Composite Body Structures 33 pages + 3 appendices 29 August 2012
Degree	Bachelor of Engineering
Degree Programme	Automotive and Transport Engineering
Specialisation option	Automotive Design
Instructor(s)	Harri Santamala, Project Manager

This Bachelor's Thesis was done for the Metropolia University of Applied Science's Concept City Car Project, funded and initiated by TEKES, the Finnish Funding Agency for Technology and Innovation, in the aim of designing and producing a lightweight vehicle for urban environments using bio composites in the body of the vehicle and having an engine that uses the next generation biodiesel as its fuel. This graduate study is but one of many done for this project, one of them being the foundation of this. The resulting product is to be unveiled at the Geneva Motorshow in spring 2014.

The aim of the study is to design and produce the moulds for the Concept City Car vehicle, using readymade surface models, done for another thesis, as the basis. The key points being the designing of the separable mould frame for the large roof and side panel assembly, the designing and production of the mould blanks and the designing of the required inserts. The biggest problems in the design process were the ever changing surface model designs, which lead to either to the need of redesigning the parts or redoing them completely.

The goal of the study was met in the sense of completing the mould designs and finishing the manufacturing of the moulds. In the process of making the study, it became clear that when designing large separable moulds, the manufacturing process has to be taken into close consideration; otherwise the assembling process could be problematic to say the least; the simpler, the better.

Keywords	Concept City Car, mould, design, composites

Metropolia

Tiivistelmä

Tekijä(t) Otsikko Sivumäärä Aika	Aki Maksimainen Mould Design for Composite Body Structures 33 sivua + 3 liitettä 29 elokuuta 2012
Tutkinto	Insinööri (AMK)
Koulutusohjelma	Auto- ja kuljetustekniikka
Suuntautumisvaihtoehto	Tuotetekniikka
Ohjaaja(t)	Projekti-insinööri Harri Santamala

Insinöörityö toteutettiin osana Metropolian kestävän kehityksen kaupunkiautoprojektia, TEKESin ja muiden yhteistyökumppaneiden avustamana. Projektin tarkoituksena on suunnitella ja rakentaa kevyt kaupunkiympäristöön soveltuva ajoneuvoprototyyppi, joka käyttää polttoaineena seuraavan sukupolven biodieseliä, kantavissa rakenteissa biokomposiitteja ja ajoneuvon sisustassa biomateriaaleja. Ajoneuvoprototyyppi on tarkoitus esitellä Geneven autonäyttelyssä keväällä 2014.

Tämän insinöörityön tavoitteena oli suunnitella ja valmistaa prototyyppiajoneuvon komposiittirakenteiden muotit, toista insinöörityötä pohjana käyttäen. Päätavoitteena oli suunnitella jaettava muottirunko isoille kylki- ja kattopuoliskoille, pienempien muottiaihioiden suunnittelu ja valmistus ja tarvittavien inserttien suunnittelu. Suurin ongelma insinöörityössä oli jatkuvasti muuttuvat ajoneuvon korin pintamallit, joita käytettiin muottisuunnittelun pohjana, minkä takia monia muottimalleja piti muuttaa tai jopa tehdä kokonaan uudelleen.

Työn tavoite saavutettiin, sillä muottien ja muottirungon suunnittelutyö ja valmistus on saatu päätökseen. Insinöörityötä tehdessä selvisi, että suuria, muottirungon vaativia muotteja suunniteltaessa pitää ottaa tarkasti huomioon valmistusprosessit, jotta valmistus olisi mahdollisimman helppoa tai edes mahdollista. Mitä yksinkertaisempi konstruktio, sitä helpompi se on toteuttaa.

Avainsanat	Concept City Car, muotti, suunnittelu, komposiitit

Contents

1 Introduction

This graduate study was done for the Helsinki Metropolia University of Applied Sciences' Concept City Car Project. The Concept City Car Project was initiated by TEKES, the Finnish Funding Agency for Technology and Innovation, for the aim of designing and producing a practical, premium class and relatively small car for urban environments while emphasizing the use of bio composites and bio fuel. A car designed with sustainable development in mind. The project started in fall 2010 as a part of a CDIO-project course in which the students were to come up with car concepts for different customer types, their lifestyles and needs. The customer then proceeded to choose one of the concepts. But due to the customer's dissatisfaction, the initial concepts were scrapped and new ones were planned. Later, two new concepts were created and from them, one concept was chosen to be the basis for the actual city car. A design goal was set to have a hybrid composite monocoque body, using bio and carbon fibre. The reason for this is to highlight green values and to search for new applications and uses for bio-composites.

1.1 Goals

The aim of this graduate study is to design and produce the mould frames and moulds for the composite body parts of the Concept City Car, the main focus being on the supporting structures of the vehicle. The mould designs are based on the CAD surface models done for another graduate study. Another goal is to try different laminating techniques on the finished moulds; the laminating techniques being pre-preg and vacuum injection.

1.2 Why Green Values?

In future motoring has to be more and more environmentally friendly regarding the production and the usage of automobiles. At the moment the main focus is set on recyclability. A good example of this is a directive which took effect in the year 2000, which determines that at least 95% of the parts of a car have to be recyclable by the year 2015. In reality, only 25-40% of the parts are made from recycled or renewable materials. In future the main challenge for the automotive industry will be the increasing use of said materials. In regards to the usage of automobiles, regulation has already forced the use of recycled and renewable fuels, also known as biofuels.

As the environmental awareness is increasing, the automotive industry has woken up to study the carbon footprint of the total lifespan of a car. According to them, a car's production carbon footprint is about 5-10% from its total carbon footprint. Renault has announced that, in the cars that they produce, the average carbon footprint from the production and the delivery is about 6,6 tonnes. If a car produces 167 grams of carbon dioxide per kilometre and the car is driven 15 000 kilometres annually for 10 years, then the carbon footprint from the usage of a car can be approximated to 25 tonnes. Using these calculations, the carbon footprint is about 20% from the total carbon footprint of a car. Regardless of the differences in the results, both values indicate that the biggest portion of the motoring carbon footprint comes from the usage; from the fuel consumption. Considerable improvements can be made in fuel consumption by developing engine technology. One other important factor in reducing fuel consumption is the weight of the automobile. Therefore the growing trend in automotive industry is to reduce the mass by focusing on light and environmentally friendly construction techniques. [1;2]

2 Theoretical Framework

This chapter describes the theoretical background of the study. A brief description of moulds in general is given and the different kinds of moulding techniques are introduced. Also, information about the materials used in the making of the moulds and the laminated parts is given, as well as about the manufacturing processes used in this study.

2.1 Moulds

A mould is a block, or a series of blocks, fashioned into a wanted shape and then used to make a part by either making a cast, by filling it with a liquid like material and then the material will set in the mould, adopting the shape of the mould in the process, the material can vary from molten metal to glass, or by laminating on it, commonly using plastics, wood or fibre-reinforced composite materials.

There are many kinds of different moulding techniques, all designed for a specific purpose and materials. Some of the techniques being vacuum forming, blow forming, compression moulding, injection moulding and laminating, to name but a few. For this graduate study the focus in on the laminating techniques. The laminating techniques used are pre-preg and vacuum injection laminating.

2.2 Materials

The fibre-reinforced composite materials used in this project are carbon fibre and bio fibre. Both of them have their own unique material properties. Carbon fibre has a high strength-to-weight ratio and good rigidity, making it optimal for supporting body structures under high stresses. Bio fibre has the advantage of reduced need of plastics, less plastic waste, a more environmentally friendly solution, and in some cases the mechanical properties of a structure can be improved with the use of bio fibres. [3]

> A composite material is a combination of two materials, with its own distinctive properties. Its strength or other desirable quality is better or very different from either of its components working alone. The principal attraction of composite materials is that they are lighter, stiffer and stronger than most other structural materials. They were developed to meet the severe demands of supersonic flight, space exploration and deep water applications but are now used in general engineering including automotive applications. Composite materials imitate nature. Wood is a composite of cellulose and lignin; cellulose fibres are strong in tension but flexible and lignin acts to cement the fibres together to create a material with stiffness. Man-made composites achieve similar results by combining strong fibres such as carbon or glass, in a softer matrix such as epoxy or polyester resin. [4]

A variety of mould block materials had to be used depending on the size of the structure, to reduce the production costs alternative material solutions had to be used for bigger moulds, the fibre and adhesive materials used for the structure in question, because different materials required different temperatures for the hardening process. For example the moulds that are designed for pre-preg require higher temperatures for hardening, thus the material has to be chosen according to its properties so that it can withstand the needed temperatures without deforming.

For this project, polyurethane and SikaBlock M650 were the materials of choice for the pre-preg parts, polyurethane for the larger moulds and SikaBlock for the smaller ones. Both of which can withstand the temperature of 80 degrees centigrade needed for the hardening process without softening, starts releasing gasses or deforming. Styrofoam and polyurethane were mostly used for the vacuum injection parts, because the manufacturing temperatures are much lower than for example pre-preg, therefore even Styrofoam is sufficient. The initial hardening happens in room temperatures and the final hardening in 50 degrees centigrade. Styrofoam cannot withstand the 80 degrees centigrade heat required for the hardening process of the pre-preg parts, thus it will start to soften and releasing gas, which makes the composite porous, weakening the structure.

2.3 Manufacturing Processes

A laminate is a material that can be constructed by uniting two or more layers of material together. The process of creating a laminate is lamination, which in common parlance refers to the placing of something between layers of plastic and gluing them with heat, pressure and an adhesive.

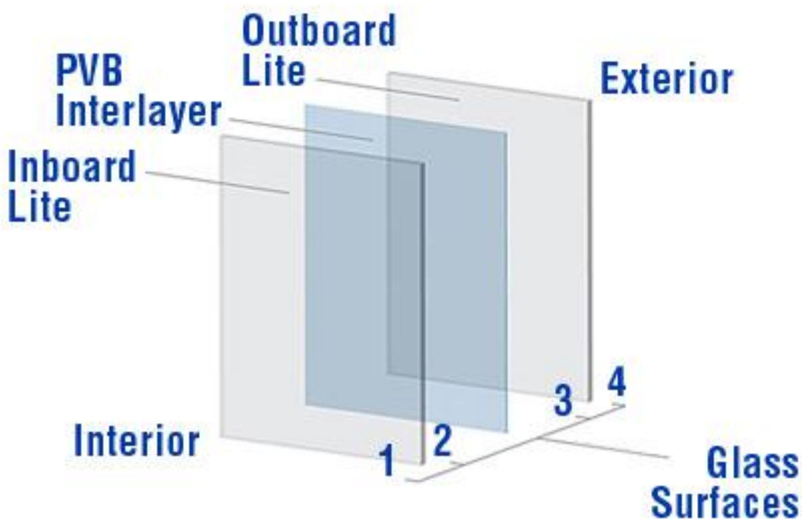

Figure 1. An illustration of a laminated glass, there is a plastic film in between two sheets of glass [5]

There are different lamination processes, depending on the type of materials to be laminated. The materials used in laminates can be the same or different, depending on the processes and the object to be laminated. An example of the type of laminate using different materials would be the application of a layer of plastic film on either side of a sheet of glass, which is a technique used to make vehicle windshields (cf. Figure 1).

3 Project Description

This chapter describes what was done in this graduate study, the goals and the different designing phases leading to the goals, what had to be taken into consideration during the said phases and also the manufacturing processes used.

3.1 Separable Mould Frame

The design and the sheer size of the side panels (cf. Figure 2) makes it necessary to use a separable mould, a mould consisting of two parts. A frame had to be designed so that the separation would be possible and that the frame would be stiff enough to keep its shape to keep the production quality satisfactory. Otherwise there could be problems while assembling the monocoque body, if the finished body panels would be too deformed. The bigger challenges with the frame design were to optimize the size of the frame to be large enough to house the mould blocks, but small enough to fit into the oven where the curing of the resin happens, also designing it in such a way that it would be as easy as possible to mount the mould blocks in place.

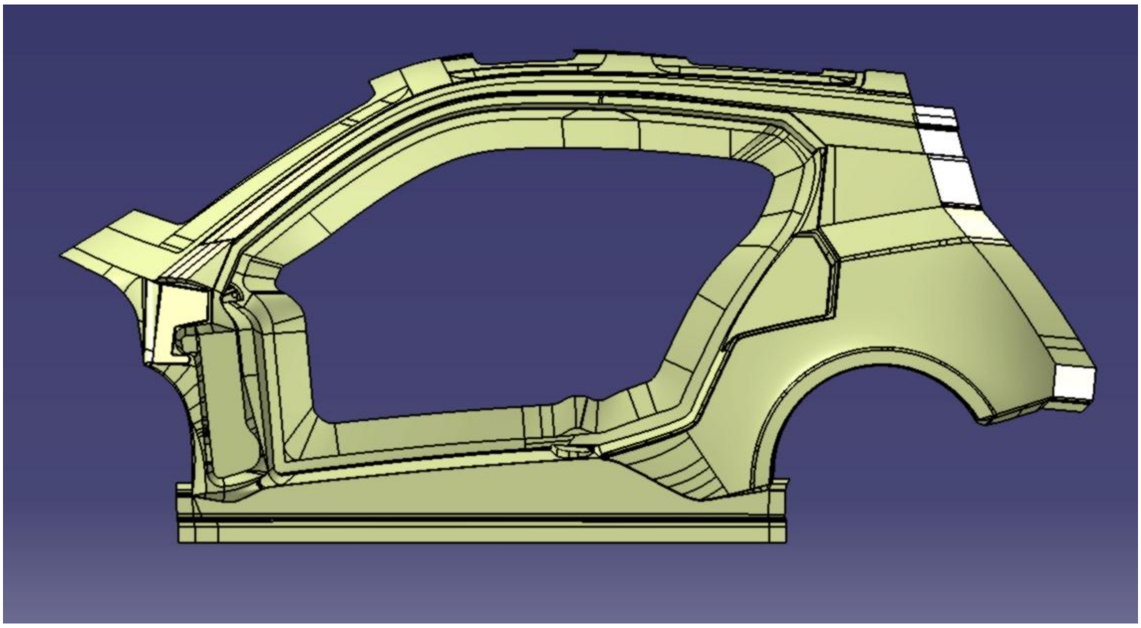

Figure 2. Side panel with added flanges

The designing of the mould frame began from a simple wireframe model (cf. Figure 3) to set the approximate size of the frame. The basic idea was to have a frame that creates flat planes following the shape of the body panels so that the mould blocks can be mounted on them. This is necessary because the polyurethane blocks are not flexible. Once the initial approximation was done, the modelling of the actual frame began.

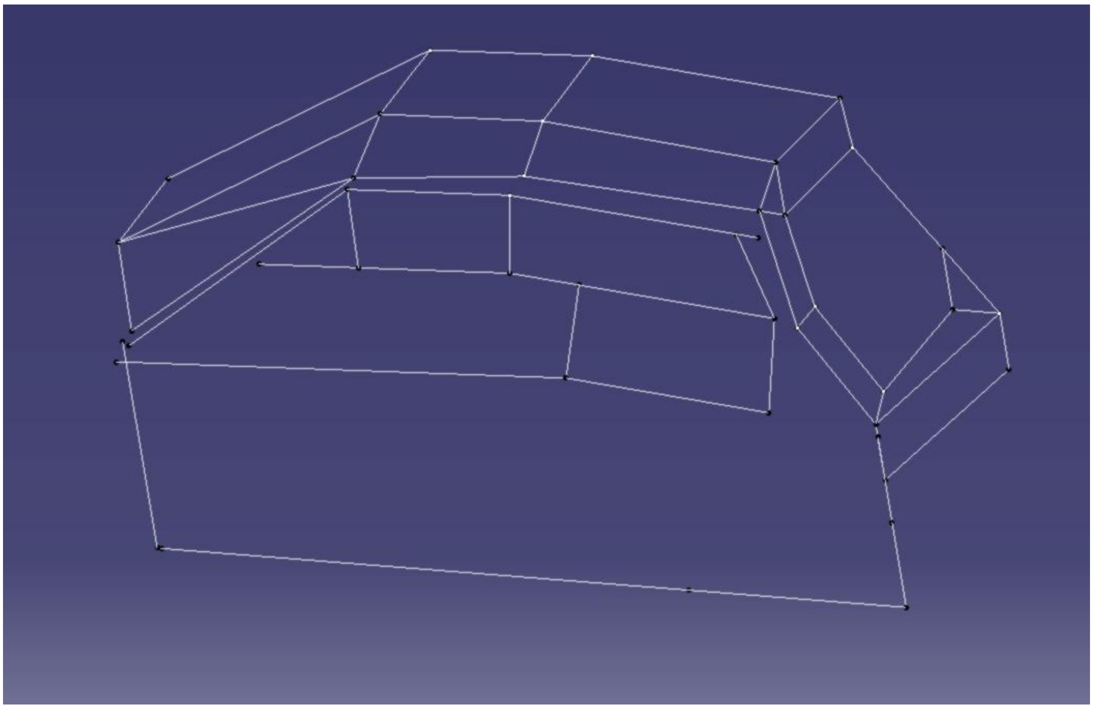

Figure 3. Initial wireframe model

The size of the rectangular profile steel tubes used to build the frame was set to 40x40mm and the thickness of the plywood panels, which will work as the base for the mould blocks, to 15mm. With this information an initial design was created (cf. Figure 4).

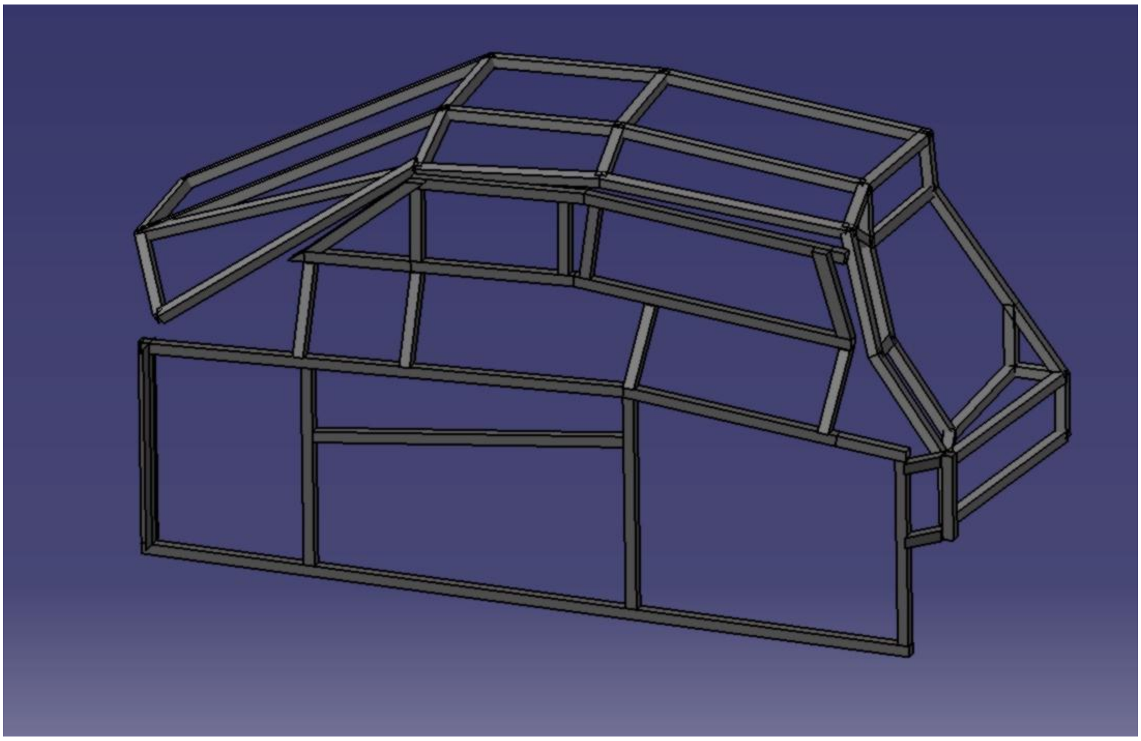

Figure 4. Initial frame design

This design was deemed too complex for the actual manufacturing process, so the next step was to simplify it while keeping in mind how easily it could be manufactured and also how many mould blocks would have to be used in the manufacturing stage, to keep the manufacturing costs as low as possible.

The next design (cf. Figures 5,6) was made less angular and also the spots with multiple cut angles were removed to simplify the manufacturing process. Although this increased the number of blocks needed, the change was necessary to make the manufacturing of the frame possible.

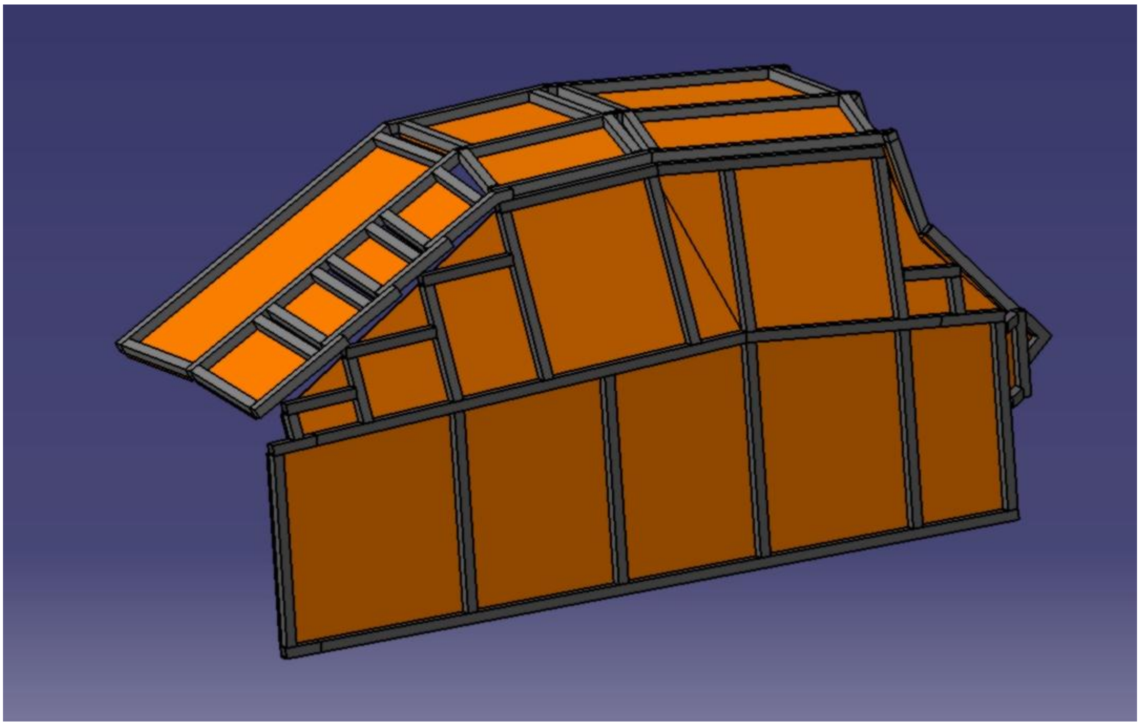

Figure 5. Final side frame design with plywood panels

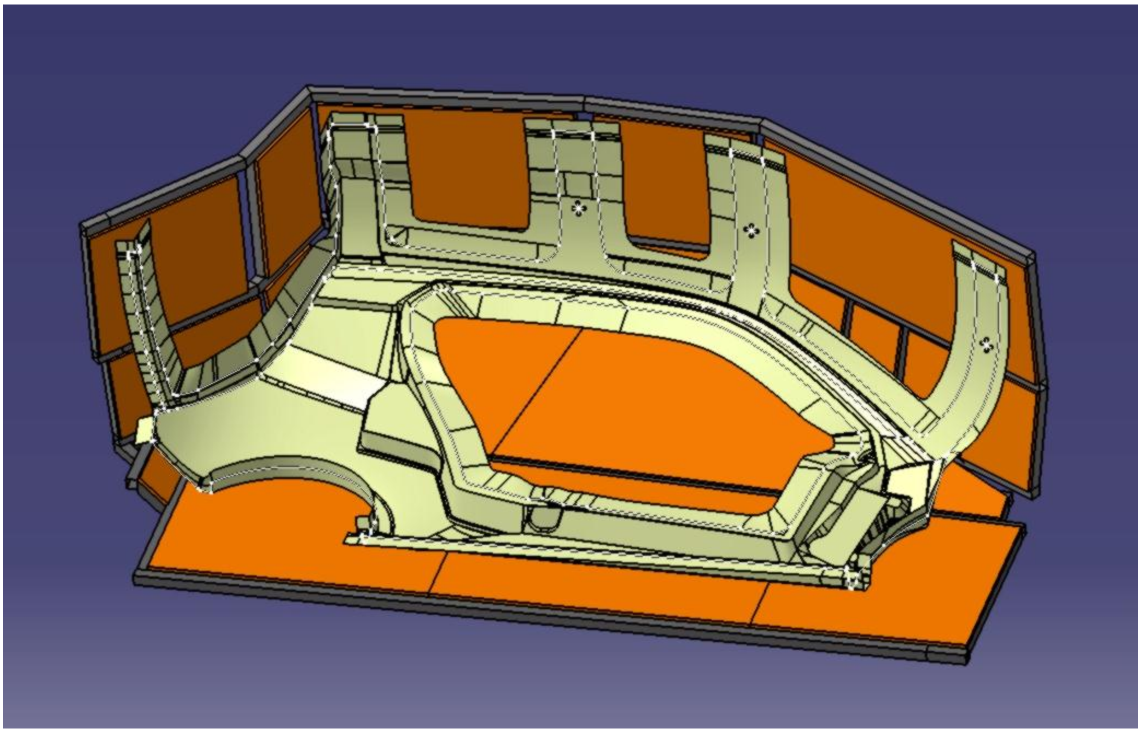

Figure 6. Side panel, with the cutting lines and the calibration points, inside the frame

This design was sent to Scan Mould to get their approval on the design. Once the approval was received, the manufacturing process began and an approximation was made for the amount of polyurethane blocks and SC 175 Epoxy extrudable paste needed for the moulds. The finished mould frames were delivered to Scan Mould and the assembling of the mould blocks was performed there.

The blocks will then get rough machined into the correct shape; the roughing is done in such a manner that the machining will be done deeper than where the surface of the actual part should be. The reason for this is that a special epoxy paste will be applied on the roughed stock, which will get roughed and fine machined after to get a good surface quality for the actual laminating process. Before the paste is applied, a layer of fiberglass will be applied and laminated on the rough stock. This is done to ensure the will keep its shape and it will stick to the rough stock. In the figure below (cf. Figure 7), one can see in principle how the different layers are stacked on one another.

Figure 7. The different layers of the mould

The same procedure is also done for the other bigger moulds that do not have a special mould frame, although the block material may vary.

3.2 Mould Designing

The mould designing process began by dividing the body structure parts depending on where the moulds were supposed to be machined. Machining is the process of physically removing material from a block of material utilizing power-driven machine tools such as saws, milling machines and drill presses to achieve a desired geometry. Machining is a part of the manufacturing process of many metal products, but it can also be used on materials such as wood, plastic, ceramic and composites. The machines used for this project are automate milling machines called CNC machines, the word CNC coming from the words computer numerical control. The machines are automated using CAD, computer-aided design, and CAM, computer-aided manufacturing. CAM being the program that produces the computer files which contain the machining path information. The information is then fed to the computer controlling the milling machine. Then the machine will execute the commands and machine the part in the given fashion. Machining can also be done with a manual milling machine (cf. Figure 8), but due to the complexity of the design, a CNC machine had to be used.

Figure 8. A manual milling machine [5]

The moulds for the smaller body structures were machined at the Metropolia University of Applied Sciences' Tikkurila's industrial design campus. The CNC milling machine at Tikkurila campus has 3-axis of movement, y-axis for diagonal movement, x-axis for lateral movement and z-axis for vertical movement. The moulds machined at Tikkurila were the supporting roof and floor beams of the vehicle.

Figure 9. 3-axis CNC machine [6]

The moulds for the larger and more complex body structures were machined at a company called Scan Mould which is situated in the city of Pietarsaari. Scan mould is one of the few subcontractors in Finland doing this kind of machining. The CNC milling machine at Scan Mould has 5-axis of movement, allowing it to rotate the tool in an angle, making it possible to machine more complex shapes, which would be impossible to make with a 3-axis machine. The moulds machined at Scan Mould were the inner and outer side panels, the bulkhead, the floor and the supporting beam for the rear compartment.

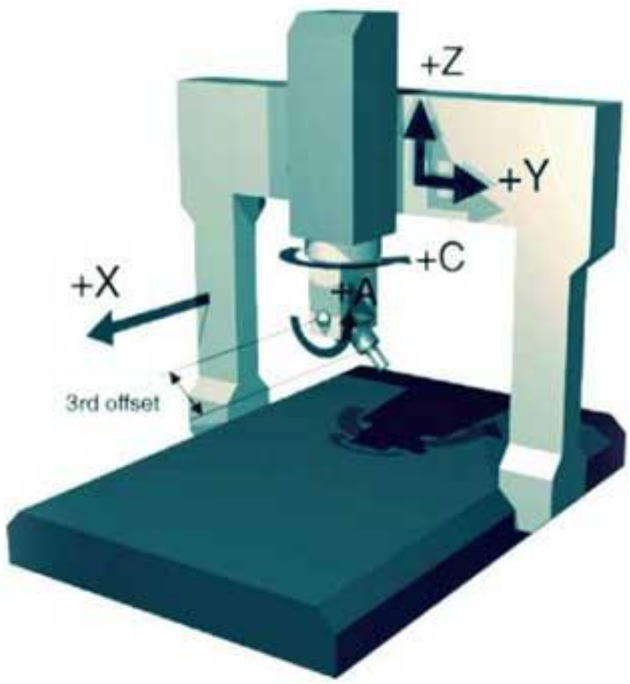

Figure 10. An illustration of a 5-axis CNC machine [7]

The mould designs themselves were based on the surface models done, for another graduate study, for the Concept City Car Project. The premade models had to be checked and fixed for any anomalies that could be present to make the model unsuited for the mould design, namely any shape or form that would make the removal of the part from the mould impossible (cf. Figure 11).

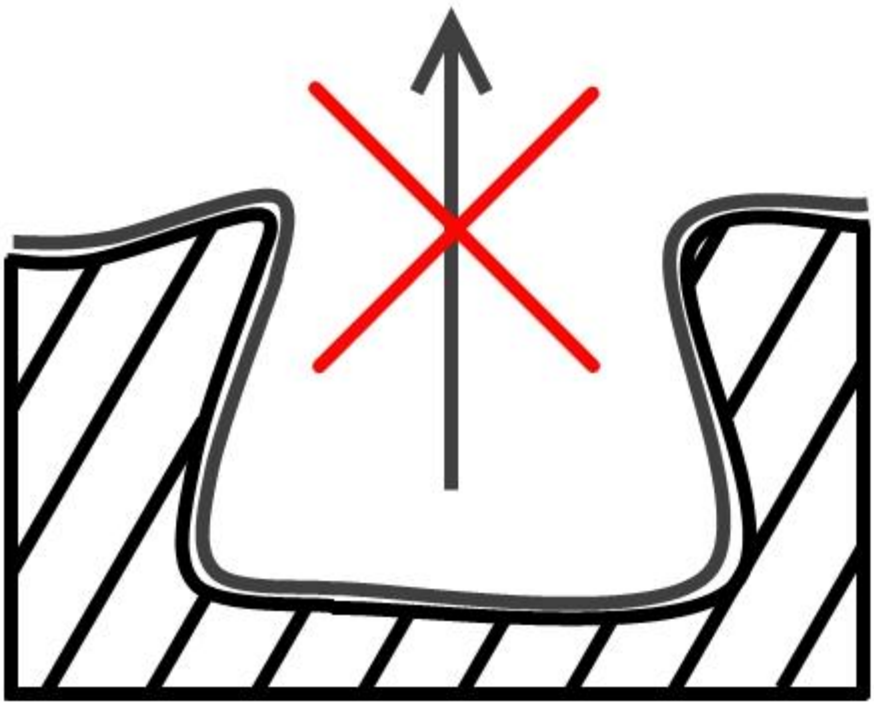

Figure 11. An example where the finished part would get stuck in the mould (the laminated part is in grey and the mould is in black)

A few other things that had to be done were to add the needed changes to the original model to suit our laminating purposes and the machining of the moulds as well. One of the changes being the addition of flanges to the original design. That means continuing of the surface tangentially along the edges of the model to give the part some extra laminating surface. This is done to make sure that the finished product has the same integrity all around. The reason for this is that the fibre fabric tends to unravel from the edges, making the structure weaker compared to the uniform structure in the middle. The design could be made without flanges if special made edge fabric were used, so that the laminating work can be made directly on to the edge of the part. This process requires an autoclave so it was decided not to use it in this project.

There were some differences with the addition of flanges. The smaller moulds have a smaller offset of the flange than the bigger moulds. The offset for the smaller moulds was set to around 20mm and from 60 to 100mm for the bigger ones (cf. Figure 12), the bigger moulds being more complex. The flange is there also to allow a more precise cut and therefore a better manufacturing quality for the edge of the part.

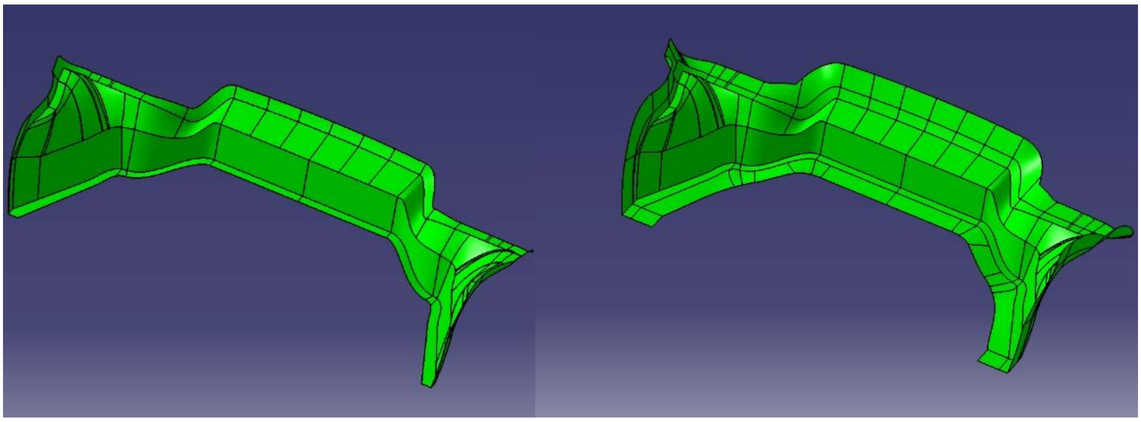

Figure 12. Before and after pictures, after flanges have been added

The next step was to round the sharp edges from the original models (cf. Figure 13). This is done to make the machining quality better. If a ball-headed tool is being used, the rounding happens no matter if the model has the roundings or not. Although, doing it this way will make the tool vibrate more and the quality will be worse than it would be if the rounding had been added during the design stage. The rounding was done with CATIA's shape fillet tool, with the same radius as the ball-headed tool being used for the machining. In some cases the shape of the edges were too complex to use CATIA's own rounding tool, so the area around the edge had to be cut out, to get the same approximate radius as the tool and then adding the rounded corner manually. Usually there is no difference whether to add the fillets first or the flanges. Sometimes it is easier to do the other first and sometimes it is not.

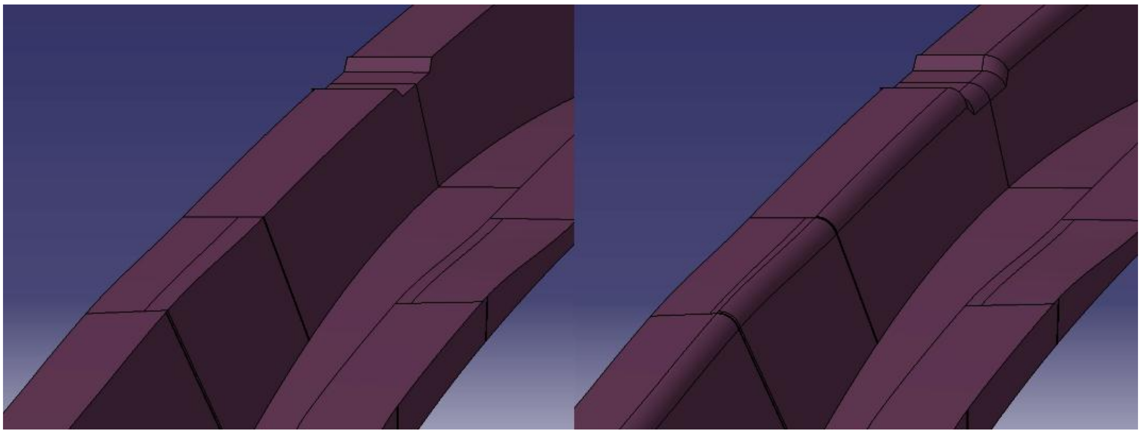

Figure 13. Before and after pictures, after shape fillet has been applied

For the moulds machined in Tikkurila, the mould blanks had to be modelled as well. The creation of the machining paths demanded it. The milling machine at Tikkurila campus has some limitations for the size of the blank that can be machined at one time, namely the z-axis being the limiting factor. It is not recommended to machine parts over 150mm high, because of the length of the tool and the limited movement area of the axis. So in some cases the blanks had to be designed to be machined in two, or even three pieces, and then later attached to each other. If a mould has to be machined in multiple pieces, additional calibration holes have to be added to the design so that the mould surfaces will be continuous.

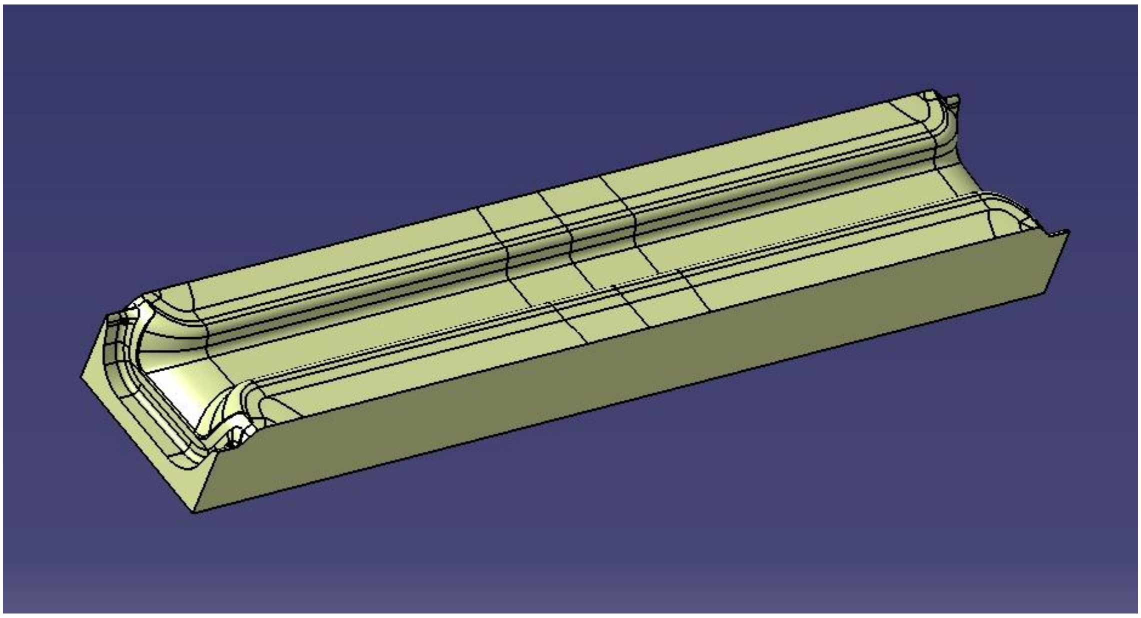

Figure 14. An example of a finished mould model for a floor cross beam.

The blocks used come in two different sizes, the length and width being the same, 1500x500mm, but in two different heights, 100mm and 50mm. To achieve the limit height of 150mm, one 100mm and one 50mm block has to be glue together. The design of the blanks was done with the dimensions in mind, to lower the use of excess material and thus lowering the production costs. So depending on the size of the original surface model, namely the height of the model, it is required to check from how many pieces the mould has to be machined. The easiest way to do this is to use the side profile of the model and see how high the part is (cf. Figure 15), and is it possible to machine it from one piece.

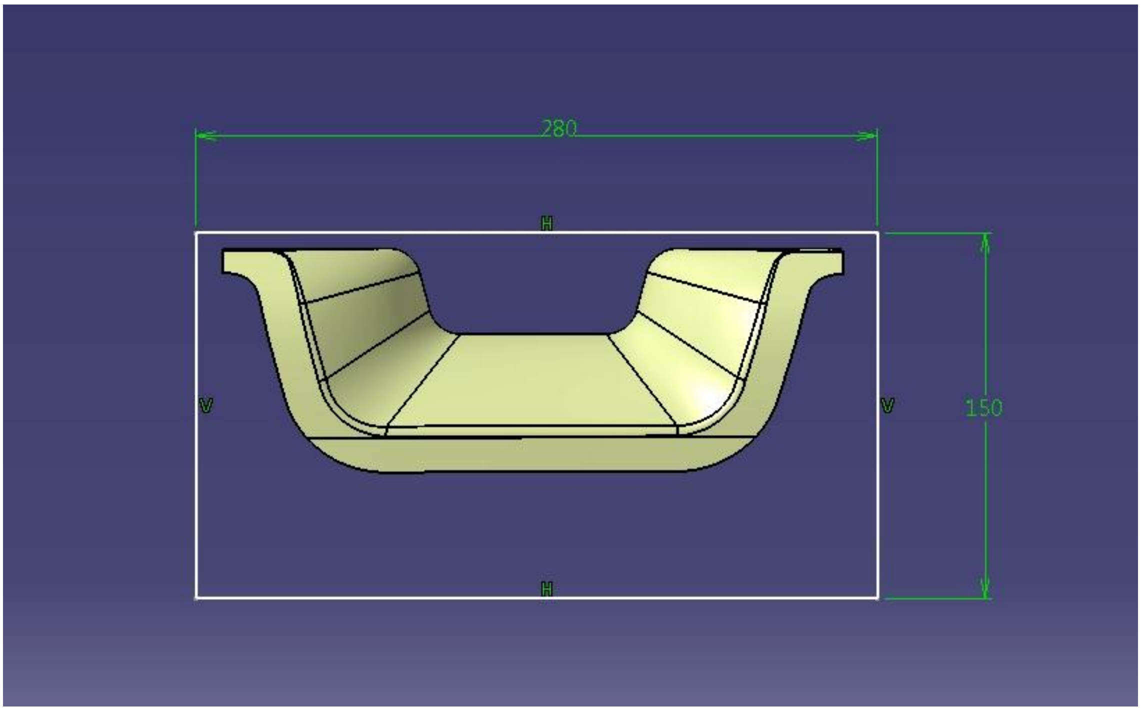

Figure 15. Fitting of the floor cross beam to the dimensions of the mould blank (side profile)

Once the size and the number of mould parts have been determined, the mould blanks will be modelled around the models with the flanges and fillets. In the figure below (cf. Figure 16), one can see a finished mould model which is done from two different parts, the line separating the parts can be seen in the middle, splitting the individual parts. Also, one can see the holes in each corner that are used to focus the parts in relation to one another to get a clean fit.

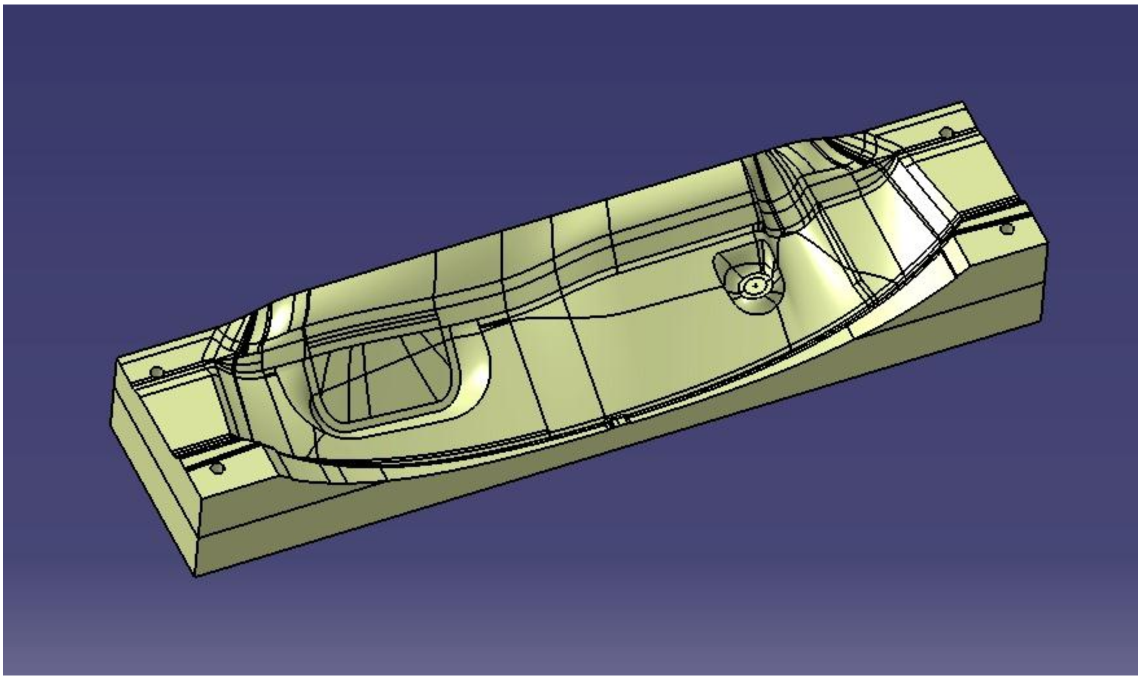

Figure 16. An example of a two piece mould (the holes, to set the mould halves firmly together, can be seen in each corner)

For the bigger moulds, only the flanges had to be added, because the machining was tasked for Scan Mould, and they would make the machining paths by themselves. Bu the actual part had to be marked without the flanges so that when the mould gets machined, a small groove will be machined around the actual part, making it easier to cut the flanges and getting the right sized part from the finished laminated structure. Also calibration points had to be marked alongside the larger parts, on the surfaces without sharp corners, so that the vehicle body assembly would be easier, getting the laminated parts in the right place. In the figures below (cf. Figures 17,18), One can see both the inner and the outer side panels with the cutting lines, in white, the flanges extruding from the cutting lines and also the calibration points, the cross marks alongside the surfaces.

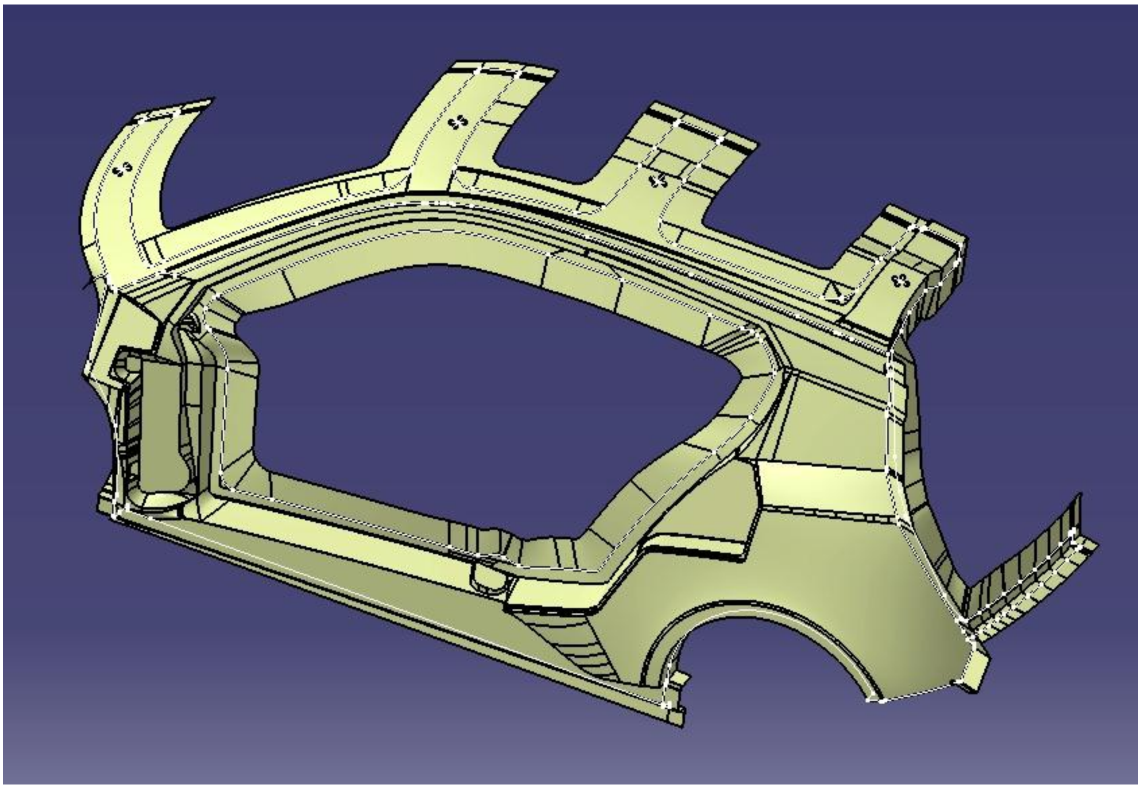

Figure 17. Finished outer side panel with calibration points and cutting lines.

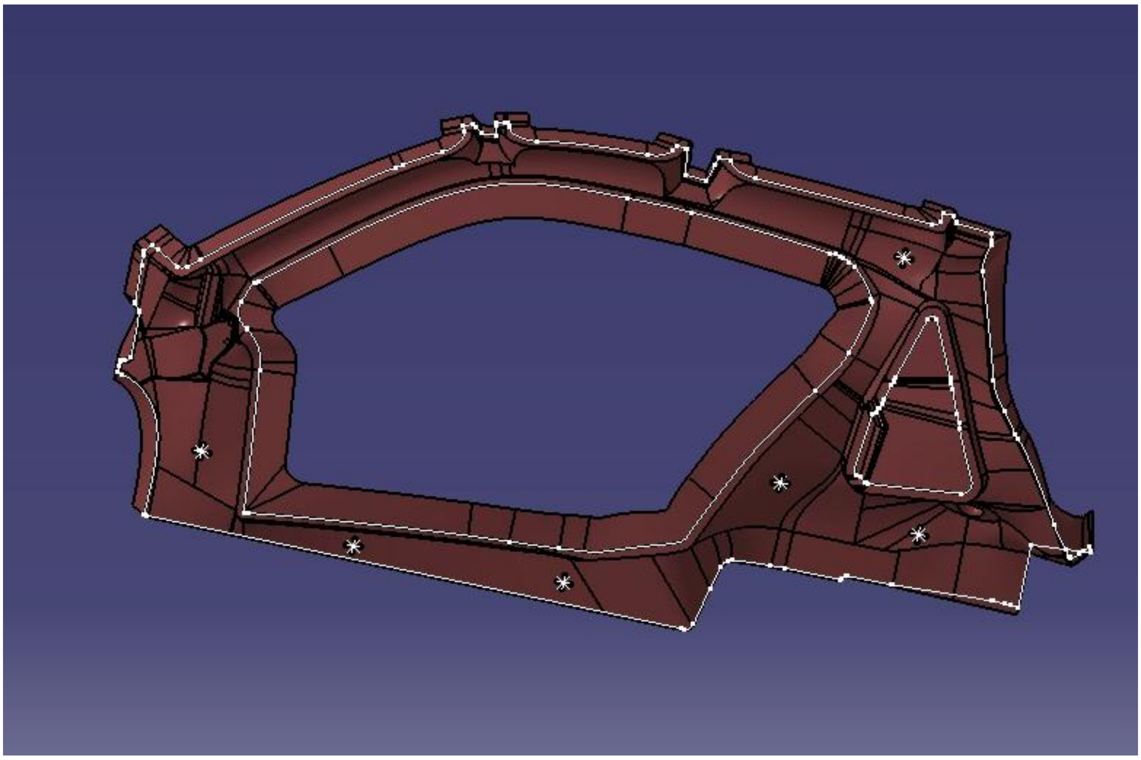

Figure 18. Finished inner side panel with calibration points and cutting lines.

The original floor model had to be cut to make room for the inserts. The shape of the floor was too complex to be made out of single mould. The mould would have gotten stuck in the mould without the inserts. The figure below (cf. Figure 19) shows the individual inserts, in different colours, and the floor mould part itself with the calibration marks, flanges and cutting lines.

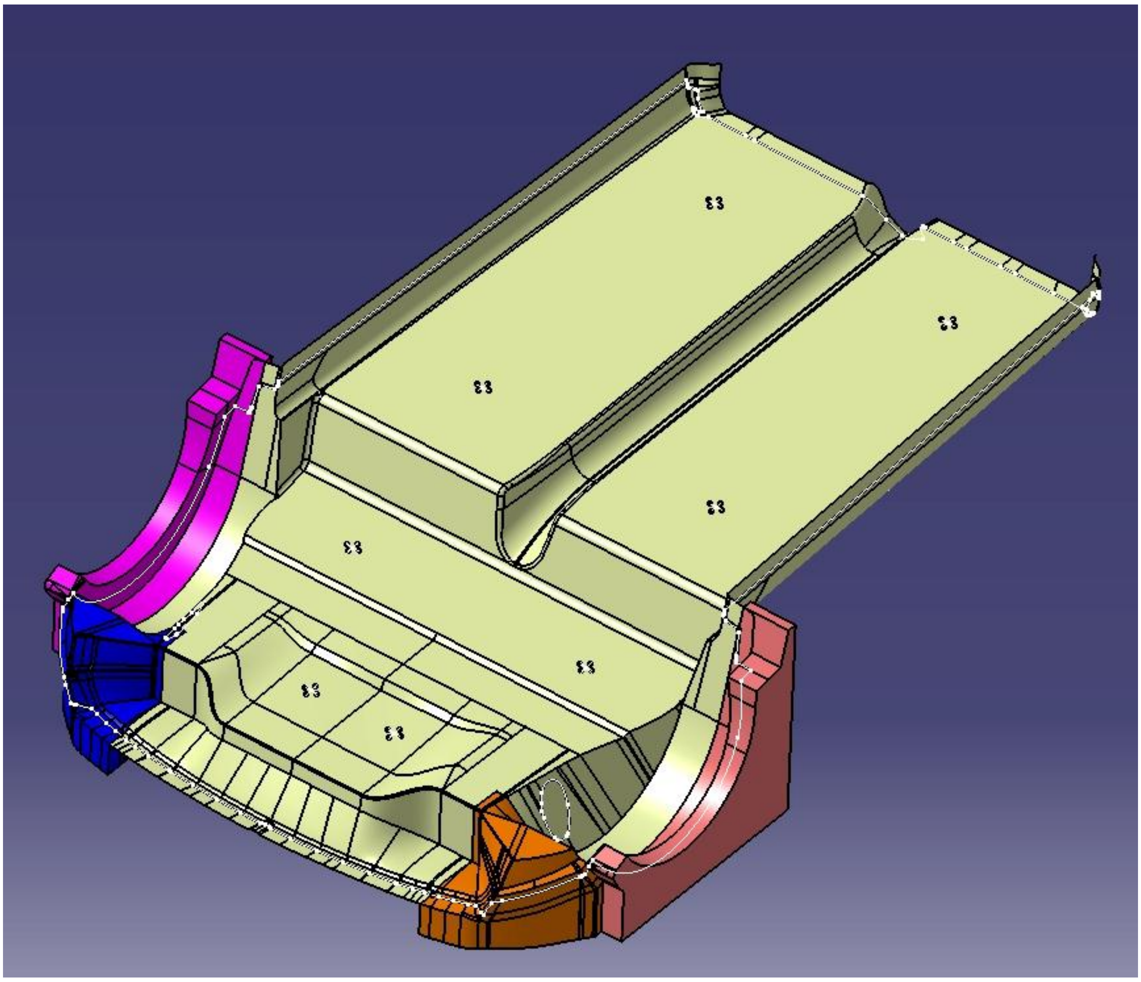

Figure 19. Floor-insert assembly with calibration points and cutting lines, the inserts are in different colour than the rest of the floor.

More information about the inserts is given in the next chapter, why are they used in the design and how will they enable the separation of the part from the mould.

3.3 Inserts

If there are areas in the part design that make it impossible to take the part out of the mould, the problem may be solved by adding inserts to the design. An insert is a separate mould part that will be loosely connected to the actual mould block, enabling an easy separation from the block. When the laminated part is taken out from the mould, the inserts will be separated from the block along with the laminated part, and the inserts will separated from it afterwards. After that the inserts are ready to be used again.

This technique was used for the floor part of the car. The rear fenders and the corners next to the fenders had to be done with inserts. Otherwise the mould block would have to be destroyed to get the finished part out. The individual inserts can be seen in the figure below (cf. Figure 20), the rear fender insert is on the right and the corner insert is on the left.

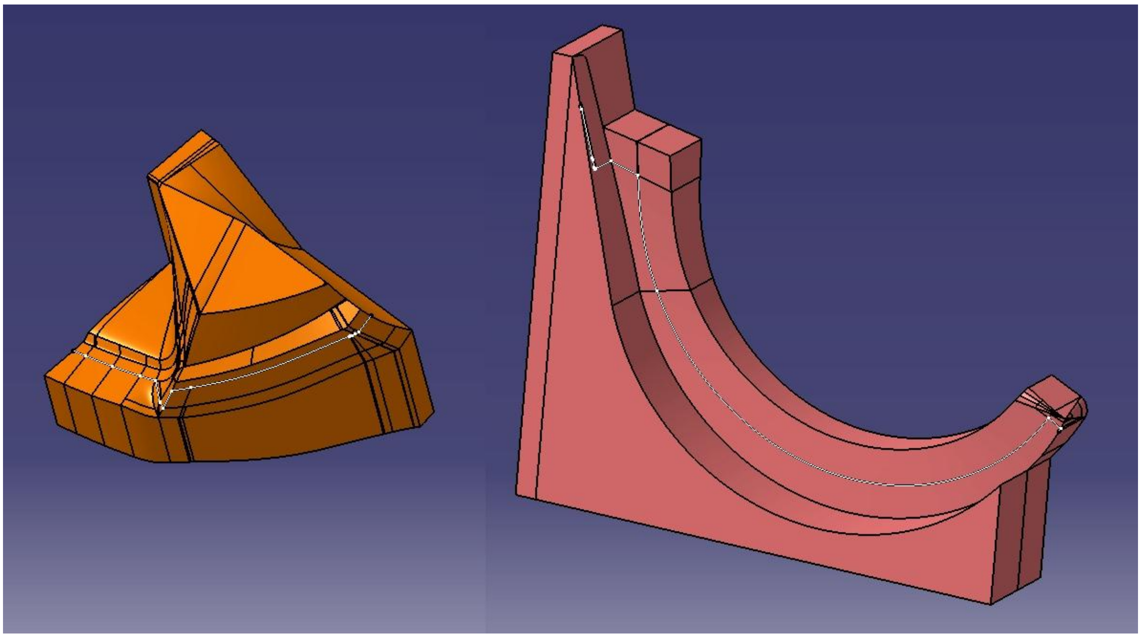

Figure 20. Right-hand side inserts separately with cutting lines

The inserts themselves had to be machined separately at Scan Mould, because the pieces were too complex for a 3-axis CNC machine.

3.4 Creating Machining Paths

Because the smaller moulds were machined at Metropolia UAS and not by a company, the machining paths had to be created. For that purpose, Catia V5R20 has an add-on called Catia CAM, Computer Aided Machining, which is designed for the purpose of creating said paths. The program itself has all the tools needed for roughing and finishing. But, only a few tools were needed for the parts used in this project, the mostly used tools being roughing and sweeping. The figure below (cf. Figure 21) shows the main window of the Catia CAM module, the tree for the machining operations, different parts and resources; and the tools for different machining operations.

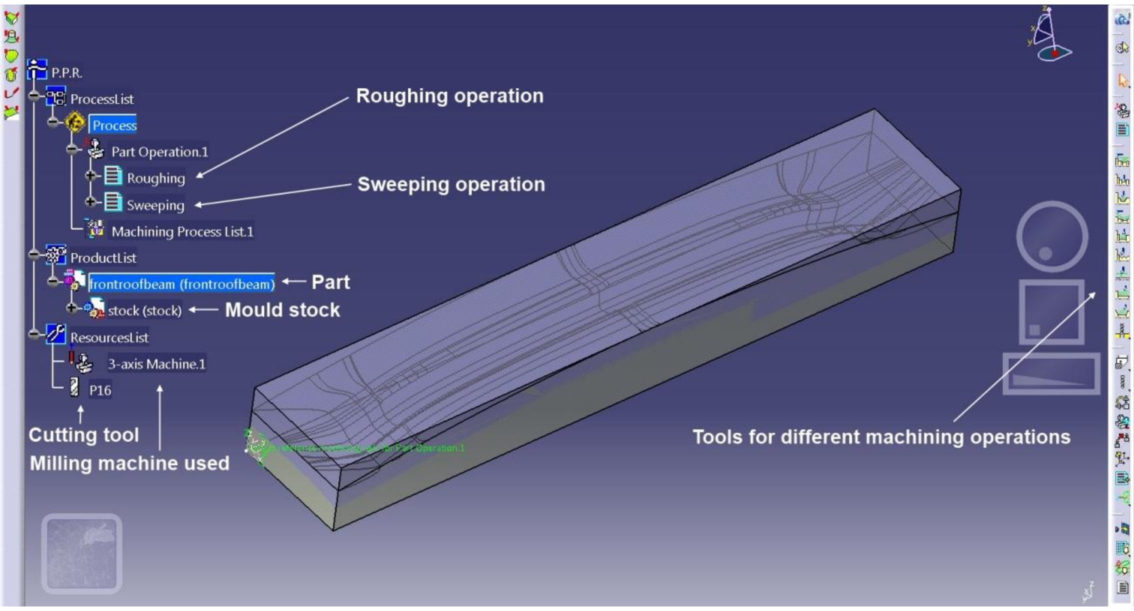

Figure 21. Catia CAM module

The Catia CAM module has a tree on the left side of the screen that shows the different machining operations tasked for the said part under the process tab, in this case, in the preceding figure, a roughing and a sweeping operation. These operations will be explained later in this chapter. Under the Product List one can find the individual parts used in the machining process, in this case, the model of the mould and the stock that will imitate the material block used for the machining of the actual part. Under the Resource List one can find the milling machine and the cutting tool(s) used for the machining. The toolbar on the right has all the different tools needed for different machining operations, whether it be roughing, sweeping or drilling.

For roughing, the machining offset is set to 0,5mm, so that there will be some excess material needed for the finishing. The offset means that the machine will not cut closer than 0,5mm to the actual part surface. Roughing is the stage in which the machine removes most of the excess material as fast as possible, making the outcome very rough. The cut-depth and speed varies depending on the material, but for SikaBlock M650 the cut-depth can be set to 10mm, rotation speed to 18000 r/min and cutting speed to 2400 mm/min. Therefore the machine can remove a lot of material in a very little time without excessive amount of vibration. If the configurations are too high for a material, there is a risk of breaking the milling tool. The figure below (cf. Figure 22) shows the mould stock after the roughing simulation is complete. The simulation shows the complete roughing sequence, the tool paths, so the user can check for any anomalies or errors, so that they will not happen when the actual part is machined. It can also be used for fine tuning the settings so that the roughing could be done faster.

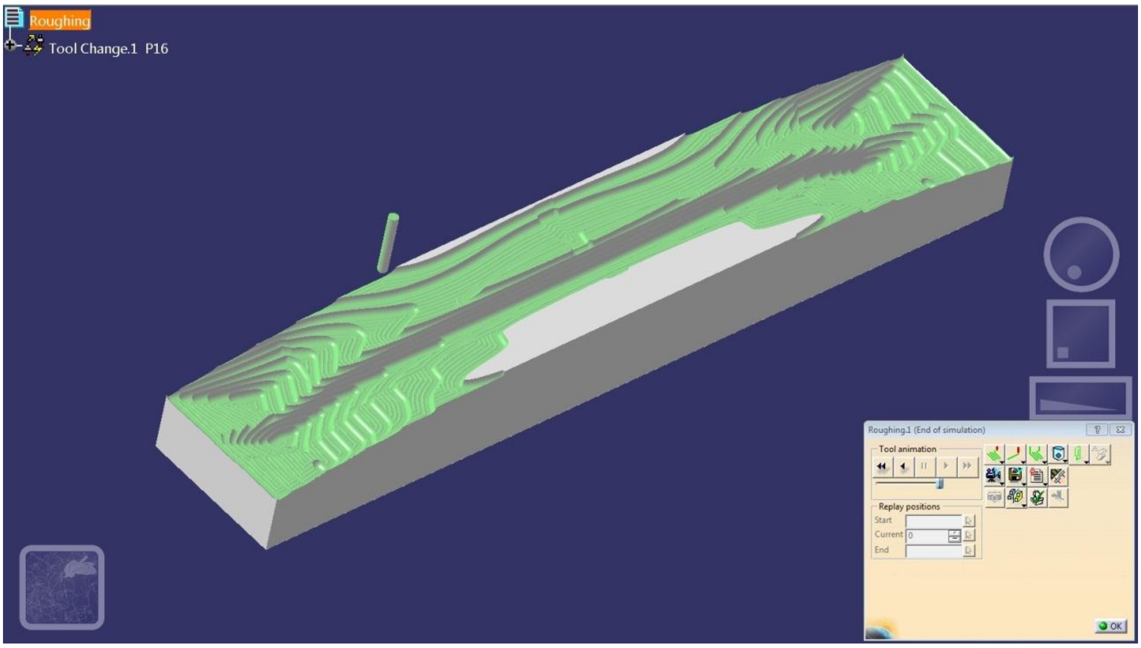

Figure 22. Mould stock after roughing simulation

For finishing, the machining offset is set to 0mm, so that the size of the mould will be correct and so that the finish will be clean. The Catia CAM tools used for finishing were mostly sweeping and z-level. Sweeping has a variety of tool paths that it can create, but for beams the best way to get a good surface quality was to use a zigzag pattern across the beam surface. Because of the fact that the machining tool makes a better finish when it is moving cross the slope and not alongside with it, if it goes alongside, small steps will be created on the slope, because of the set cut depth and of course depending on what kind of milling tool is being used. In the figure below (cf. Figure 23), one can see the results of a sweeping simulation. The results can be used for fine tuning for either changing the machining direction or using a different finishing operation to get a better surface quality.

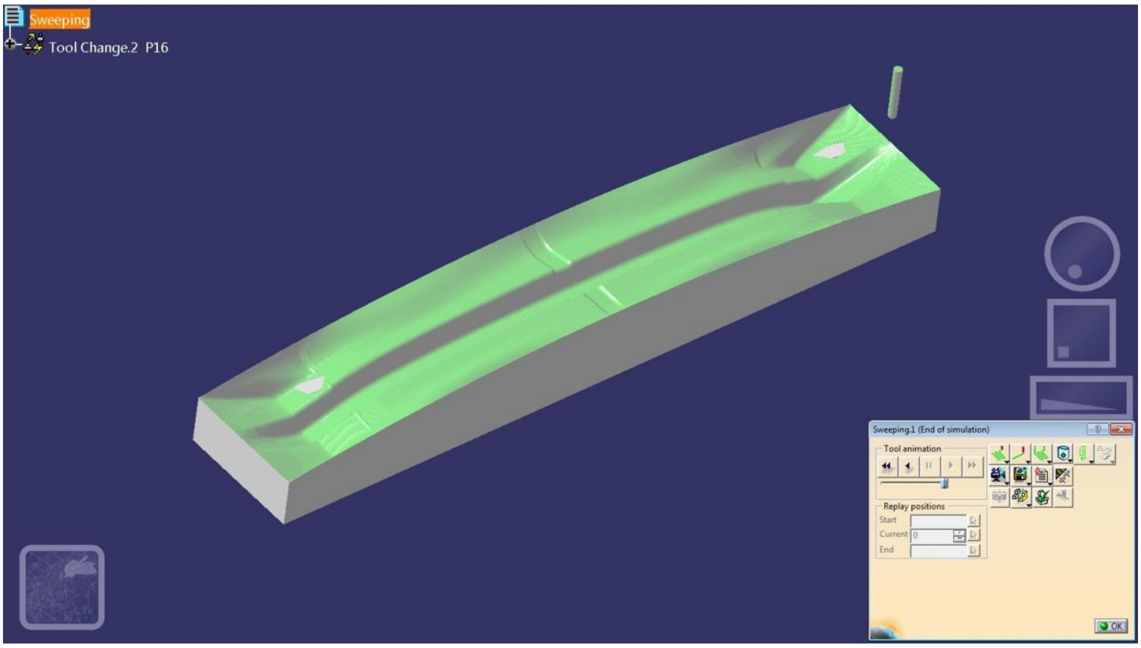

Figure 23. Mould stock after sweeping simulation

In some cases, because the beams are not just simple, straight and uniform surfaces, small steps would be created on the surface of the slope, but there are ways to get around it, either making another sweeping in the opposite direction or just grinding them off with sandpaper. Z-level is another tool for finishing. It is a tool that sweeps around the part one layer at a time, starting from the top and finishing at the bottom. The height of the step can be adjusted to make a better quality finish, but the machining time will increase as the machining quality is set higher.

3.5 Machining

The machining of the smaller moulds was done at Metropolia University of Applied Science's Tikkurila campus. The block material used for machining was SikaBlock M650, which is polyurethane. It is much denser than the polyurethane used for the bigger moulds. The machining process started by selecting the right sized stock block for the part getting machined. The stock will be cut into the right size and then it will be attached to the machining table with double-sided adhesive tape. The tape is sufficient to hold the stock in place for this kind of material. Then the CNC machine will have to be calibrated according to the position of the stock. The tool will be moved to the upper right corner of the stock and that point will be the zero point for x and y-axis.
The z-axis will be calibrated using a special tool that will be laid on the machining table and then the tool is slowly lowered on it. That way the machine will know the height of the table. After the calibration, the machining path information is fed to the computer controlling the CNC machine and the position of the tool will be double checked relating to the machining paths. If everything seems to be in order, the machine is set on. It is usually a good thing to supervise the beginning of the machining, to check if the tool will meet the stock in the right spot, and if it will start doing the correct path. It is recommended to do the approach of the tool with lowered tool speed to ensure that nothing goes wrong.

3.6 Laminating

Pre-preg, pre-impregnated, also called the dry layup method, is a term used for a fibre-reinforced composite material, where the adhesive, namely epoxy, is already present in the fibre fabric. The pre-preg materials are mostly stored in cooled areas because of the fact that the hardening process of the adhesive is usually done by heat. Hence, the structures made using this technique require an oven. The pre-preg fibre material used in this project is carbon fibre and the moulding technique used is vacuum bagging. This kind of moulding is well suited for relatively low production output and when only a few copies are needed.

The process of pre-preg laminating starts with the application of the release agent on the mould, so that the finished product will not stick to the mould. Then the pre-impregnated carbon fibre fabric will be laid on the mould in such a way that the fabric will follow the shape of the mould, sometimes the fabric has to be cut in order to get the fabric to follow certain shapes and then extra fabric needs to be applied in order to fill in the gaps. Usually the next step would be the adding of resin into the fabric, but since the fabric is already impregnated with resin, this step is unnecessary. The assembly is then placed in a vacuum bag to cure. The vacuum bag is needed to keep the fabric pressed on the mould, to keep the right shape, and also removing all the small air bubbles in the material that would reduce the strength of the structure. Then the vacuum bag is placed in an oven to cure. The curing process of the pre-preg material used in this project needs the temperature of 80 degrees centigrade and it has to stay in that temperature for a time depending on the size and the thickness of the part. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup, wet layup meaning that the fabric and resin are added separately. In the figure below (cf. Figure 24), one can see the process of laying pre-preg carbon fibre fabric on a finished mould.

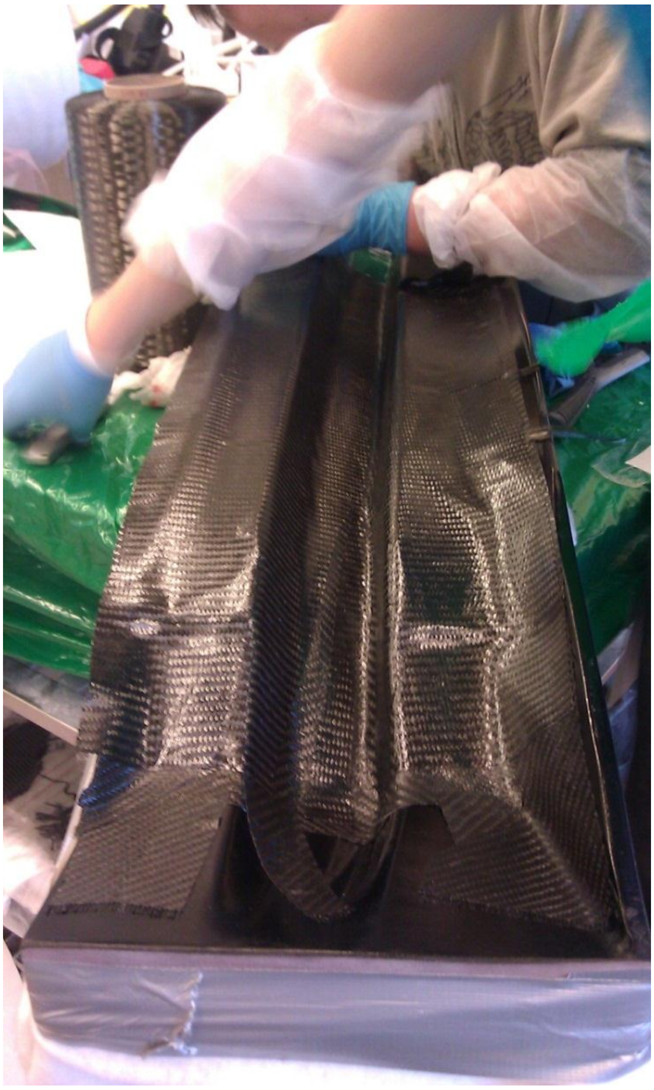

Figure 24. The laying of pre-preg carbon fibre fabric on a mould

In the figure below (cf. Figure 25), one can see the different stages of laying pre-preg carbon fibre on a mould. In the first stage, a certain number of layers are applied in a zero angle, meaning that the carbon fibre weave is applied in a way that it is aligned with the mould, and strands of carbon fibre threads are applied in between each layer, which can be seen in the figure as black dots between the layers, this is done to ease the flow of resin within the layers. In the second stage, the mould is vacuum bagged, can be seen as the green line surrounding the mould and the carbon fibre layers in the second figure, and the layers are pressed against the mould to remove all the air from between the layers. In the third stage, another set of layers are added but this time in a different angle, usually in a 90 degree angle, sometimes in a 45 degree angle, to make the structure stronger in every direction. After the third stage, the stage 2 is repeated and if necessary, more layers are added, but this time again in a zero angle. When the required thickness is achieved, the mould is then vacuum bagged and put in an oven to cure.

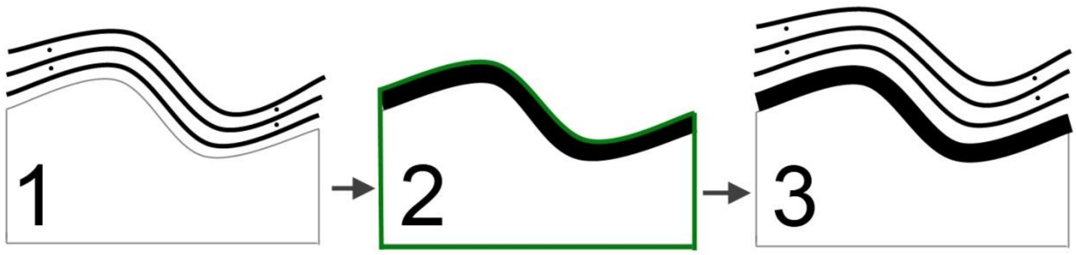

Figure 25. A diagram illustrating how the fabric layers are laid on the mould

The wet layup method used in this project is called vacuum injection. It is a technique where one has the fibre fabric and the resin separately. This process needs a vacuum bag with two hoses going into it, one hose for the vacuum pump and a second one for the resin to flow into the bag. The preliminary moulding works just like with the pre-preg parts. The release agent is added on the surface of the mould. The fabric material is then set on to the mould, but before the assembly is placed in a vacuum bag, the part itself and the vacuum and injection hoses (cf. Figure 26) have to be covered in a plastic web to allowing the flow of resin inside the vacuum bag. The resin is then sucked in a vacuum through the bag to remove all the air and getting an even spread of resin all over the fabric. Once the resin has been applied, the injection hose will be blocked so that the bag will keep its vacuum and therefor the fabric will keep its shape. The preliminary curing of the resin happens in room temperatures and once it is done, the part can be removed from the mould and then be cured completely in an oven in the temperature of 50 degree centigrade.

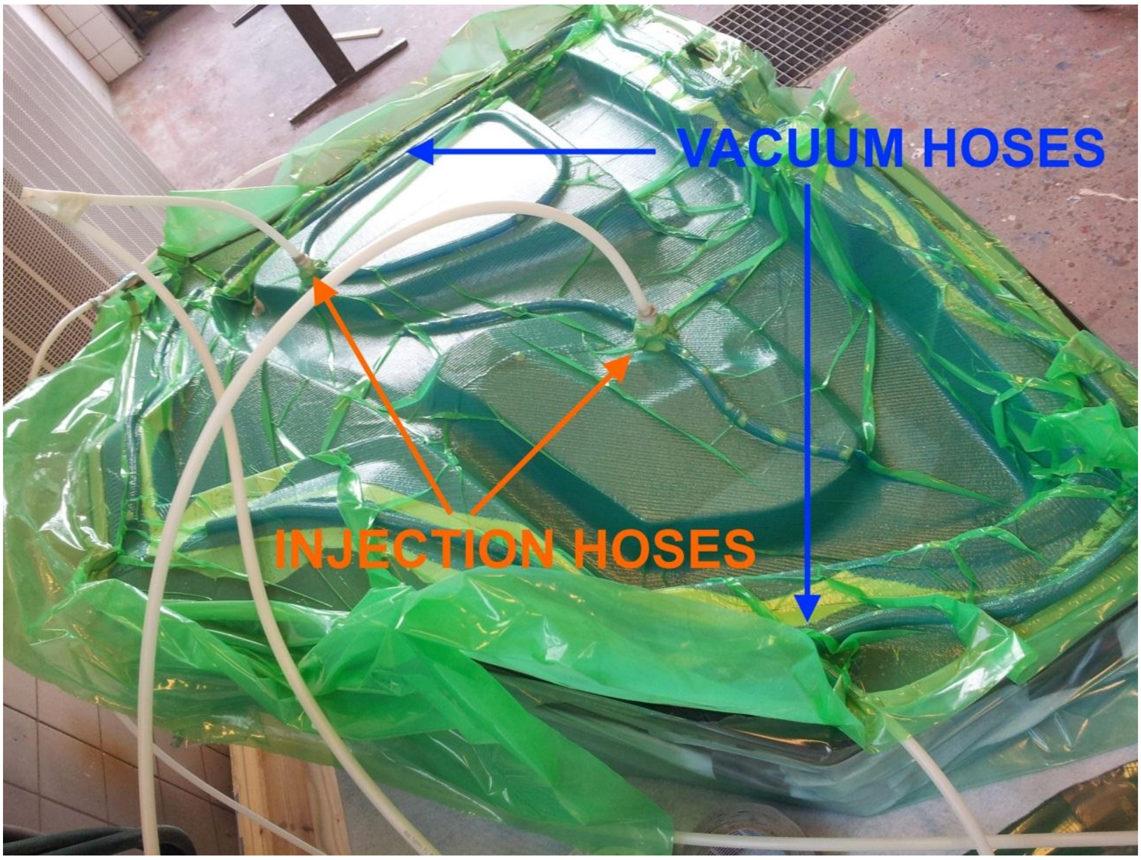

Figure 26. Rear door being vacuum injected, the plastic web is visible between the part and the bag

This technique is good for parts that have large, planar and simple surfaces, because it is relatively easy to set the fibre material on such surfaces for smaller cost compared to pre-preg laminating.

3.7 Measuring the moulds

After the moulds had been used, they had to be measured to check if the moulds had kept their shape under the heat during the hardening process of the resin. To do this, a digitizer had to be used. The tool used was a Baces3D Portable measurement system (cf. Figure 27), which is designed for acquiring 3-dimensional measures, points and surfaces within its workspace with a simple manual movement of the user. The measurement system is calibrated to work with Rhinoceros 3-D modelling software, from where the measurements can be imported directly into Catia V5 workspace, where the actual measurement comparison is done.

Figure 27. Baces3D portable measurement system [8]

After the measuring was done, it was clear that the moulds that were used for pre-preg parts had been deformed during the hardening process because of thermal expansion of the mould block material. The moulds had been curved and stretched in the oven, deforming the moulds even up to 6 millimetres from their intended length. The moulds that were used for vacuum injection retained their intended size, proving that the heat was the source of the deforming. Figure 28 shows a split view of a floor beam in its intended size with red lines illustrating how it has deformed. The part has grown in length and curved slightly.

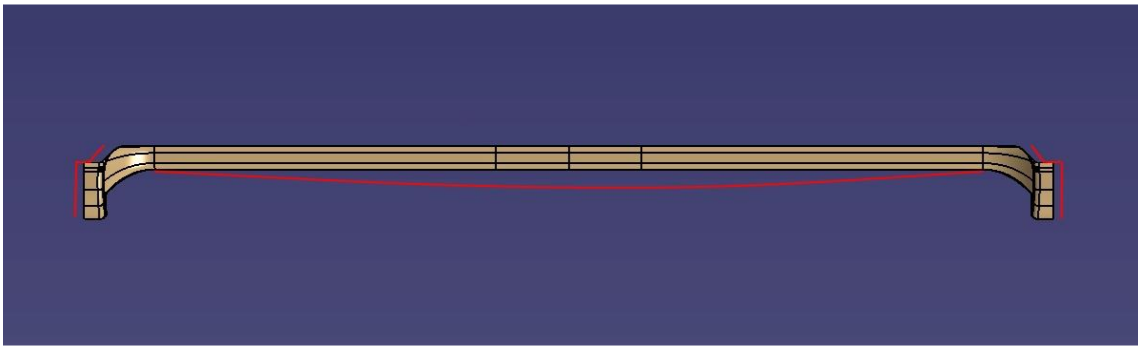

Figure 28. A split view of a floor beam, red lines illustrating the deformations (not in scale)

This particular part (cf. Figure 28), had grown almost 6 millimetres in length and the middle section had sunk for almost 3 millimetres lower than intended.

4 Conclusion

As this graduate study was initiated, the designing phase of the vehicle body was still in progress, neither the body strength calculations nor the design of the body were finalized, meaning there were nothing concrete that could have been worked on without the need of modifications in a later stage, except the approximate size of the vehicle's body. This led to a large number of wasted work hours, when all the modified body parts had to be redone to fit the modified designs, sometimes even from scratch. Another major problem was the deadlines. The mould designs had to be done by a certain date to keep the production of the moulds alive; therefore some of the designs had to be rushed because the designs of the actual parts were finalized in the last minute. This led to some human errors; a couple of moulds were made incorrectly so that the laminated part grew in the opposite direction than it was supposed to. Otherwise the designs were a success. The moulds were machined and treated for the lamination process and none of the actual laminated parts got stuck in the moulds. So the moulds fulfilled their purpose, although the designs could have been improved given more time. Still, there were some problems with the polyurethane used for the pre-preg moulds. The heat of the oven deformed the moulds slightly, due to thermal expansion, curving and stretching them. This was an unforeseen contingency, since the material was supposed to withstand the temperature used for the curing process. Some of the moulds had deformed more than the others. For some parts it didn't cause any problems since they could be modified slightly, but for those that couldn't, it caused bigger problems, such as replacing sections of a finished laminated structure to fix the deformation issue.

As for the mould frame, the whole designing process took a lot of time and effort, as there were a lot of limitations that had to be considered. The biggest limitation being the size, the frame had to fit in the oven used for the curing process of the epoxy and also be big enough to have room for the CNC machine to work. Another limitation was the shape, flat planes were needed so the polyurethane blocks could be attached and have a shape that requires the least amount of blocks. Also, the fact that the frame had to be separable into two pieces to make the removal of the finished part possible. During the designing phase the first two designs were discarded, because they were deemed too complex. The third design seemed to be functional, the frame was easy to build and the planes for the blocks were quite large, but when it came to the assembling of the polyurethane blocks, it no longer seemed so functional. The polyurethane was quite hard to work with, especially with the given tools. It was impossible to create the right sized pieces for the assembly and even if one succeeded, it was even harder to get the piece in the same place when it was getting glued in place. The assembling of the frame really showed the design flaws. The frame should have been designed to be more like a box, with only a few surfaces. This way the frame would have required a lot more of polyurethane blocks, making it more expensive, but at the same time making it more functional and the assembling of the blocks would have been a lot easier. The functionality of the finished frame will not be analysed in this graduate study because the mould will not get machined until fall 2012.

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SikaBlock M560 Technical Data Sheet

Tooling & Composites

Temporary Technical Data Sheet
Version 02 / 2009

SikaBlock® M650
Model board

Areas of Application

- Data control models and cubings
- Master models in tool and mould construction
- Manufacture of moulds for low pressure reaction injection moulding
- Vacuum forming moulds for lower number of pieces

Product Benefits

- Very high dimensional stability
- Good compressive strength and edge stability
- Good solvent resistance
- High heat distortion temperature
- Easy machinability
- Low dust formation by milling
- Dense fine surface and good to varnish

Description

- Basis — Polyurethane, reddish brown
- Adhesive — **Biresin® Kleber braun**, two-component-PUR-system, brown
- Filler — **Biresin® Spachtel braun**, two-component-polyester-system, brown

Physical Data (approx.-values)

SikaBlock® M650			
Density	ISO 845	g/cm³	0.58
Shore hardness	ISO 868	-	D 58
Flexural strength	ISO 178	MPa	18
E-Modulus	ISO 604	MPa	700
Compressive strength	ISO 178	MPa	17*
Impact resistance	ISO 179 Ue	kJ/m²	5
Heat distortion temperature	ISO 75 B	°C	85
Linear thermal expansion coefficient α_T	DIN 53 752	K^{-1}	55×10^{-6}

* at 10% compressive strain

Processing Data

Adhesive / Filler		Biresin® Kleber braun	Biresin® Spachtel braun
Mixing ratio	in parts by weight	100 : 65	100 : 2
Potlife	min	20	5
Setting time	h	8 - 10	> 20 min

Packaging

Board materials	**SikaBlock® M650**	1500 mm x 500 mm x 50 mm, 25 pieces / pallet 1500 mm x 500 mm x 75 mm, 16 pieces / pallet 1500 mm x 500 mm x 100 mm, 12 pieces / pallet 1500 mm x 500 mm x 150 mm, 8 pieces / pallet
Adhesive	**Biresin® Kleber braun**, resin	1.5 kg net
	Biresin® G53, hardener	4 kg; 0.975 kg net
Filler	**Biresin® Spachtel braun**, resin	2 x 8.74 kg net cartridges 6 x 1.76 kg net resin tins in a box
	BPO-Paste, hardener	2 x 0.16 kg net sticks (for cartridges) 6 x 0.04 kg net tubes in a box (for tins)

SikaBlock® M650 172

SC 175 Epoxy extrudable paste Technical Data Sheet

SC 175 Epoxy extrudable paste

MARKETS
- ✓ Composite applications in general
- ✓ Aeronautics, Windmill , Marine

APPLICATIONS
- ✓ To make a large model /tool

SC 175 has been designed for marine, wind energy and automotive customers looking for a fast and reliable way to manufacture patterns and direct mould

1) Benefits - characteristics

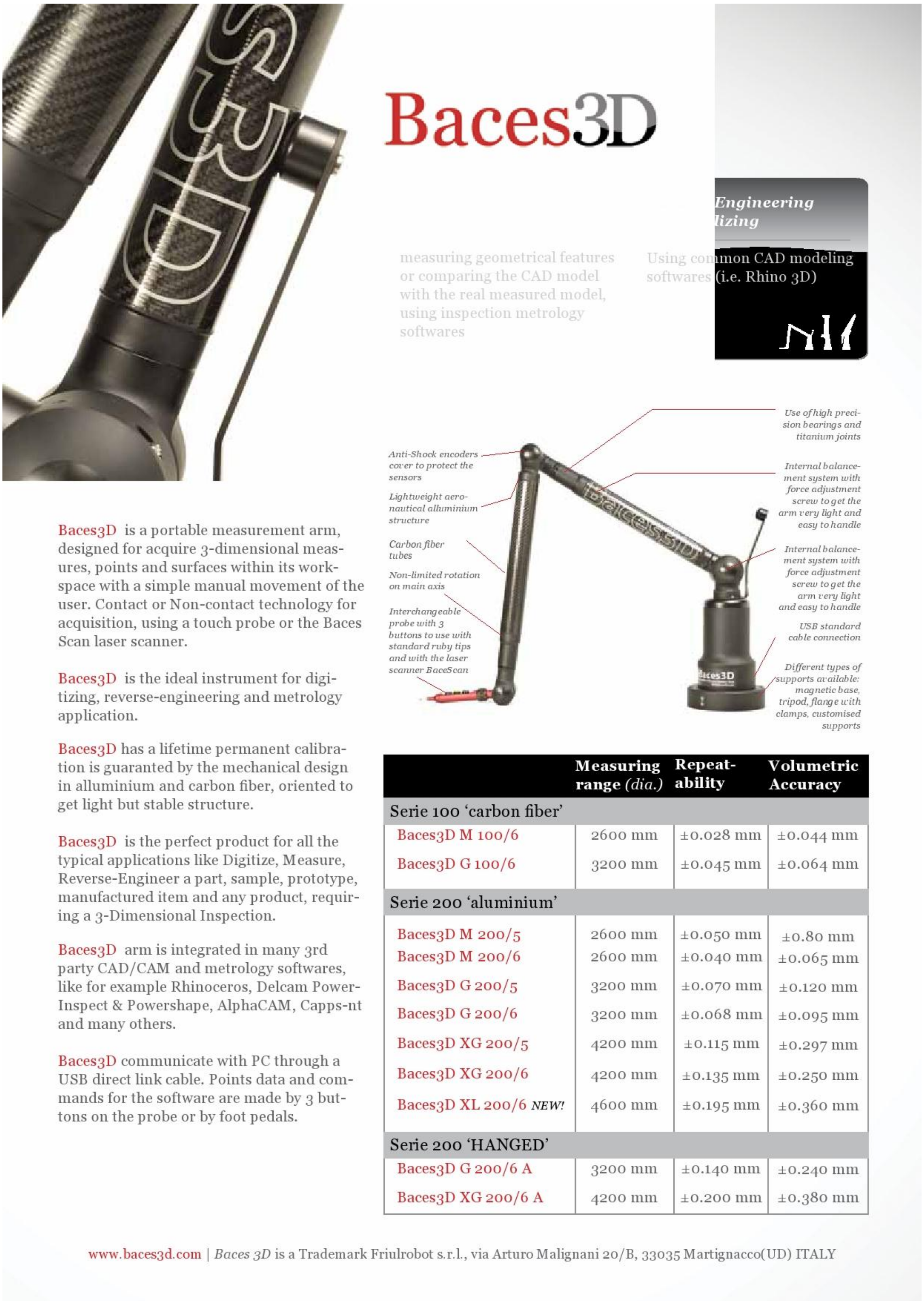
- With a High Tg.
- Low CTE: 70.
- Easy to process 1/1 mixing ratio.
- Good dimensional stability and low density: 0.63.
- Low exotherm, can be machined after 1 day cure at room temperature
- Layer thickness 30 mm without slump on vertical surfaces.
- Pasty component material (no sagging).
- Smooth surface aspect & non porous.
- Easy to repair (see page 4).

With Main Machine Suppliers ...

static & dynamic mixer

DOC-MKT-005 REV00 (05/08)

Baces3D Portable measurement system Brochure



Baces3D

Engineering
lizing

measuring geometrical features or comparing the CAD model with the real measured model, using inspection metrology softwares

Using common CAD modeling softwares (i.e. Rhino 3D)

Anti-Shock encoders cover to protect the sensors

Lightweight aero-nautical alluminium structure

Carbon fiber tubes

Non-limited rotation on main axis

Interchangeable probe with 3 buttons to use with standard ruby tips and with the laser scanner BaceScan

Use of high precision bearings and titanium joints

Internal balancement system with force adjustment screw to get the arm very light and easy to handle

Internal balancement system with force adjustment screw to get the arm very light and easy to handle

USB standard cable connection

Different types of supports available: magnetic base, tripod, flange with clamps, customised supports

Baces3D is a portable measurement arm, designed for acquire 3-dimensional measures, points and surfaces within its workspace with a simple manual movement of the user. Contact or Non-contact technology for acquisition, using a touch probe or the Baces Scan laser scanner.

Baces3D is the ideal instrument for digitizing, reverse-engineering and metrology application.

Baces3D has a lifetime permanent calibration is guaranted by the mechanical design in alluminium and carbon fiber, oriented to get light but stable structure.

Baces3D is the perfect product for all the typical applications like Digitize, Measure, Reverse-Engineer a part, sample, prototype, manufactured item and any product, requiring a 3-Dimensional Inspection.

Baces3D arm is integrated in many 3rd party CAD/CAM and metrology softwares, like for example Rhinoceros, Delcam Power-Inspect & Powershape, AlphaCAM, Capps-nt and many others.

Baces3D communicate with PC through a USB direct link cable. Points data and commands for the software are made by 3 buttons on the probe or by foot pedals.

	Measuring range (*dia.*)	Repeat-ability	Volumetric Accuracy
Serie 100 'carbon fiber'			
Baces3D M 100/6	2600 mm	±0.028 mm	±0.044 mm
Baces3D G 100/6	3200 mm	±0.045 mm	±0.064 mm
Serie 200 'aluminium'			
Baces3D M 200/5	2600 mm	±0.050 mm	±0.80 mm
Baces3D M 200/6	2600 mm	±0.040 mm	±0.065 mm
Baces3D G 200/5	3200 mm	±0.070 mm	±0.120 mm
Baces3D G 200/6	3200 mm	±0.068 mm	±0.095 mm
Baces3D XG 200/5	4200 mm	±0.115 mm	±0.297 mm
Baces3D XG 200/6	4200 mm	±0.135 mm	±0.250 mm
Baces3D XL 200/6 *NEW!*	4600 mm	±0.195 mm	±0.360 mm
Serie 200 'HANGED'			
Baces3D G 200/6 A	3200 mm	±0.140 mm	±0.240 mm
Baces3D XG 200/6 A	4200 mm	±0.200 mm	±0.380 mm

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