Oscar Nissinen

ConceptCar-project: Experimental Polypropylene-Biofiber Composite Components

Helsinki Metropolia University of Applied Sciences
Degree

Automotive and Transportation Technology

Thesis

4.6.2012

Abstract

Author(s) Title Number of Pages Date	Oscar Nissinen ConceptCar-project: Experimental Polypropylene-Biofiber Composite Components 31 pages + 4 appendices 4th of June 2012
Degree	Bachelor of Science
Degree Programme	Automotive and Transport Engineering
Specialisation option	Automotive Design
Instructor(s)	Harri Santamala, Project Engineer Robert Tanskanen, Laboratory Assistant

This Bachelor Thesis was carried out for the Metropolia ConceptCar–project, funded by TEKES, the Finnish Funding Agency for Technology and Innovation, which produces a multifunctional prototype passenger vehicle. The vehicle is a showcase of multiple different areas of competence in the field of automotive design and yields a large number of other Bachelor Theses during its lifetime. The resulting ConceptCar vehicle will also work as a platform for the participating companies to exhibit their input in the project for their customers and associates.

The aim of this Thesis was to test a new type of polypropylene-biofiber composite and find out methods for producing body parts for the ConceptCar vehicle out of this material. The aim was to find methods that would suit the nature of the project as a small-scale production, would be easy to use with little or no previous expertise in thermoplastic molding and would not require expensive, large or otherwise unavailable machinery. The results of the process and findings are recorded in this Thesis. Standardized and simplified material testing for the composite was also carried out, whenever possible. The results of these tests were not as useful as desired, but gave nevertheless important information about testing and manufacturing processes.

The goal of the study was met in the form of finding a method for manufacturing parts by thermoforming them without dedicated machinery or exhaustive knowledge in thermoplastics. In the process of making the study, it became clear that working with composite in granulate form with *ad hoc* –tools is impractical and purpose-built extruder and injection molding machines or stock materials made with professional tools are to be used when manufacturing any kind of end product with this material.

Keywords	composites, thermoplastics, polypropylene, ConceptCar Project

Tiivistelmä

Tekijä(t) Otsikko Sivumäärä Aika	Oscar Nissinen ConceptCar-project: Experimental Polypropylene-Biofiber Composite Components 31 sivua + 4 liitettä 4. kesäkuuta 2012
Tutkinto	Insinööri (AMK)
Koulutusohjelma	Auto- ja Kuljetustekniikka
Suuntautumisvaihtoehto	Tuotetekniikka
Ohjaaja(t)	Projekti-insinööri Harri Santamala Laboratorioassistentti Robert Tanskanen

Insinöörityö toteutettiin osana Metropolian, TEKESin ja yhteistyökumppaneiden ConceptCar–projektia, joka tuottaa monikäyttöisen demonstraatioajoneuvon prototyypin. Tämä ajoneuvo on työnäyte, joka esittelee useita eri autosuunnittelun osa-alueita ja jonka puitteissa tehdään lukuisia insinööritöitä. ConceptCar-demonstraatioajoneuvo toimii myös yhteistyökumppanien esittelyalustana, jolla voidaan esitellä kunkin osallistujan panosta ja osaamista omille sidosryhmilleen.

Tämän insinöörityön tavoitteena oli testata uudentyyppistä polypropeeni-biokuitukomposittia, ja kehitellä työtapoja, joilla voitaisiin valmistaa koripaneeleja ajoneuvoteollisuudessa, erityisesti ConceptCar-demonstraatioajoneuvoon. Tavoitteena oli löytää sellaisia keinoja työskennellä materiaalin kanssa, jotka sopivat projektin luonteeseen, piensarjatuotantoon ja jotka eivät vaadi kalliita, suuria tai muulla tavoin vaikeasti saatavilla olevia koneita. Materiaalille suoritettiin myös materiaalikokeita ISO/SFS standardien pohjalta tai niiden prosesseja imitoiden. Näiden materiaalikokeiden tulokset antoivat tärkeitä tietoja valmistusprosesseista. Työn tulokset on kuvattu tässä insinöörityössä.

Työn tavoite saavutettiin, sillä lämpömuovauksen havaittiin olevan edullinen, helppo ja nopea tapa valmistaa kokeellisia osia jopa improvisoiduin (*ad hoc*) työkaluin ja vähäisellä kokemuksella kestomuovien muokkaamisesta. Työssä käy myös ilmi, että improvisoidut työkalut eivät ole riittäviä materiaalin saattamiseksi granulaattimuodosta työstettävään muotoon, vaan osien valmistukseen tarvitaan ammattilaistyöstömenetelmin valmistettua aihiomateriaalia.

Avainsanat	komposiitti, kestomuovi, polypropeeni, ConceptCar

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1 Introduction

Advances in the field of material technology in these days are the driving force behind new innovations and consumer products. Products that were unimaginable a few decades ago are now a part of our everyday life, and this is made possible by our better understanding of materials of different kinds. Also, the ever-increasing concern for the environment forces us to focus on producing more with less and with a more sustainable way. [1] Because of legislation and commercial trends, automotive industry is under a high stress to reduce the amount of unrecyclable waste, and to increase the use of materials that contain bio-based components, as well as to make increasingly lighter end products with minimum increase in the unit cost. The use of thermoplastic composites with bio-based materials is an excellent way to approach these objectives, and that is one reason why the automotive industry has become one of the largest sectors to use such materials. [1; 3; 4]

The aim of this Thesis was to test a new kind of product, polypropylene-biofiber -composite, wide range of its properties and usability in automotive applications, as a part of the joint ConceptCar Project of Metropolia University of Applied Sciences and other associates.
The ConceptCar Project is a Metropolia University of Applied Sciences' automotive project started in 2010, funded by TEKES, the Finnish Funding Agency for Technology and Innovation, with a goal of producing a premium-class compact city car for four persons, exhibiting new innovations in the field of environmentally friendly automotive solutions. The end product, a finished car, will be premiered at the Geneva Motor Show in 2014, and the project will yield a large number of theses, ranging from mechanical design to testing of a new type of biodiesel.

This thesis was carried out in two phases: material testing and manufacturing tests. When the work was started, the main focus was in the material testing, as it was assumed that the material would be so new that data from its mechanical properties would be scarce. When it turned out that there was sufficient data available from previous testing done by the material provider, the focus was shifted towards the manufacturing tests. These manufacturing tests had a goal to find a way to manufacture parts for the ready ConceptCar vehicle and to find tools to achieve this easily, inexpensively and with the resources available to the project. A large part of the material testing was carried out in the materials laboratory situated in Metropolia’s Kalevankatu campus with the assistance of laboratory assistant Robert Tanskanen, who has worked with thermoplastic materials for several years. Manufacturing tests were carried out both in Kalevankatu campus and in Tikkurila campus in co-operation with Industrial Design lecturers Mika Ihanus and Tuomo Äijälä, who both have vast experience in making prototype components and working with thermoplastics.

2 Manufacturing Testing

For the ConceptCar –project experimental demonstration vehicle, some body parts and panels are manufactured from the polypropylene-biofiber composite. The material was introduced to the markets during the course of this study, thus its behavior and working methods while using the material were unknown in the start and therefore methods of manufacturing parts had to be studied beforehand.

2.1 Testing Different Methods of Manufacturing

The raw material used is in premixed granulate form, where the fiber is already mixed into the resin in factory. The first goal was to find an easy and relatively inexpensive ways to manufacture objects or parts from this granulate raw material, and choose the most suitable one. Usually, granulated thermoplastics are intended to be used in processes such as injection molding or extrusion. Both of these processes are excellent for large production lines and quantities, but since now only small-scale production was necessary, both of them were considered too expensive methods to be used throughout the whole project. Also, because of the lack of machinery required, new methods of manipulating the raw material had to be found. The use of vacuum molding would provide an inexpensive and easy method of manufacturing sheet-kind objects, which are crucial for the purposes of the project.

In order to be malleable, thermoplastics need to be heated to their melting temperature, which in this particular case was close or at 190 degrees Celsius. Also, the presence of oxygen at these temperatures will start to degrade the properties of the material quite fast, and the fiber in the composite was shown to start burning at temperatures near 120 degrees Celsius. First off, methods usually associated with manipulating thermosets were implemented, such as vacuum molding in an oven and assisted with overpressure. One problem with the granulated material is also its form: there is an uneven distribution in the material at any given point, since the shapes and sizes of the granules vary and there is air trapped in between them. Problems also occurred with the high temperatures required to melt the material: vacuum bags, pipes and sealants started to degrade when the temperature rose over 175 degrees. Also, it would seem that a mechanical force is needed in addition to air pressure to actually form an uniform material out of the granulates. In Figure 1, there is an aluminium block with for heating the granules under pressure.

2.1.1 Aluminium Pressure Block

One type of test piece manufacturing test used was an aluminium block (cf. Figure 1), which had heating elements placed onto its outer surface.

Figure 1. Aluminium block

The inner cavity of this four-pieced block formed approximately a lozenge shape. The idea was that the granulate would be placed inside the block, it would be heated near to the materials glass transition temperature and then high pressure of air would be introduced to the cavity in order to make the material to compress. Unfortunately, no method for making the pressure difference high enough on different sides of the material, and the method would not work. Figure 1 shows the aluminium block with several visible parts: overpressure valve on top, heating wire element coiled inside the surface of the block and the temperature gauge wire in the back. Figure 2 shows the results of another experiment, aimed to form a cylindrical block with heat and pressure.

2.1.2 Cylindrical Press Mold

The second type of testing was done with mechanical pressure, using tensile test equipment to press an aluminum piston into a heated stainless-steel cylinder, which contains the raw material.

Figure 2. Cylindrical mold (cutout)

The second type of testing was done with mechanical pressure, using tensile test equipment to press an aluminum piston into a heated stainless-steel cylinder, which contains the raw material. As the granulate melts, it does not liquefy totally, but becomes more like a paste. This made it possible to use this kind of method, since the cylinder/piston-joint did not to be specifically sealed, which in turn made manufacturing of the test rig fairly easy. The granulate was heated gradually to a temperature of 185 degrees Celcius along with the cast iron mold and aluminium piston. The granulate was placed inside the mold already during the heating phase. Heating was allowed to take place for 6 hours and then a aluminium piston was placed inside the mold. This assembly was then pressed with a tensile test machine used to test metals. When the pressing force exceeded 17kN, the cast iron mold cracked from one side and the test had to be aborted. When analyzed, a several notes were made:

- Mold design is crucial in this method. All materials used should be able to withstand large forces and pressures.
- A method for releasing the ready part would have to be designed to the mold. This could be a detachable bottom or some other method of dissassembling of the mold.
- Even with very long heating times, the material did not homogenize, as can be seen in Figure 2. In the cut mold, a very large portion of the material has remained virtually unchanged. This would suggest that even longer heating period (48-72 hours) and the raw material should probably also be dried before use, as it absorbs humidity from air.

2.1.3 Aluminium Plate Molds

At the same time, a second manufacturing method was also tested: a system which contained two aluminum plates, the bottom one with a small offset and the upper one acting as the female part. The two plates and approximately 4 dl of granulate material were heated in a fan-assisted oven separately. The temperature was 185 degrees Celsius, and heating time 45 minutes. The material was then placed on a pile in the middle of the bottom plate, after which the two plates were pressed together with the aid of multiple vises. This provided a sheet of the material, after it was cooled down for a period of several hours.

Spreading the material evenly over the bottom plate before closing the mold was also tested, but this was deemed ineffective, as the spreading of the material under pressure added to the melting process. Results of the testing can be seen in Figure 3.

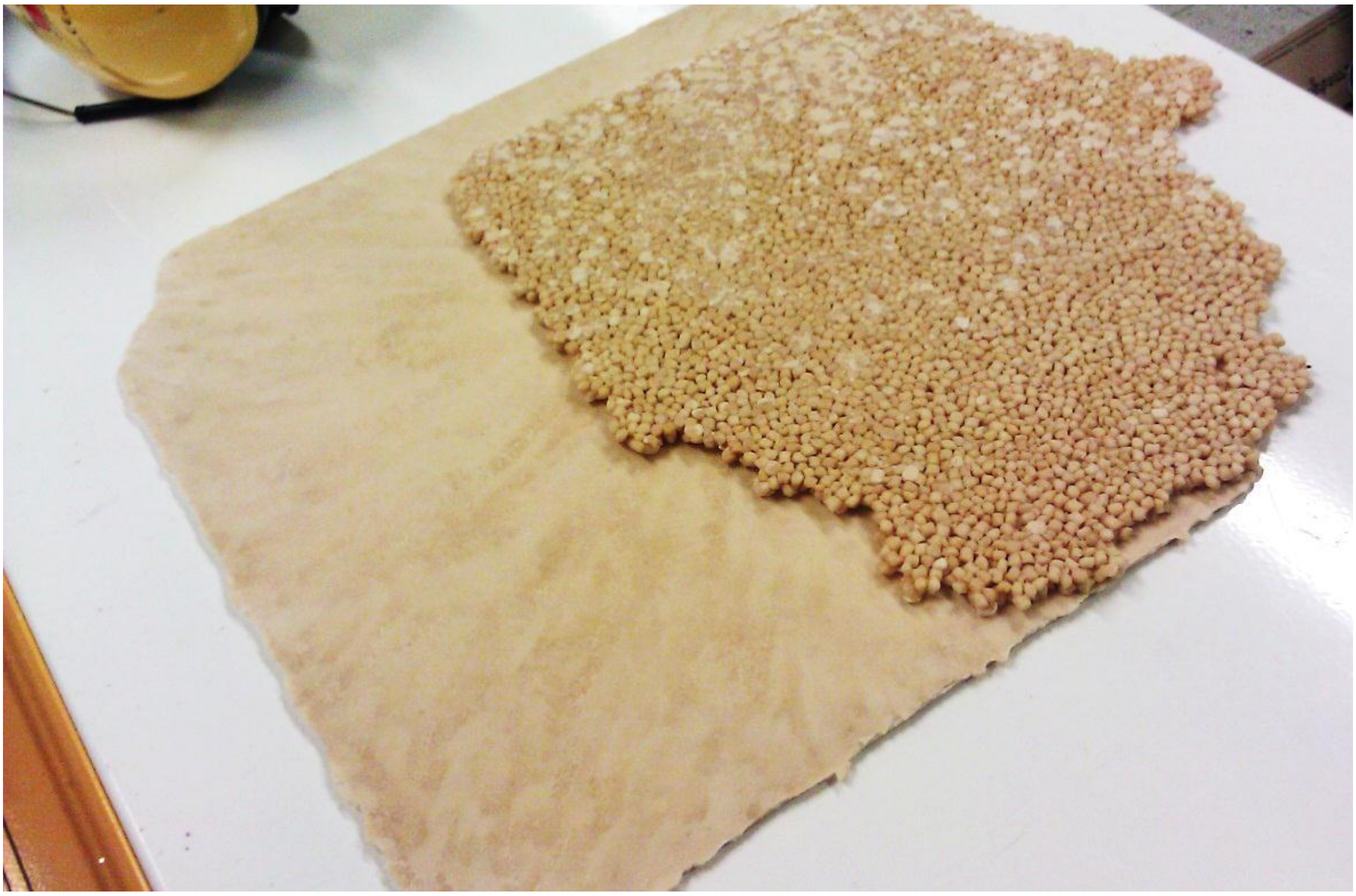


Figure 3. Two compressed plates

Figure 3 represents the result of these two types of test, the lower plate is the result of granulates being placed in a pile and the top plate is the result of granulates being placed evenly to the plates. In the Figure 3, it can be easily seen from the streaks in the plate how the material flows outwards from the pile as the plates are compressed. The top plate shows that the material is not uniform, because the melting process has not been complete

2.1.4 Injection Molding (IM)

From earlier experience it was known that the material is well suitable for injection molding, and all standardized tests (mechanical properties e.g.) are carried out with test pieces made with injection molding. 128 pieces of dog-bond shaped test specimens were manufactured with an Engel injection molding machine at Arcada University of Applied Sciences in Helsinki for the use of tensile strength and flexural properties testing.

During these test of manufacturing methods it became evident that the material needs to be properly dried before use. The biodegradable fiber in the material will absorb humidity from air and the water content will degrade the properties of the material. This fact became extremely clear when several test specimens were injection molded from undried material and then compared to specimens made out of dried material. The resulting test specimens from the undried material were really dark in color and extremely brittle. Also, water content in the material is a probable cause why heating up the granules proved rather difficult in a regular oven – the results when using a fan-assisted oven were clearly better as the vaporized water was not reabsorbing to the material.

2.2 Prototype Components

Results gathered from the manufacturing testing lead to preparing the actual manufacturing of the components. Before any part can be made into existence, a lot of preparing and preliminary designing will take place. This section will clarify what steps was taken before the prototype components were made.

2.2.1 Polypropylene-Biofiber –Composite Parts in ConceptCar-Project

A number of components in the Metropolia ConceptCar-project are designed to use the polypropylene-biofiber composite. The most important components in question are e.g. large outer body panels, such as side skirts, rear bumper, rear skirt and front wheel arches. The use of this material enables the components to be more environmentally friendly when compared to metal or thermoset –based solutions, as there is a 40 % bio-based fiber content in the raw material.

2.2.2 Designing of Components

The component design was started by the industrial designer team at Tikkurila, who provides the shape of the design. This shape was then used as a basis for mold-making, which were designed in 3D by the engineering team, using CATIA V5 – software for the task. The process of bringing the part into reality from the designer’s sketches has several steps: first, the designer makes a 3D-model out of his/hers ideas of what the part should look like, what kind of design drivers and shapes should it incorporate, bearing in mind how to fit the component to the actual assembly of the car. This 3D-model in this project was made with a tool in CATIA software called Generative Shape Design, so the result was basically just a shape without any thickness dimension. The finished model is shown in Figure 4, where a final version of the rear bumper can be seen. This part is then revised by the engineering team, so that it would not have any issues with e.g. fitting and so that the part is also possible to be manufactured as easily as possible. Rather often, during this part of the process, some issues arise or the design of the part is changed, so rather many revisions of the part can be made in the end, and this meant also constant exchange of information between the designer and the engineer. In this project, the engineering student or a third company employee is the one who is responsible of eventually manufacturing the part itself. When the design is complete, it is said to be "freezed" (sic), meaning no major (and preferably not even minor) changes are made to the part any more, and the manufacturing process may start. Depending on the method of manufacture, various things happen – in case of thermoforming, mold-making starts.

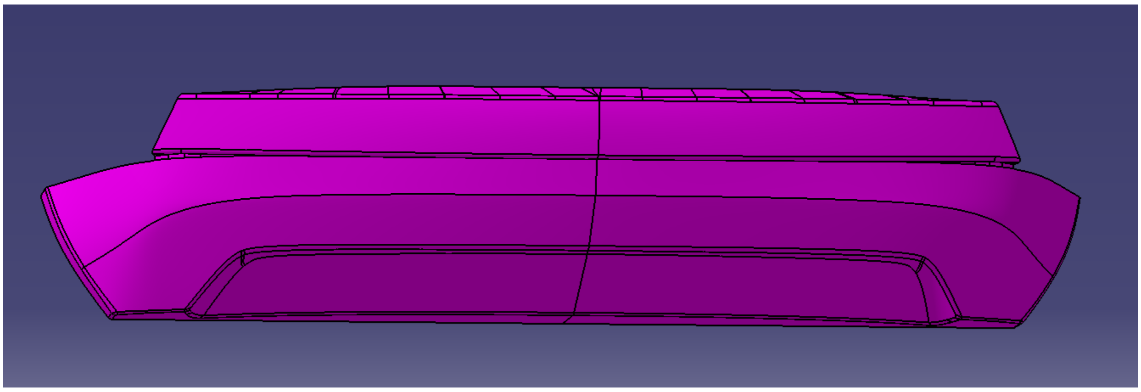


Figure 4. 3D-model of the rear bumper, final version

The mold is designed by measuring how big a stock the part needs, in other words, what is the smallest "box" the part fits into (final stock size will, however, be somewhat larger than this box of minimal disposition, as is explained later on). A screenshot of the fitting process is shown in Figure 5.

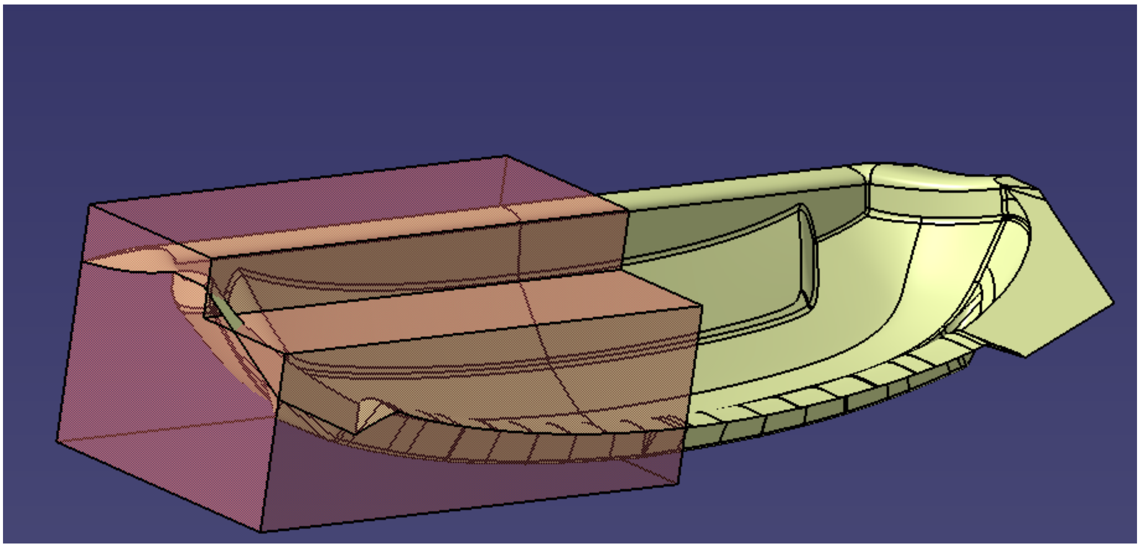


Figure 5. Rear bumper mold (light yellow) and stock block (transparent red)

Depending on the size of this resulting box and the limitations of CNC-machinery at disposal, the machining process may have to be divided in several operations, where each operation deals with one stock, and these "sub-stocks" are then eventually attached together to form a complete mold. In Figure 6, three different sub-stocks are shown (pink, violet and orange) laid on top of each other in the 3D model, featuring the part itself (light yellow) inside. The design of the actual mold in CATIA employs the Generative Shape Design as well, and during this operation, the mold will receive additional design features, such as flanges (for gluing or other means of attaching the final product) or holes to direct multiple-layer mold pieces together properly. Usually, the shape of the actual part is also extruded for 15-20 mm and then "bent" to meet the outside of the stock, as this will increase tolerance in the after-treatment and manufacturing of the part.

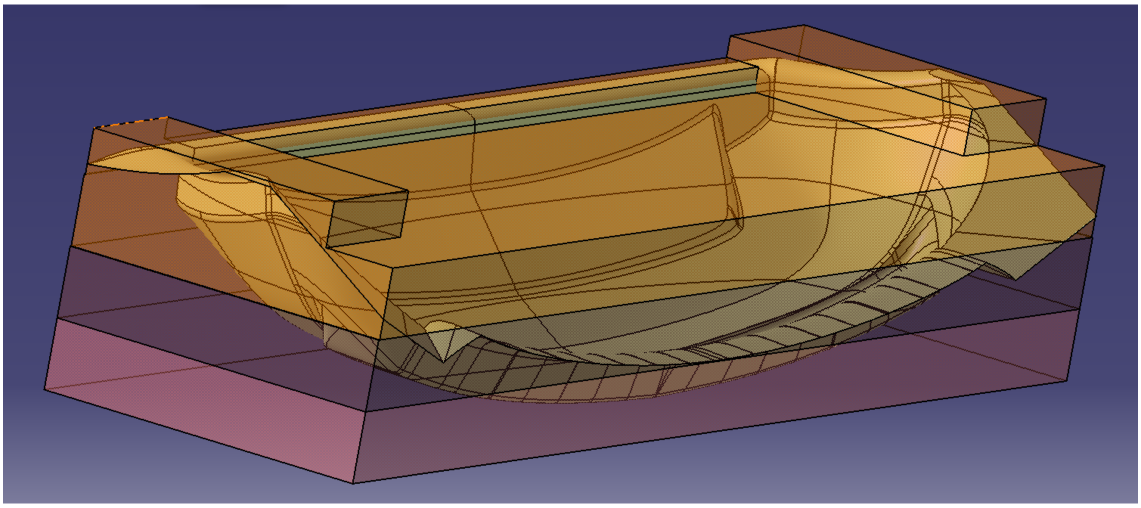


Figure 6. – Three different coloured sub-stocks (orange, violet, pink) covering the part (light yellow)

In Figure 6, all of the three different stock colours represent one machining process, the rear bumper mold was machined in three different layers that were then glued on top of each other to form a complete mold. Positioning of the three layers can be done by following the curvature and shape of the underlying mold layer, but it is highly recommended that positioning holes and rods are used in multiple-layered molds. The positioning holes should be machined (and therefore incorporated in the 3D model as well), and not drilled by hand tools to ensure the right alignment of the holes. In Figure 7, the difference in the designs of the ready part and the mold can be clearly seen.

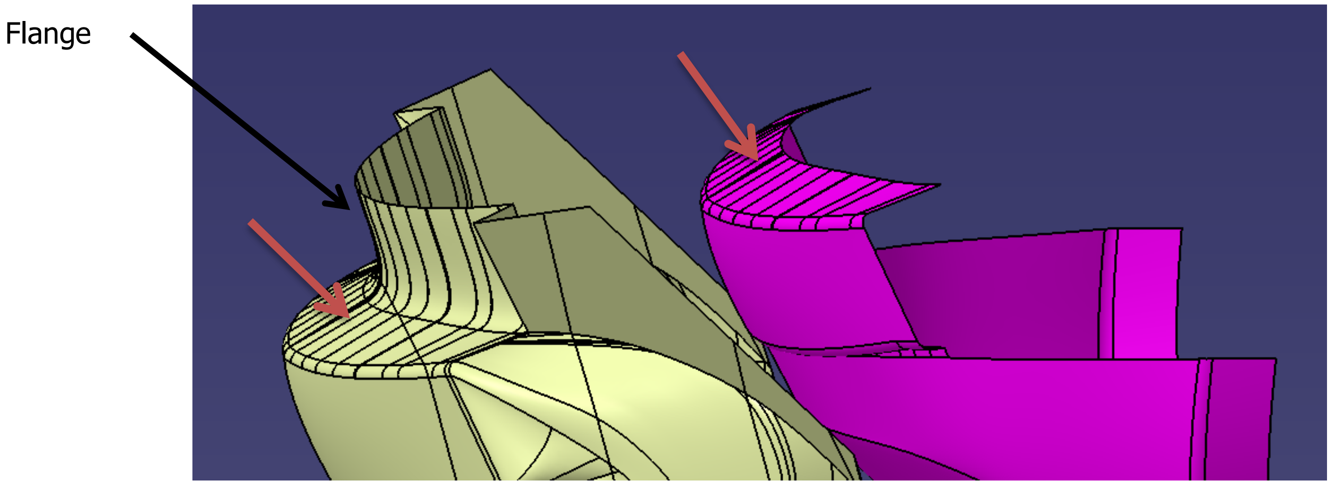


Figure 7. Mold surface (light yellow), part surface (pink), corresponding surfaces (red arrows) and flange surface (black arrow)

2.2.3 Mold Manufacturing

Mold design is in close connection with the actual machining of the components. Mold is made out of hard material by machining it out of the polyurethane block with computer controlled milling machine, which is controlled by code that is generated from the 3D-visualization. The CATIA 3D-software that is used by the project, is also equipped with CAM-module (*computer assisted manufacturing*), where the designer can calculate the pathways for the milling machine on the computer screen and also simulate the movements of the tool before the actual run in the real life. In this project, mainly two tools in CATIA Surface Machining –module were used: they are called *roughing* and *sweeping*. Roughing is intended for quickly removing material from the stock without actually making any design shapes. This phase is always quicker than the corresponding sweeping phase, but does not result a ready part. After roughing, a sweeping tool was used; although the physical tool was not changed in between - all molds were cut with a ballpoint tool with a radius either 16 mm or in most cases, 14 mm. These two pathways were usually "posted" (ie. generated via postprocessor) in the same process, so the sweeping followed seamlessly after the roughing phase was completed. This resulted in machining times well over 20 hours, which is really resource-fatiguing as the machine has to have a two-man watch by its side at all times. In Figure 8 can be seen a broken machining tool, which was destroyed as a result of an user mistake.

Figure 8. A broken machining tool (ballpoint tool, 16 mm diameter)

The benefit of posting the two paths in the same code and running them without interruptions lied in the possibility that the CNC machine might lose its configuration and reference points during the breaks. This could happen by an interference from a third party (as was witnessed during the project when the machine was turned off during a pause) or as a result of problems in electric supply. Other CAM tools used were *drilling*, mainly used for drilling vertical positioning holes, *z-level (roughing)* to improve the quality of vertical surfaces and *curve follow*, which was used to draw a line to the surface of the mold to show where to cut the finished part. The difference between results after sweeping and roughing is shown in Figure 9.

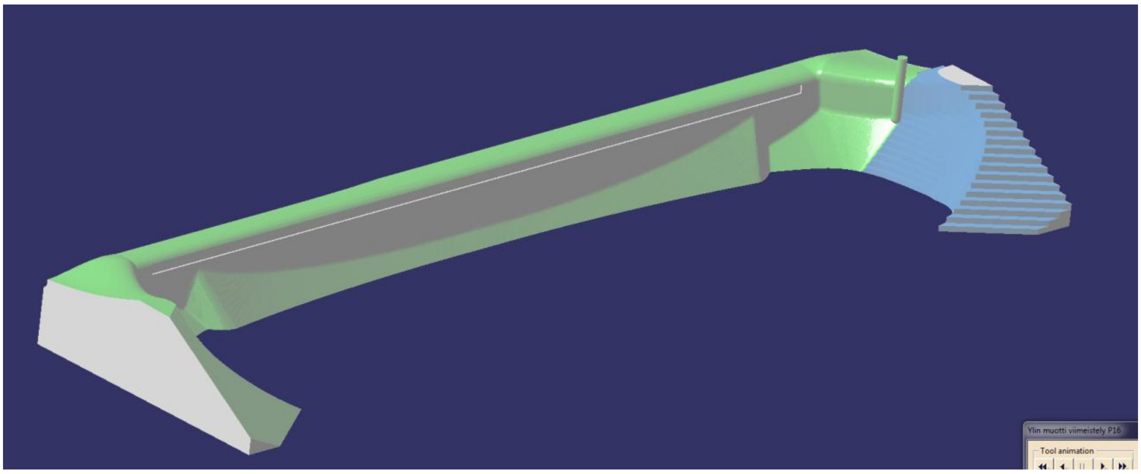
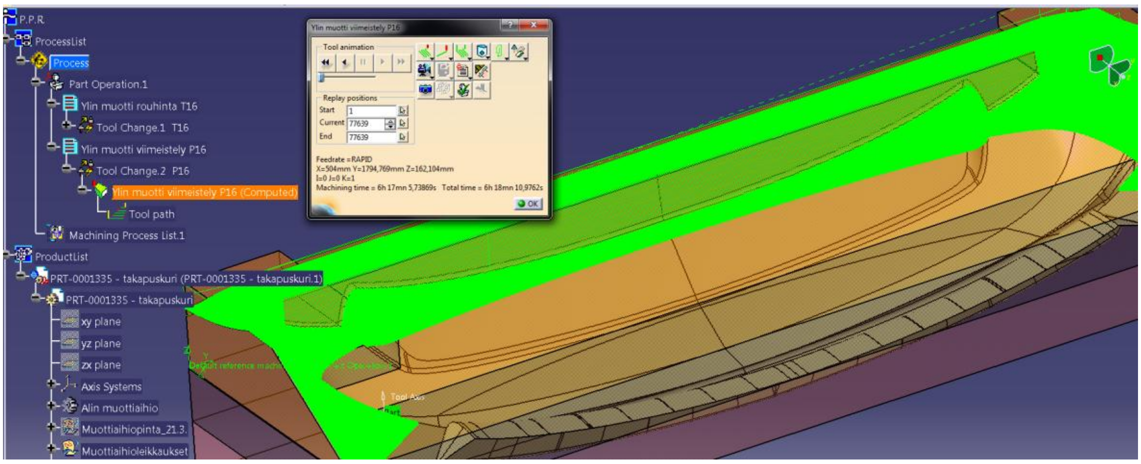


Figure 9. Visualization of the tool path and surface, sweeping (green) and roughing (blue).

Computer Assisted Manufacturing and the tool path visualization are very useful tools, as the designer can ensure that the design is flawless and does not result in a collision with the stock block or the machine itself, which can lead into very expensive damage or a significant increase in manufacturing time. Designing the pathways for the machine is always a compromise between the maximum cutting values, desired surface quality (R_a-value) and machining time. Maximum cutting values, such as feed rate and spindle speed, are affected, among other things, by the material in question (softer stock materials may be cut with faster values) and capabilities of the milling machine. The basic feed rate used with the Exitech CNC router in Tikkurila for the M650 polyurethane block was 2400 mm/min, and spindle speed was 18000 rpm in all cases. With wrong settings, the designer may end up with a product that has inferior surface quality compared to desired, or with impractically high manufacturing times, or even causing damage to the tool, stock or the milling machine. The desired surface quality is closely connected to the manufacturing times, e.g. with really coarse roughing settings, for a component with surface area of approximately 0,9m², milling time is approximately 7½ hours, whereas using finishing settings for the same component, the running time can be as high as 20-50 hours, depending on the required surface quality: finer the quality, longer the time. In Figure 10, the basic screen for CATIA CAM – module is shown, with the machining time dialog box and the green tool path visualization lines visible.

The molds in the present project are machined either in-house or at third-party company called Scan Mold. Mold materials used are polyurethane blocks (density approximately 650 kg/m³) or polystyrene foam, respectively. After machining, the molds are sanded by hand to get a smooth surface for the part-making. Sanding is done with grit of 180 and then finished off with grit 360. These molds (unlike the ones that are going to be used for thermoset-laminating) are not painted nor polished before use.



Start 1
Current 77639
End 77639

Feedrate =RAPID
X=504mm Y=1794,769mm Z=162,104mm
I=0 J=0 K=1
Machining time = 6h 17mn 5,73869s Total time = 6h 18mn 10,9762s

Figure 10. CATIA Surface Machining –tool, showing computed machining time and machining tool path (green lines)

Polystyrene molds are coated with casting epoxy resin, in order to increase thermal resistance of the material, whereas polyurethane is thermal resistant enough on its own to begin with. The reason for using two different materials and machining sites are following: polyurethane blocks are of limited size and the cost of one block is rather high, whereas polystyrene material cost is somewhat lower. Larger component molds, such as the mold for front wings / wheel arches, are machined at Scan Mold, since the maximum stock block size their machining equipment is able to use is considerably higher than the one for the CNC-machine at the project’s disposal in Tikkurila facilities.

2.2.4 Thermoforming

The thermoplastic components are manufactured by thermoforming extruded composite plastic sheet on top of the aforementioned molds, using sufficient heat and vacuum. Temperature over the glass transition point of the material (T_g) makes the thermoplastic material malleable and as vacuum is introduced, the force of vacuum makes the plastic sheet assume the shape of the female mold.

In practice, the mold is first prepared for the thermoforming by making the surface as smooth as possible, the importance of the surface quality of the mold increases drastically if the finished surface is not coated or treated in the ready part and/or if the finished surface is easily and often viewed by the end user. For example, if the dashboard would have a design element that is not treated (e.g. painted) in the finished product, the finishing of this design element's mold surface would have to be significantly better than that of for example painted side skirts.

Because thermoforming uses vacuum, the mold needs "venting", a way for air to escape in between the material (hereinafter, the stock) and the mold. Venting can be done by using extremely porous material (Sikablock M650 is rather porous material, but not enough), or by making holes to the mold surface, as is done in this case. Mold is then moderately heated to a temperature of about 60 degrees Celsius, and the stock is heated close to its glass transition temperature, which in this case is about 180 degrees Celsius. The mold is placed inside a heat-resistant nylon bag that is connected to a vacuum pump and three of its sides are sealed tight with Play-Doh –like sealing tape. Then, the heated stock is placed inside the bag, over the mold, the fourth side is sealed and then, a vacuum is sucked inside the bag. Pressure difference between the vacuum inside the bag and the atmosphere causes a force large enough to shape the stock to take the shape of the mold. In theory, after cooling down, the part would be ready, but in reality, it still takes some trimming, cutting, surface treating and fitting for the part to be actually ready for assembly. In Figure 11, two finished thermoforming molds are shown, the rear bumper mold on the left and the mold for the two side skirts on the right. Please note that the rear bumper mold is the result of the 3D models shown earlier.

Figure 11. Ready thermoforming molds, rear bumper (top), side skirts (bottom)

Because a proper sized stock material for full-scale testing was not available, a proof of concept was achieved with a small-scale testing, using a smaller mold than would be used to make the final parts and with a smaller piece of stock material. This mold was originally a mold for a lamp shade, and it was machined out of another type of Sikablock (other than M650). This material had a lower resistance to heat, so if this block stood the heat, so would the proper block material. A vacuum bag made of proper size was made, sealed with vacuum tape and a vacuum pipe inlet was also made to the bag. This pipe was connected to a Venturi-type vacuum pump that takes its power from a compressed air outlet. The mold was then placed inside the bag and one of the sides was left open for the material to be inserted. The plate was heated in an oven at a temperature of 180 degrees Celsius for 10 minutes and then transferred on top of the mold. This stock material was 5 mm thick, and it cooled slowly enough so there was no need to heat the mold. After the plate was placed on top of the mold, the bag was sealed and the pump sucked vacuum to the bag. Very quickly after the vacuum was achieved inside the bag, the material assumed the shape of the mold. In Figure 12 all components of this test are visible: stock material is the white part, mold can be seen as orange, light red is the vacuum bag and the vacuum bag is the blue.

Figure 12. The mold in vacuum bag after thermoforming

3 Testing of Material Properties

In the very start of the study, the emphasis was firmly on the testing of the material properties. During the course of the study, obtaining existing material data and realizing the lack of expertise in the field of thermoplastics and testing facilities for thermoplastics lead to a shift in the emphasis towards the prototype components. This section will explain what kind of material testing was done and also what kind of testing was planned, only to be left out of the testing schedule.

3.1 Mechanical Properties

All of the materials properties will be compared to plain polypropylene plastic, which is the matrix resin of the composite. Hypothesis is that if a composites property is better or equal than plain PP's corresponding property, the composite is a better choice as a material due to its higher biodegradable content. Testing of these properties are not carried out to find explicit new research information for the product's manufacturer but mainly for educational reasons and to document what kind of tests have been made, thus enabling possible quality control in project's later stages.

In the start of this Thesis, the main focus was on these material tests, but when it came out that test data from this material's mechanical properties is available from the manufacturer, the focus was shifted away from testing. Also, lack of proper testing equipment, time or experience diminished the size and the role of material testing in this Thesis.

3.1.1 Tensile Strength

Tensile strength is a property of a material that describes the maximum stress of pulling force that a material can stand before the objects cross-section starts to significantly contract. [5] The force per the unit area, i.e. pressure (1) of the cross-section of the specimen when the specimen breaks is the ultimate tensile strength, which is usually shortened simply as tensile strength.

$$p = F/A \tag{1}$$

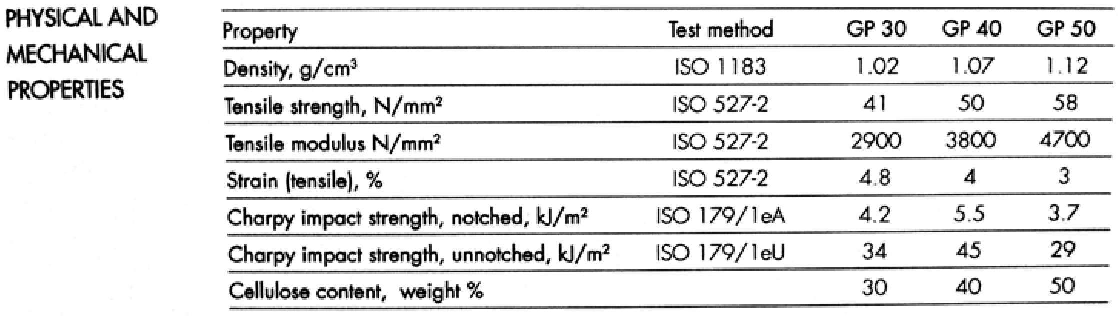
Where

p is the pressure in pascals

F is the applied force in newtons

A is the area in square meters.

Testing the tensile strength properties of the material was started by first manufacturing the test specimens, according to standards, at Arcada UAS. The second step was to obtain the ISO standards for the testing. These included the ISO 291 for test specimen conditioning and ISO 527-1 for the tensile test properties itself. [6;7] 30 test specimens were conditioned in standard atmosphere for a time period of 48 hours. Using the Metropolia UAS materials laboratory, the tensile testing machine was set up according to the standard, and testing was carried out with these conditioned test specimens. Throughout the whole project, there have been several problems with the tensile test results. First tensile test bars did not give out good results when compared to the manufacturer's table of properties. Injection molding process was altered, drying times of the material were extended to over 20 hours, and three different raw material batches were used but the results did not change for better. Table 1 shows the properties of the material provided by the manufacturer.



PHYSICAL AND MECHANICAL PROPERTIES

Property	Test method	GP 30	GP 40	GP 50
Density, g/cm³	ISO 1183	1.02	1.07	1.12
Tensile strength, N/mm²	ISO 527-2	41	50	58
Tensile modulus N/mm²	ISO 527-2	2900	3800	4700
Strain (tensile), %	ISO 527-2	4.8	4	3
Charpy impact strength, notched, kJ/m²	ISO 179/1eA	4.2	5.5	3.7
Charpy impact strength, unnotched, kJ/m²	ISO 179/1eU	34	45	29
Cellulose content, weight %		30	40	50

Table 1. Mechanical properties of the material, provided by the manufacturer.

GP-values represent the fiber content in weight percentage of the material. Throughout this study, GP40 (i.e. 40/60 fiber/polypropylene ratio) was used. Manufacturer-provided test bars fared significantly better and the result were in fact very close to the values provided by the manufacturer. In the in Appendix 1 is a tensile test result sheet, showing the results for both the batch injection molded in Arcada UAS and the reference batch from the manufacturer, and in Appendix 2 is a result sheet for the manufacturer provided batch only.

3.1.2 Impact Strength

Charpy impact strength test determines the amount of energy absorbed by the material during an fracturing impact. The test is carried out by swinging a pendulum at a material, breaking the specimen. The energy absorbed by the material is then read from the force scale of the pendulum. Unfortunately, no suitable testing pendulum for the material was found on time and the impact strength testing was not concluded.

3.1.3 Flexural Strength

A three-point flexural testing was done for the test pieces to get an idea what kind of differences are there between the reference batch, injected molded batch and polypropylene table values. Flexural stress testing tells how the material is able to resist deformation under load. This test was done according to the standard SFS-EN ISO 178: Plastics. Determination of Flexural Properties (ISO 178:2010).
Flexural stress can be calculated from equation (2):

$$\sigma_f = \frac{3FL}{2bh^2} \tag{2}$$

Where
σ_f is the flexural-stress parameter in question
F is the applied force in newtons
L is the support span in millimeters
b is the specimen width in millimeters
h is the specimen thickness in millimeters

Flexural modulus can be calculated from equations (3), (4) and (5)

$$\varepsilon_f = \frac{6sh}{L^2} \tag{3}$$

> To determine the flexural modulus, calculate the deflection s_1 and s_2 corresponding to the given values of the flexural strain ε_{f1}= 0,0005 and ε_{f2}= 0,0025 using the following equation: [8, p. 14]

$$s_i = \frac{\varepsilon_{fi} L^2}{6h} \text{ (i = 1 or 2)} \tag{4}$$

> Calculate the flexural modulus, E_f, expressed in megapascals, using the following equation: [8, p.14]

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f2}} \qquad (5)$$

In equations (3), (4) and (5) parameters are:
ε_f is the flexural strain parameter in question, dimensionless ratio or percentage
s is the deflection in millimeters
h is the specimen thickness in millimeters
L is the support span in millimeters
s_i is one of the deflections, in millimeters
ε_{fi} is the corresponding flexural strain, whose values ε_{f1} and ε_{f2} are given above
σ_{f1} is the flexural stress, in megapascals, measured at deflection s_1
σ_{f2} is the flexural stress, in megapascals, measured at deflection s_2

The results are shown in Appendices 3 and 4, and they clearly show that the flexural modulus and flexural strength for the reference batch (modulus average: 2,79 GPa, strength average: 50,97 MPa) is lower than for the injection molded batch (modulus average: 3,75 GPa, strength average: 63,10 MPa). This in turn tells that the reference batch is more ductile and therefore less brittle than the injection molded batch. This result is well in line with the previous results with for example tensile testing.
Compared to pure polypropylene, which has flexural modulus of approximately 1,5-1,2 GPa and flexural strength 50-40 MPa, even the reference batch is much more brittle. [9; 10]

3.1.4 Density

Density is the property of a material that describes its weight per volume unit (6)

$$\rho = \frac{m}{V} \qquad (6)$$

Where
ρ is the density (SI unit kg/m^3)
m is the mass of the object (in kilograms)
V is the volume of the object (in cubic meters, m^3).

If m is given in grams (g) and V in cubic centimeters, the density unit will then be g/cm³, which has the same absolute value than if the unit would be kg/m³.

A rough estimate of the material density was measured using a displacement method: a number of test pieces were weighed (to define the mass m), submerged in water, the displacement was measured (to define the volume V) and it was possible to calculate the density. This method is a valid method of testing the density of the material, but to get accurate results, a special measuring device for the displacement should be used. In this study, a tall glass with graduation where the volume could be read from. This method gave and average density of approximately 1,06 g/cm³ for the manufacturer-provided test pieces and 1,04 g/cm³ for the parts that were injection molded in Arcada UAS.

These results are fairly well in line with the values provided by the manufacturer, and the porosity and bad results in the tensile strength testing of the injection molded material can also be a result from the lower density.

3.1.5 Water Absorption

Water absorption was tested by submerging a number of test pieces in water and keeping them there for four days. The pieces were weighed before (dry weight) and after (wet weight) the test. This was carried out only for the so-called reference batch that is the manufacturer provided test pieces.

The hypothesis was that the material would absorb water several percents (by weight), but the results indicated that almost no water was absorbed (less than 0,2%). The validity of the results has to be questioned and the absorption should be retested.

3.2 Methods of Bonding

There are several possible methods for bonding thermoplastic parts, ranging from adhesives and mechanical joints from plastic welding. Two mechanisms were planned to be the main methods of bonding the ready parts, but in the end of the study no actual parts were manufactured, so the final method of bonding was remained unsolved. In this paragraph, to main methods are briefly introduced.

3.2.1 Adhesive

Bonding of polyolefin materials (polyethylene and polypropylene) with adhesive is very difficult, because of their inherent chemical resistance. [11; 12] In recent years, different kinds of glues and adhesives has been developed for bonding polyolefin materials together, as traditional methods, such as cyanoacrylates or epoxies are not feasible for these materials.

For this project, Loctite 3038 –glue was intended to be used, but as it is with all these kinds of special glues, obtaining them can be very difficult. No glue was found from Finland on time for exhaustive testing.

3.2.2 Mechanical Joints

Mechanical joints are an easy and inexpensive way to bond two sheet-like materials quickly and firmly together. Mechanical joints are very commonly implemented in engineering solutions. [13] These types of joints include everyday common joints such as rivets, nails and screws. For this project, rivets are the primary mechanical jointing method that would be used if appropriate. Mechanical testing of the rivets was not carried out, since there were no plans of using riveting in joining thermoplastic components together.

4 Results and Conclusions

The main goal of the study was changed several times between the start and finish. In the initial planning phase, the leading research problem was to test the properties of the new material according to the ISO/SFS standards with a very large scope. After acquiring the raw material and the required standards, it became evident that there was not enough equipment or expertise at disposal for such exhaustive testing. This rather quickly lead to a shift in the focus of the goals of the study, as the most concrete progress was achieved with the manufacturing processes. There was also rather accurate data available on the mechanical properties of the material, so the need for all testing became less urgent.

The idea of preparing molten mass with improvised tools proved to be quite hard. Polypropylene batches are often heated to temperatures up to 260 degrees Celsius [14], whereas the biofiber-composite starts to degrade at temperatures exceeding 200 degrees Celsius. Degrading is visible as decolouring of the material, and degrading of mechanical properties might occur as well, if the material is kept in too high temperatures for too long time. Temperatures of 170-190 degrees Celsius were used to manipulate the material in every phase of the study, and this resulted in difficulties in making a molten mass that could be used to make stock material for machining parts.

The main result of the manufacturing testing was that using *ad hoc* –tools and methods for manipulating the material is extremely difficult and manufacturing components from the material will require purpose-built thermoplastic machinery in some form, at least in the making of the stock materal. It was also found out that, when using extruded or injection molded stock material, thermoforming is a fast, easy and inexpensive method of manufacturing components from the material. Machining the molds for the thermoforming also gave precious information and experience in mold machining for the future. The mold for the rear bumper was one of the most complex molds to be manufactured in-house for the project and the manufacturing it pointed out problems in aligning submolds as well as problems with the adhesive used for attaching the submolds together. Because of these findings, some working methods were changed for the following molds that were machined in-house.

The results from the material testing were not as useful as was hoped in the beginning of the study. The main reason for testing the material properties is usually quality control, but since no parts were finished during the scope of this study, no quality control was needed at this time. In the future, when the project continues and finished components are made from the material, the need for quality control rises and it should be given more emphasis. Preparing for the material testing has given valuable experience in the field of thermoplastics and testing of thermoplastic materials. Also, a lack in thermoplastic testing capabilities was pointed out, this information may be valuable for someone researching this (or similar) material in the Metropolia Automotive Engineering department. The results did, however, point out some kind of problems in the injection molding process that was carried out in the Arcada UAS. Although every changeable injection molding parameter and nearly all other parameters (such as raw material batch and drying times), were changed in the injection molding process, the test bars did not achieve the mechanical properties comparable to the reference batches or to the table values. The reason(s) for this remained unsolved, although the underlying cause might be in the injection molding machinery itself or in the three raw material batches that were received. Finding the cause for the inferior mechanical properties in the injection molded test bars would probably be worthwhile to look into in future projects or Theses.

As for the *ad hoc* –tools for preparing stock material for machining, little success was gained. The two most promising tools, cylindrical press and aluminium block mold, had both one common factor: high pressure. The cylindrical press suffered significant damage during the tests and the object was not easily removable from the mold. With some development work, this press system might prove to be a rather useful tool in making stock blocks for machining. It is recommended that at least these changes in the design should be made:

- Press cylinder would have to withstand great amounts of pressure, so the material should be chosen with this in mind. High-strength steel tube with sufficient wall thickness (8-15 mm) should suffice.
- Higher pressure should be introduced to the pressing piston. Pressure should exceed 20 kN. A right holding time for the pressure should be searched.
- A mechanism for releasing the ready part should be designed. A type of releasing agents may be introduced to the cylinder walls as well as a locking mechanism for releasable bottom plate, so the ready part could be pressed through the cylinder. The mechanism for attaching the bottom plate to the cylinder so that it withstands the pressure is critical.

Also, a completely new method of working was hypothesized in the late stages of this study: a screw-like feeder tube, which mimics the barrel in injection molding machine. This screw should have adjustable heating elements on its sides, preferably divided in four sections that could be adjusted separately. With this screw, it could be possible to introduce enough heat and pressure to the raw material that it would melt sufficiently. It would be extremely hard to build a set-up that features the rapid movement of an actual injection molding machine, so this tool would work more like an extruder, and the molten mass would be fed through a hole in a plate to form desired shape.

This project has shown that it is possible, but not easy nor fast, to find and make experimental methods and tools for manipulating thermoplastics. The properties of the polypropylene-biofiber composite did, in fact, make the task even harder, since lower temperatures and therefore higher pressures had to be used than when working with pure polypropylene. Delays in obtaining stock material resulted in the fact that no ready parts for the ConceptCar demonstration vehicle were prepared during the timeframe of this study, but this Thesis has provided an infrastructure and basis for manufacturing the parts quickly and easily after the stock material has been obtained. The preliminary results also show that, if the stock material is properly manufactured and its mechanical properties are in line with the table values provided by the manufacturer, the material can be used in making experimental components for automotive solutions. Long-term testing and material testing for the ready parts should be done in the future, to ensure the suitability for manufacturing actual components. This study has also brought a great amount of knowledge of thermoplastics and testing of the properties of thermoplastics to the ConceptCar-project.

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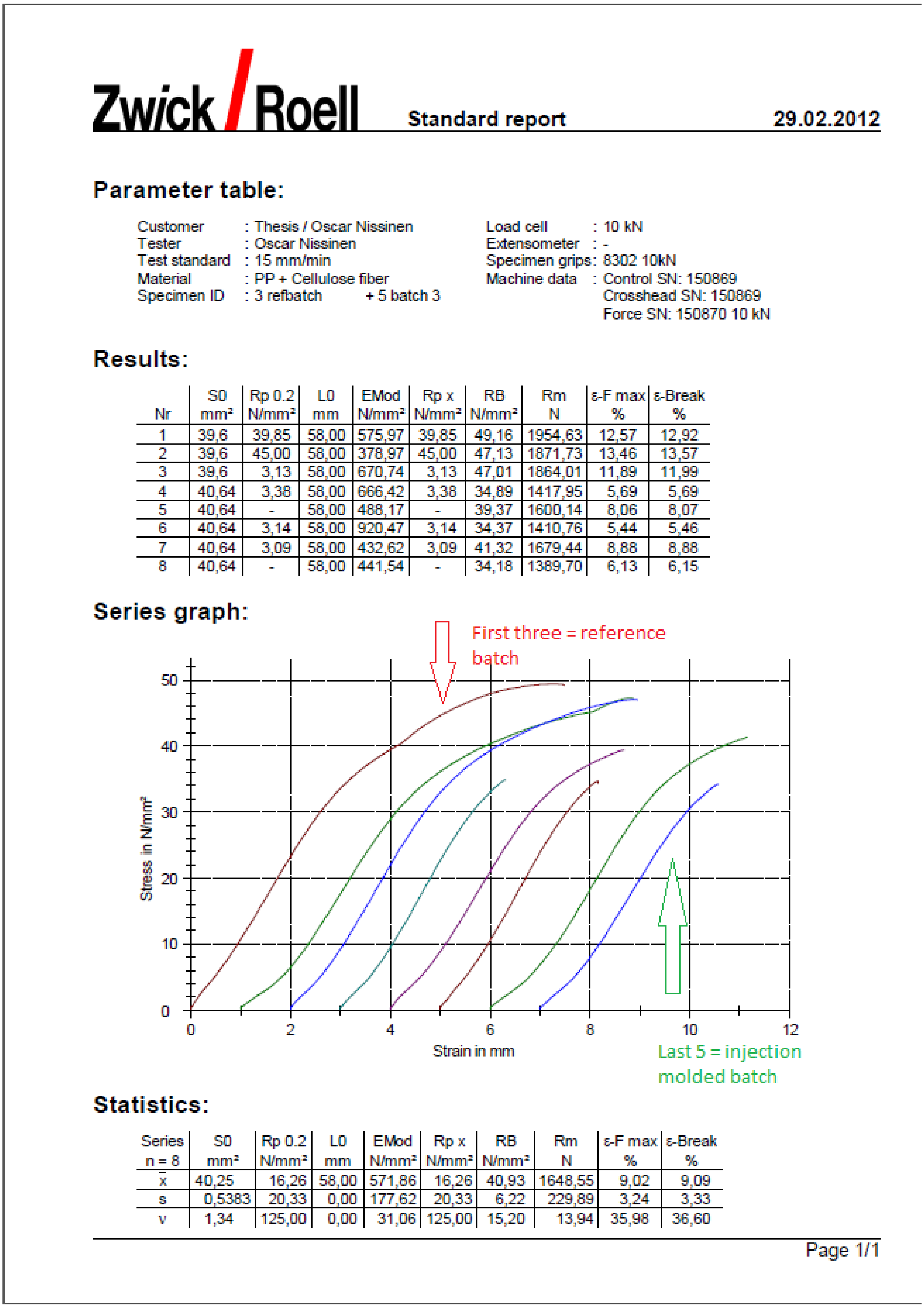
Tensile Testing Results: Reference Batch + IM Batch



Zwick Roell **Standard report** **29.02.2012**

Parameter table:

Customer : Thesis / Oscar Nissinen
Tester : Oscar Nissinen
Test standard : 15 mm/min
Material : PP + Cellulose fiber
Specimen ID : 3 refbatch + 5 batch 3

Load cell : 10 kN
Extensometer : -
Specimen grips: 8302 10kN
Machine data : Control SN: 150869
Crosshead SN: 150869
Force SN: 150870 10 kN

Results:

Nr	S0 mm²	Rp 0.2 N/mm²	L0 mm	EMod N/mm²	Rp x N/mm²	RB N/mm²	Rm N	ε-F max %	ε-Break %
1	39,6	39,85	58,00	575,97	39,85	49,16	1954,63	12,57	12,92
2	39,6	45,00	58,00	378,97	45,00	47,13	1871,73	13,46	13,57
3	39,6	3,13	58,00	670,74	3,13	47,01	1864,01	11,89	11,99
4	40,64	3,38	58,00	666,42	3,38	34,89	1417,95	5,69	5,69
5	40,64	-	58,00	488,17	-	39,37	1600,14	8,06	8,07
6	40,64	3,14	58,00	920,47	3,14	34,37	1410,76	5,44	5,46
7	40,64	3,09	58,00	432,62	3,09	41,32	1679,44	8,88	8,88
8	40,64	-	58,00	441,54	-	34,18	1389,70	6,13	6,15

Series graph:

Statistics:

Series n = 8	S0 mm²	Rp 0.2 N/mm²	L0 mm	EMod N/mm²	Rp x N/mm²	RB N/mm²	Rm N	ε-F max %	ε-Break %
x	40,25	16,26	58,00	571,86	16,26	40,93	1648,55	9,02	9,09
s	0,5383	20,33	0,00	177,62	20,33	6,22	229,89	3,24	3,33
ν	1,34	125,00	0,00	31,06	125,00	15,20	13,94	35,98	36,60

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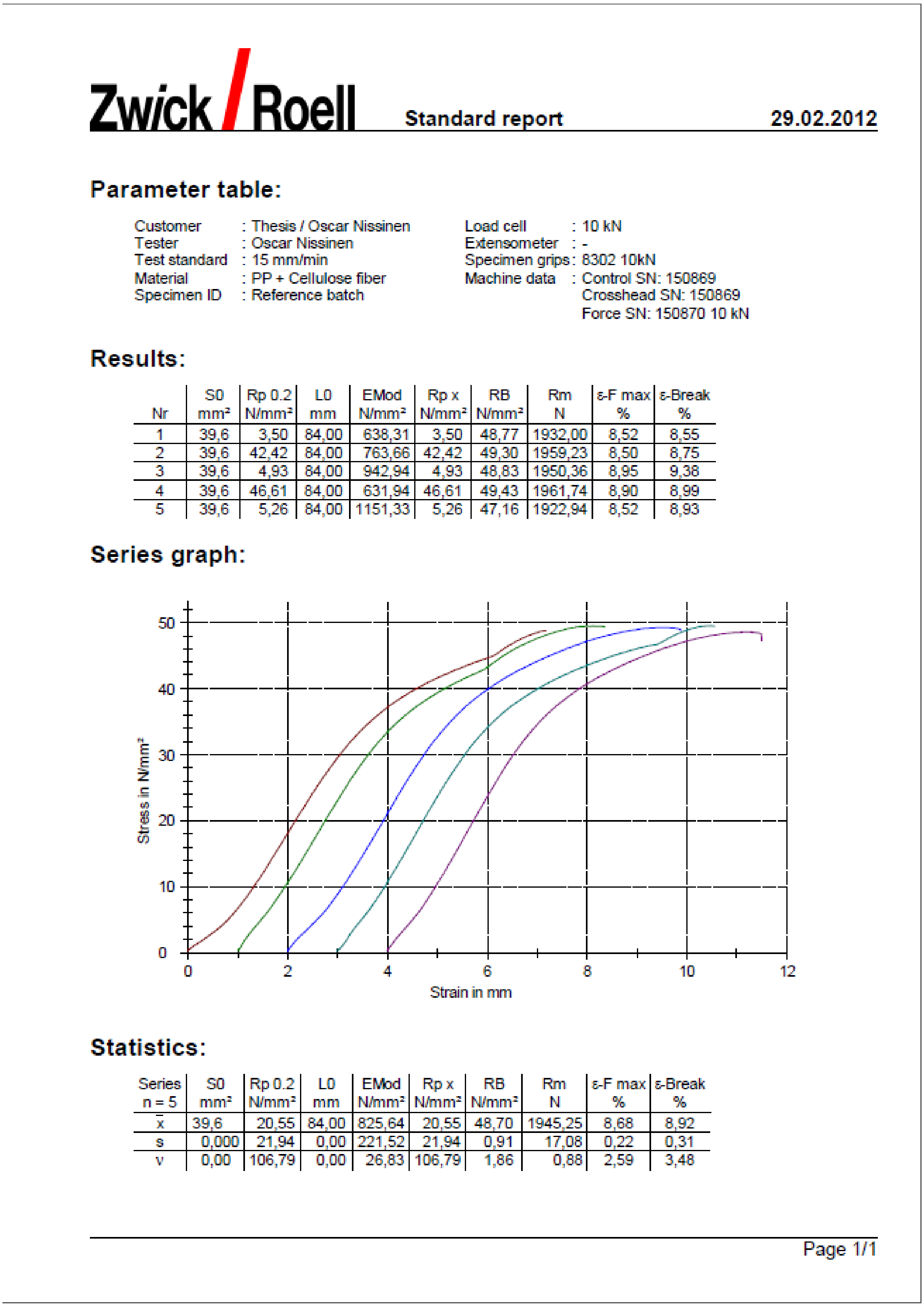
Tensile Testing Results: Reference Batch



Zwick / Roell **Standard report** **29.02.2012**

Parameter table:

Customer : Thesis / Oscar Nissinen
Tester : Oscar Nissinen
Test standard : 15 mm/min
Material : PP + Cellulose fiber
Specimen ID : Reference batch

Load cell : 10 kN
Extensometer : -
Specimen grips : 8302 10kN
Machine data : Control SN: 150869
Crosshead SN: 150869
Force SN: 150870 10 kN

Results:

Nr	S0 mm²	Rp 0.2 N/mm²	L0 mm	EMod N/mm²	Rp x N/mm²	RB N/mm²	Rm N	ε-F max %	ε-Break %
1	39,6	3,50	84,00	638,31	3,50	48,77	1932,00	8,52	8,55
2	39,6	42,42	84,00	763,66	42,42	49,30	1959,23	8,50	8,75
3	39,6	4,93	84,00	942,94	4,93	48,83	1950,36	8,95	9,38
4	39,6	46,61	84,00	631,94	46,61	49,43	1961,74	8,90	8,99
5	39,6	5,26	84,00	1151,33	5,26	47,16	1922,94	8,52	8,93

Series graph:

Statistics:

Series n = 5	S0 mm²	Rp 0.2 N/mm²	L0 mm	EMod N/mm²	Rp x N/mm²	RB N/mm²	Rm N	ε-F max %	ε-Break %
$\bar{x}$	39,6	20,55	84,00	825,64	20,55	48,70	1945,25	8,68	8,92
s	0,000	21,94	0,00	221,52	21,94	0,91	17,08	0,22	0,31
ν	0,00	106,79	0,00	26,83	106,79	1,86	0,88	2,59	3,48

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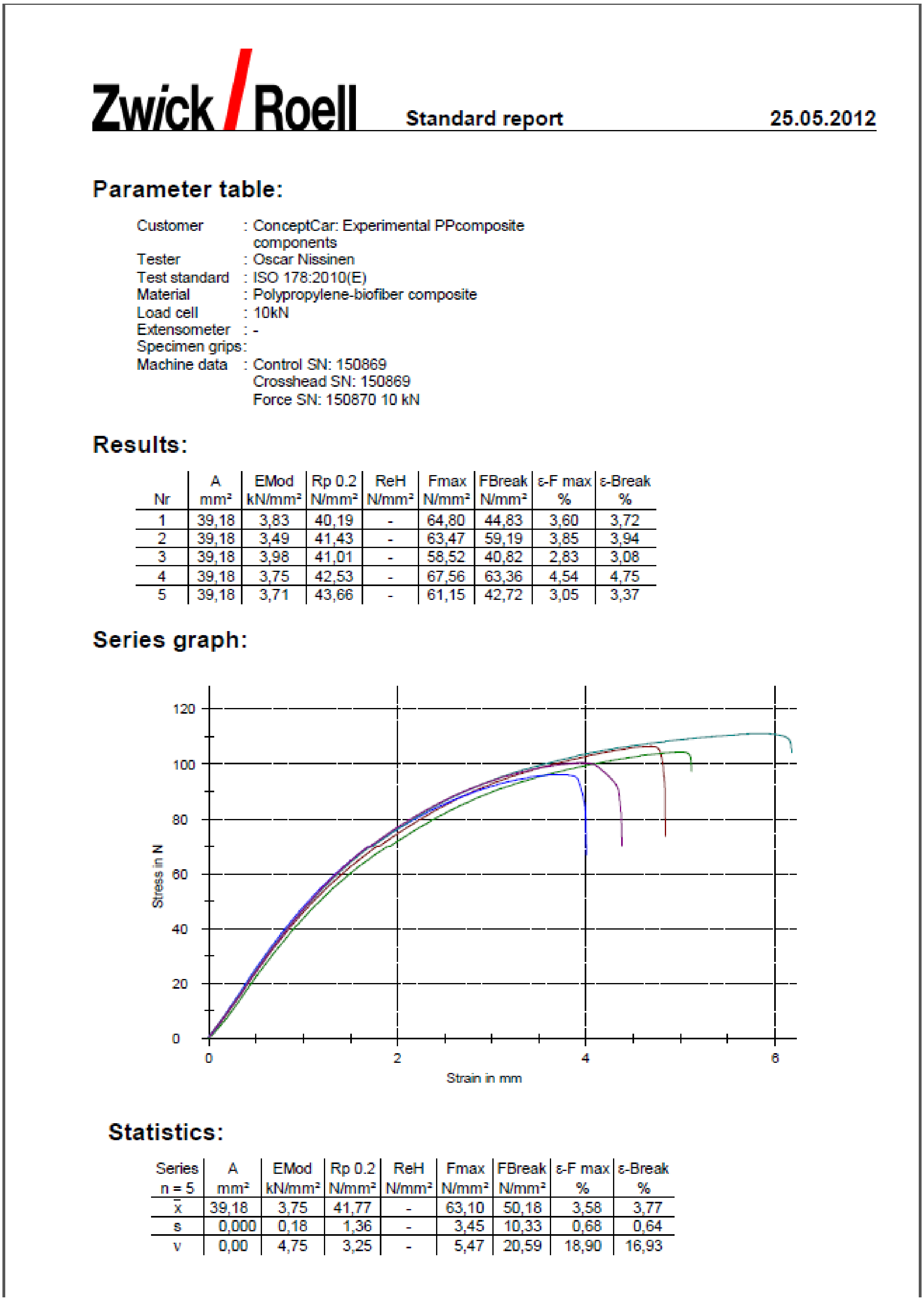
Three-point Flexure Results: Injection Molded Batch



Zwick Roell **Standard report** **25.05.2012**

Parameter table:

Customer : ConceptCar: Experimental PPcomposite components
Tester : Oscar Nissinen
Test standard : ISO 178:2010(E)
Material : Polypropylene-biofiber composite
Load cell : 10kN
Extensometer : -
Specimen grips:
Machine data : Control SN: 150869
Crosshead SN: 150869
Force SN: 150870 10 kN

Results:

Nr	A mm²	EMod kN/mm²	Rp 0.2 N/mm²	ReH N/mm²	Fmax N/mm²	FBreak N/mm²	ε-F max %	ε-Break %
1	39,18	3,83	40,19	-	64,80	44,83	3,60	3,72
2	39,18	3,49	41,43	-	63,47	59,19	3,85	3,94
3	39,18	3,98	41,01	-	58,52	40,82	2,83	3,08
4	39,18	3,75	42,53	-	67,56	63,36	4,54	4,75
5	39,18	3,71	43,66	-	61,15	42,72	3,05	3,37

Series graph:

Statistics:

Series n = 5	A mm²	EMod kN/mm²	Rp 0.2 N/mm²	ReH N/mm²	Fmax N/mm²	FBreak N/mm²	ε-F max %	ε-Break %
$\bar{x}$	39,18	3,75	41,77	-	63,10	50,18	3,58	3,77
s	0,000	0,18	1,36	-	3,45	10,33	0,68	0,64
v	0,00	4,75	3,25	-	5,47	20,59	18,90	16,93

Three-point Flexure Results: Reference Batch

Zwick Roell **Standard report** **25.05.2012**

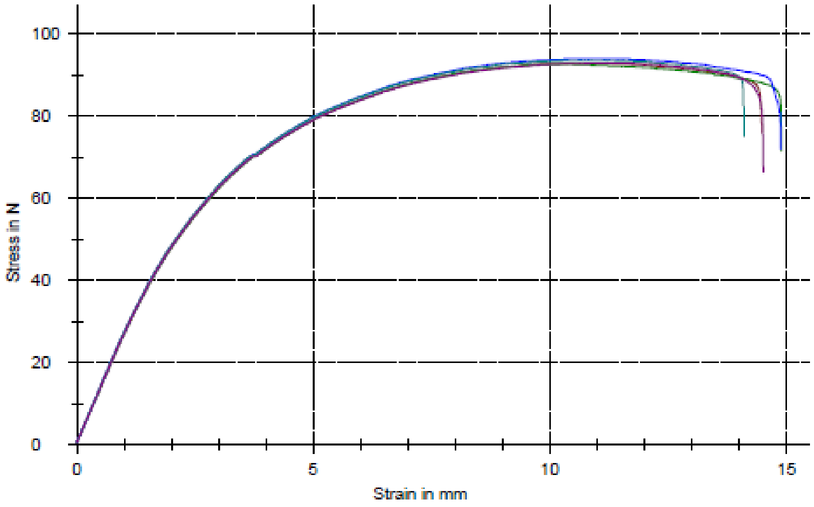
Parameter table:

Customer : ConceptCar: Experimental PPcomposite components
Tester : Oscar Nissinen
Test standard : ISO 178:2010(E)
Material : Polypropylene-biofiber composite
Load cell : 10kN
Extensometer : -
Specimen grips :
Machine data : Control SN: 150869
Crosshead SN: 150869
Force SN: 150870 10 kN

Results:

Nr	A mm²	EMod kN/mm²	Rp 0.2 N/mm²	ReH N/mm²	Fmax N/mm²	FBreak N/mm²	ε-F max %	ε-Break %
4	43,82	2,73	30,19	50,79	50,79	41,53	5,50	7,65
5	43,82	2,78	29,39	50,66	50,66	39,05	5,43	7,87
6	43,82	2,82	29,43	51,38	51,38	39,35	5,98	7,86
7	43,82	2,84	29,35	51,19	51,19	41,04	5,76	7,46
8	43,82	2,76	29,86	50,83	50,83	36,22	5,81	7,67

Series graph:



Statistics:

Series n = 5	A mm²	EMod kN/mm²	Rp 0.2 N/mm²	ReH N/mm²	Fmax N/mm²	FBreak N/mm²	ε-F max %	ε-Break %
x̄	43,82	2,79	29,65	50,97	50,97	39,44	5,69	7,70
s	0,000	0,04	0,37	0,30	0,30	2,09	0,23	0,17
ν	0,00	1,59	1,24	0,60	0,60	5,29	4,00	2,24