

**Incoming Exchange Student - Master Thesis**  
Erasmus x Techno  Other (specify):

**Title of master course:** Master Enginyeria Industrial

**Title of master thesis:**

Investigation and optimization of 3D printers setting and surface treatment

**Document:** Master Thesis

**Student** (Name & Surname): Bence Pál Gávay

**EPS Advisor:** Dr. Norbert Blanco

**Department:** Eng. Mecànica i de la Construcció Industrial

**Delivered on** (month/year): 1/2016

## **Acknowledgements**

First of all I would like to say thanks to my supervisors; to Jordi Torrent and Norbert Blanco they helped me a lot to solve my problems in this study.

I would like to say also to Yunior Batista and his colleagues in the test laboratory for preparing and testing the specimens.

I am very thankful to the Erasmus+ Student Exchange Program which provided expertise that greatly assisted the research and to Patricia Eyskens Erasmus coordinator for her support and patience.

## **Abstract**

In the recent years the fused deposition modelling (FDM) became one of the most popular rapid prototyping (RP) techniques. With this method we are able to build a composite object layer-by-layer. However, because only a limited number of materials, such as thermoplastics have been used as a feedstock for FDM, the final products have limited mechanical properties. The fiber reinforcement materials can significantly increase the mechanical properties, such as stiffness and strength, of the final product, especially in the direction of the filament. Nevertheless, the mechanical properties of the final part on the transverse directions still rely on the poor adhesion between filament layers.

In this study the main purpose is to investigate the 3D printed object structures and fiber-orientation, and find the best settings in case of carbon fiber reinforced plastic 3D printing. The study also considers the need of the tuning of different manufacturing parameters and the modification of certain parts of the 3D printer to adapt it to the new material configuration. Furthermore this study includes the effect of surface-treatment with acetone at the printed objects in order to improve the transverse mechanical properties of the final parts.

To carry out the study, different test specimens will be manufactured according to different manufacturing configurations and the mechanical properties of the material will be characterized by means of different standard tests.

In my study to reach the desired quality I will print specimens with several parameters and investigate the effect of the settings to obtain the best setting for the best results. After I reached the proper settings in printing of both materials I printed more than 40 specimens in 3 directions to investigate the effect of the printing direction.

Independently from the thickness of the layers the surface of the printed object never will be perfectly smooth. To reach the smooth surface to use acetone vapor as a surface treatment is a feasible way. In my study I would like to examine the effect of acetone, the necessary time for the treatment.

After I prepare all of the specimens I can them with a tensile test machine. With this experiment I will be able to obtain the following mechanical properties: tensile stress, Young's modulus, Yield strength and Poisson ratio.

## Table of content

1. Introduction .....	5
2. Rapid Prototyping.....	6
3. Fused Deposition Manufacturing (FDM).....	7
3.1. Parts of the 3D printer .....	8
4. Modeling of Large Scale Reinforced Polymer Additive Manufacturing .....	10
5. Materials for FDM.....	12
5.1. Acrylonitrile Butadiene Styrene (ABS).....	12
5.2. Carbon Fiber Reinforced Plastics (CRFP) .....	13
6. Printer settings.....	15
6.1. Print settings .....	15
6.2. Filament settings.....	16
6.3. Printer Settings .....	16
7. Printing from neat ABS.....	17
7.1. First type of specimens .....	19
7.3. Third type of specimens .....	22
8. Printing from carbon fiber reinforced ABS.....	25
8.1. Observations with microscope .....	26
9. Effect of acetone surface treatment .....	28
10. Results of printing .....	31
10.1. Tensile strenght test.....	31
10.1.1. Comparison of specimens I. – Maximum stress.....	32
10.1.2. Comparison of specimens II. - Young modulus .....	33
10.1.3. Comparison of specimens III. - Poisson ratio.....	34
10.1.4. Comparison of specimens IV. - Strain at failure .....	34
11. Conclusions .....	36
12. Bibliography.....	37
13. Appendix A – Test results .....	38

## **1. Introduction**

In the recent years the 3D modelling and 3D printing has become one of most popular engineering field. With these printers we can easily give shape to our plans quasi without any boundaries. These 3D printer works from a computer aided design (CAD) file. Who is able to use this kind of program it will be easy to print 3D objects. In the early years the type of manufacturing was developed to create rapid prototypes on a cheaper way before the fabrication process. Nowadays these methods are used for education, research projects, personalized medical equipment. From the other side these days the price of the small, entry level 3D printers allows to the users to print cellphone adds, gifts, replacements or use the printer for do-it-your-project.

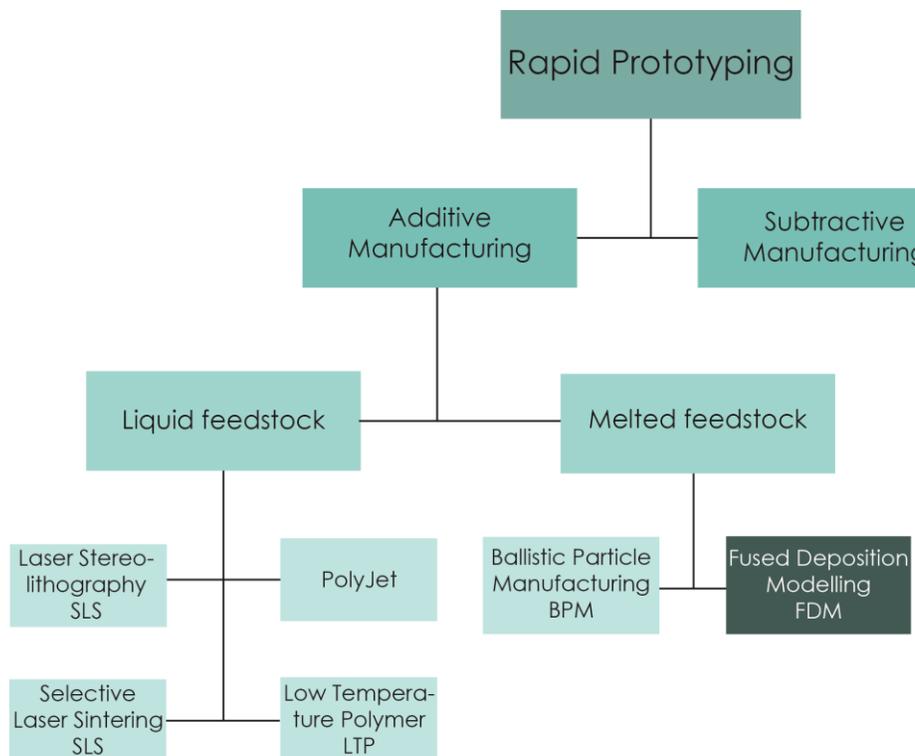
The companies, who are fabricating feedstock for this technology, developed a lot of kind of material for printing, wide variety of colors and material quality of thermoplastics. One of the newest and the most advanced material is the carbon fiber reinforced ABS that is becoming more popular for desktop printers also. With these materials the mechanical properties are even better than in case of neat polymers. This fact allows the spreading of engineering field were we can use this technology.

## 2. Rapid Prototyping

The rapid prototyping (RP) is a group of manufacturing techniques whereby we are able to produce the prototype version of the final product. The greatest advantage of this method is that the production time is much shorter and the manufacturing cost is much lower than in case of traditional techniques. The other benefit of RP is that we don't waste material in the manufacturing process compared to the original subtractive methods.

Every RP process starts with designing the product in a computer aided design (CAD) software then we have to save this file in stereolithographic (.stl) format. We can put the file in slicer software then this software creates a tool-path for our RP machine.

Nowadays we have several solutions to fabricate our prototype as you can see in the Fig. 1.

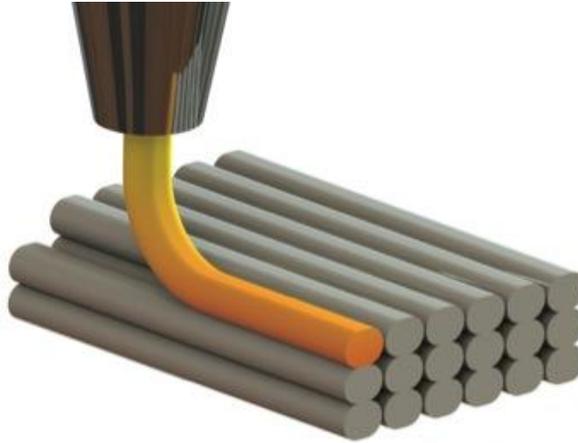


**Figure 1 Classification of rapid prototyping**

In my study I used fused deposition modelling which is one of the most popular 3D printing techniques. The rapid prototyping name doesn't fit for this process anymore because of the quality of materials and printers thus we are able to print the final product.

### 3. Fused Deposition Manufacturing (FDM)

In FDM, 3D plastic parts can be built layer by layer depositing build material which are heated and extruded through extrusion nozzles on the liquefier head, as shown in Figure 2.



**Figure 2 Fused deposition manufacturing**

The process begins with creating a 3D model by a modeling software, saved as stereolithographic file format (STL). The second step is mathematically slicing and orienting the model for the build process. In some cases if it is necessary, support structures may be generated by the slicing program.

The machine may use multiple materials to achieve different goals with two nozzles: one may use one material to build up the model and use another as a soluble support structure.

The model or part is produced by extruding small flattened strings of molten material to form layers as the material hardens immediately after extrusion from the nozzle.

A plastic filament or metal wire is unwound from a coil and provides material to an extrusion nozzle which can turn the flow on and off. There is typically worm-drive that pushes the filament into the nozzle at a controlled rate.

The nozzle is heated to melt the material. The thermoplastics are heated past their glass transition temperature and are then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism. The nozzle follows a tool-path controlled by a computer-aided-manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear design, although other mechanical designs such as Deltabot have been employed.

Although as a printing technology FDM is very flexible, and it is capable of dealing with small overhangs by the support from lower layers, FDM generally has some restrictions on the slope of the overhang, and cannot produce unsupported stalactites. [1]

Each single layer will be deposited repeatedly in the same way on the previous one, being fed by the filament spools of the two types of materials until the part is completed. Finally, support material can be removed by water-based cleaning solution in tank with no surface damages.

There are several benefits to the Additive Manufacturing (AM) process. A key benefit of AM lies in the fact that AM processes are able to produce parts free of geometrical constraints, and provides complete flexibility in design and construction. The fact that materials are added rather than subtracted, results significant reduction of waste material. Furthermore, parts are built directly from a CAD model, without the direct need of application-specific tooling. This makes AM feasible for low-volume production of complex parts. The geometrical freedom means AM technologies are capable of producing freeform channels and lattice structures.

### 3.1. Parts of the 3D printer

The printer, what I used is a Cooking-hacks Prusa i3. Fig. 3 shows the printer and the most important parts of printer.

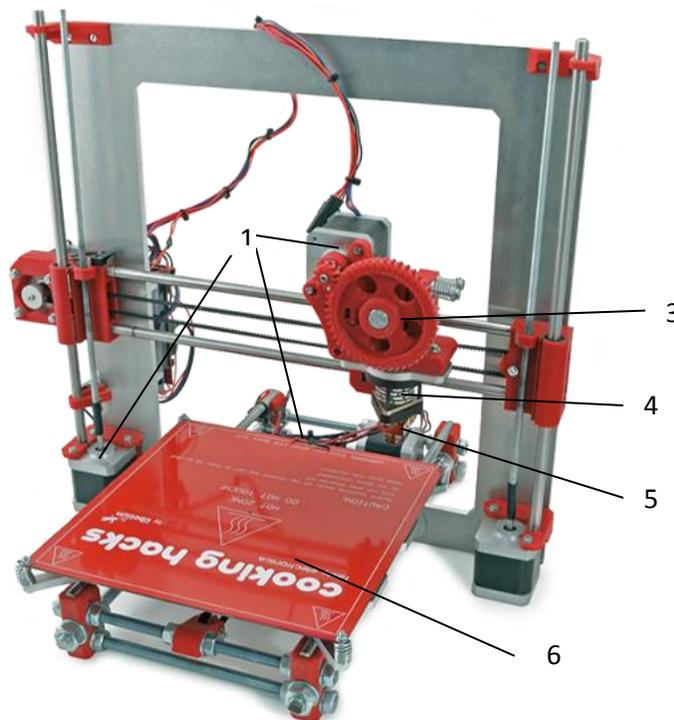


Figure 3 Cooking Hacks 3D printer

1. Servomotors: There are 3 servomotors in the printer. These motors are responsible for keeping the nozzle in the right position while printing and to follow the path as the G-code supposed.
2. Filament: The feedstock can be pellets and filament also. To use filament is a common method, you can find it usually above the printer in spooled form. (It isn't in the picture.)
3. Worm-drive: There is a typically worm drive, which is responsible to transmit the filament from to the bed from the spool. This process is controlled by computer also.
4. Liquefier head: The worm-drive push the filament in the direction of the nozzle through the liquefier head. This part of the printer melts the filament and the temperature is controlled by computer between 0-260 Celsius degree.
5. Extrusion nozzle: The liquid filament comes out from the nozzle and it solidifies on the top of the last layer. The diameter of the nozzle is usually 0.35 mm, but it depends on the material, what we print.
6. Heated bed: In our printer we can heat the bed which is quite important to print an object with excellent quality. The maximum bed temperature is 110 Celsius degree. The temperature, what we set depends on the material and the circumstances.

#### 4. Modeling of Large Scale Reinforced Polymer Additive Manufacturing

The dilatation, warp and residual stresses frequent design problems. Nowadays the engineers are able to build significantly bigger 3D printer systems than the entry level 3D printers. In collaboration of Cincinnati Inc. and ORNL has a large FDM system developed. This system usually build formations several meters in size at rates between 5 *kg/hr* and 50 *kg/hr* using a combination of robotic and extrusion deposition technology. (A desk-3D printer produced objects measured in centimeter with material deposition rates ranging from 0,010 to 0,081 *kg/hr*.) The material that used for this project was carbon fiber reinforced ABS.

With this system the engineers were able to print a frame of vehicle, it is called Strati Vehicle. The common problems warps, cracks and deformations were also visible in this project. The cracks usually occur in thin features. The thermally induced stresses caused by differential cooling of the CFRP material from nearby melt temperature close to the extruder to ambient temperature of the vehicle. Because of the size of the model, the quantity and quality of the material to develop a virtual tools to analyse the model was required.

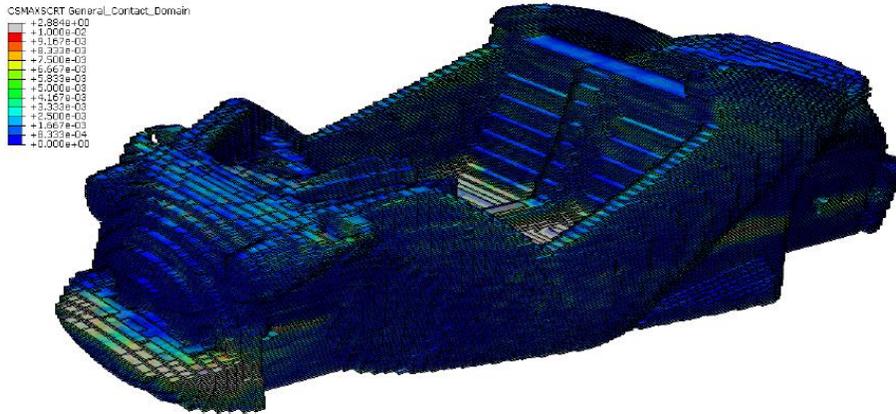
The first step is to generate Finite Element Method (FEM) mesh of the compound structure. Alpha Star Inc. combined a device in their Genoa software for meshing of 3D printed structures. This device creates a regular rectangular mesh using a G-code from path generation software. The tool path is threaded through the background grid and activates the elements for the FEM model.

All of the finite elements contain information about the time, orientation and printing parameters from the G-code based on the traversal path and its residence time in the element. This orientation information is then used for generation of anisotropic mechanical and thermal properties within each element.

For each layer, finite elements with orientation information can then be assembled into an FEM mesh representing partially built structure.

*“The solution approach depends on available computer resources and the available simulation time. For the simplest solution, the thermal profile as a function of time can be assigned to each element based on g-code information and previous observations for similar builds. Such observations can be obtained from infrared camera or strategically placed thermocouples. Alternatively, the thermal problem involving conduction, convection and radiation can be solved along with the deformation and stresses. The utilized solution was the following. The fully coupled thermal-stress analysis is by knowing the temperature field from the test. The temperature field data (which might be influenced by stress responses) are used as the input to the analysis.*

*Distortion (due to thermally induced residual stresses) during the FDM process is vital information for subsequent assembly of additional components connected to the vehicle. Figure 31 shows predicted crack initiation locations calculated from the stress state of the printed part. The predicted crack locations correspond to empirically observed problem areas with the thin section of the front fender being particularly susceptible to crack.”*



**Figure 31 Possible cracks locations caused by residual stress**

After the mesh of the vehicle is generated, additional loads can be applied to the structure whichever in an un-deformed state. The rectangular nature of the FEM mesh will likely result in artificial localized stress concentration, however global stiffness and predicted deformations may add helpful data about the performance of the structure in service.

With this project a feasible computational approach demonstrated for simulation ED process of large complex structures. [13]

## 5. Materials for FDM

However, there is only a limited number of materials, such as thermoplastics and some engineering plastics have been used as a feedstock for FDM, the final products have limited mechanical properties. The disadvantages are given by this phenomenon.

The most frequently used as a feedstock for fused filament fabrication (FFF) is ABS (acrylonitrile butadiene styrene), followed by PC (polycarbonate), PLA (polylactide), PPSF (polyphenylsulfone), and mixtures thereof. [2]

### 5.1. Acrylonitrile Butadiene Styrene (ABS)

ABS is a frequent thermoplastic polymer, made by polymerizing styrene and acrylonitrile in the presence of polybutadiene as shown in Figure 4. The portions can be the following:

- 40-60 % styrene provides shiny and impervious surface,
- 15-35 % acrylonitrile gives the strength,
- 5-30 % butadiene (a rubbery substance) grants the toughness to the material. [3] [4] [5]

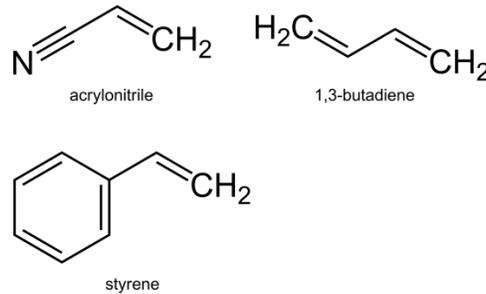


Figure 4 Monomers in ABS polymer

Properties of ABS	
Features	Limitation
<ul style="list-style-type: none"> <li>➤ Dimensional stability</li> <li>➤ Very high impact strength</li> <li>➤ Excellent ductility</li> <li>➤ Good chemical resistance</li> <li>➤ Rigid</li> <li>➤ Excellent toughness</li> <li>➤ Good creep resistance</li> <li>➤ Useful characteristics within a temperature range from -20 to 80 C</li> <li>➤ relatively low cost</li> </ul>	<ul style="list-style-type: none"> <li>➤ It can be sensible for the sunlight</li> <li>➤ Poor weather ability</li> <li>➤ Poor solvent resistance (ketones, acetone, esters etc.)</li> </ul>

Table 1 Properties of ABS

Mechanical properties for ABS (Extruded)		
Properties	Average value	Unit
Density	1,05	g/cc
Hardness, Rockwell R	102	-
Ultimate tensile strength	38,2	MPa
Yield tensile strength	41,5	MPa
Glass transition temperature	108	Celsius degree
Melt temperature	221	Celsius degree
Nozzle temperature (for processing)	229	Celsius degree

**Table 2 Mechanical properties for ABS [6]**

ABS is used in very wide variety of everyday life, for example:

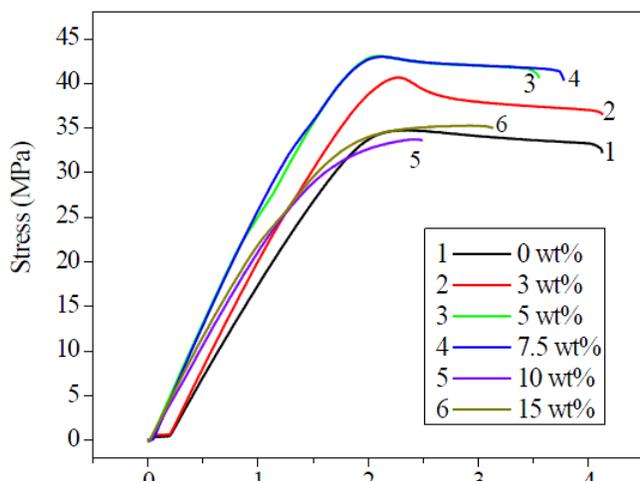
- household goods
- mobile phones
- car industry
- toys (Lego)
- electrical segment

## 5.2. Carbon Fiber Reinforced Plastics (CRFP)

To enhance the aforementioned limited mechanical properties we have few methods. Using carbon fiber for reinforcing of the neat material is a feasible possibility.

### Effect of carbon fibers

Fu-da Ning et al. [7] investigated the effect of carbon fibers and then compared the effect of



**Figure 5 Stress-Strain curves at different CF loaded ABS**

100  $\mu\text{m}$  and 150  $\mu\text{m}$  fiber lengths and the effect of different carbon fiber content. For this experiment they used 150  $\mu\text{m}$  carbon fiber reinforced ABS.

The first step was to manufacture the filament. The fabrication process started with mixing the plastic pellets and the carbon fibers in a blender, then extruded the material with an extruder machine to achieve the filament that used for the FDM process. The following mechanical properties can be obtained from strain-stress curves: tensile strength, Young's

modulus, toughness, ductility, and yield strength. The result of different carbon fiber content is

visible in the Figure 5. The largest tensile strength value (42 MPa) was at carbon fiber content of 5 wt% and the smallest value was at carbon fiber content 10 wt% (34 MPa) that is close to the value of neat ABS.

The Young modulus was increased between 0-7,5 wt% carbon fiber content (25 MPa), after the fiber content exceed this value the Young's modulus started to decrease but the smallest value was in case of neat ABS specimens (19 MPa). In case of toughness and yield strength had an overall decreasing tendency when carbon fiber content increased from 0 wt% to 10 wt%. When they investigated the ductility, the results were the following. The best ductility was in the neat ABS and then the values decreased until the fiber content reached the 10 wt%. After 10 wt% fiber content the ductility value started to increase.

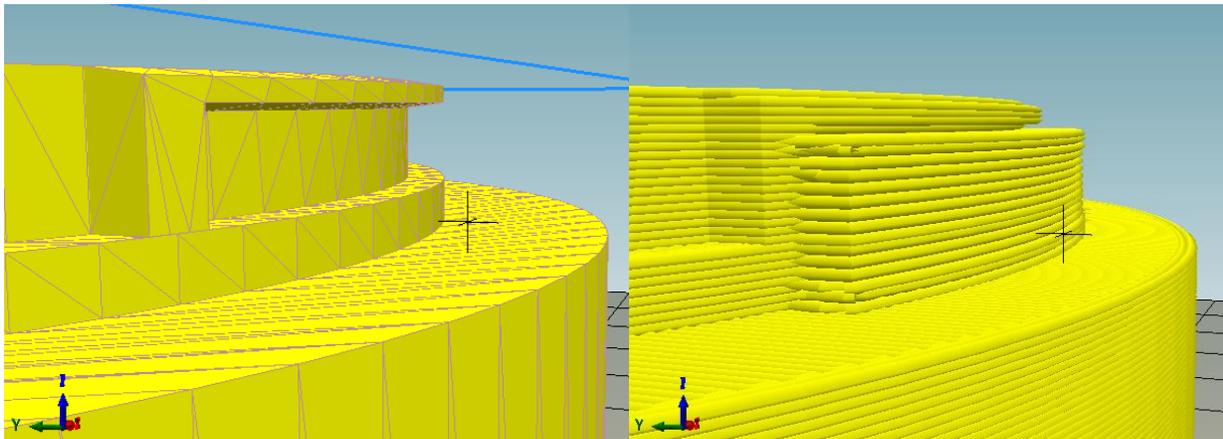
The carbon fiber reinforced plastic composites specimen with 150  $\mu\text{m}$  carbon fiber had larger tensile strength and Young's modulus than that with 100  $\mu\text{m}$  carbon fiber. Compared with CFRP composites specimen with 100  $\mu\text{m}$  carbon fiber, specimen with 150  $\mu\text{m}$  carbon fiber had smaller toughness and ductility. The yield strengths of these two kinds of specimen are nearly the same.

## 6. Printer settings

The printing process starts with the creation of the 3D model then we can put the file in the slicer program. In this program we have to set the printer parameters before we slice the object for layers. The printers use a special programming language it's called G-code. The G-code is used in general AM techniques to control automated machine tools. With this method the engineers can tell to the computerized machine tools how to make the appropriate object. In this case “how” determine information on how fast to move, where to move, what path to move how many materials to use etc. [8]. The parameters what we set can define the G-code. These settings are the following.

### 6.1. Print settings

In this part we can set the infill and perimeters, so the height of the layers and the number of vertical/horizontal (top and bottom) shells. We can also define by the infill part the density and pattern of filling inside of the object and the top and bottom layers also. In those case, where the layers should be printed “in the air” without underpinning part we can use support material as shown in Figure 6-7.



**Figure 6 Object before slicing without support material**

**Figure 7 Support material after slicing**

We can set the speed of the printing. From the point of quality, the speed is an important factor. There are two toothed belts in the printer. One of them is responsible for moving the nozzle in X direction, the other moves the bed in Y direction. The fast moves can load the toothed belt dynamically and if the belts are not tight enough, the perimeter of layers above to each other can't be in one plane. From the other hand the shorter printing time would be better for the connection between the layers, because we don't let enough time for the layers to cool down therefore the whole object can cool down at the end of the printing. In this case the chance for the breaking by dilatations is smaller, but it depends on the size and the shape of the object, the

number and thickness of layers. In the setting we can add another nozzle which is able to work with the basic nozzle and add support material to the object in the same time. We use just only one nozzle.

## **6.2. Filament settings**

In this section we can set the properties of filament. We can tell the printer how many materials have to be used for printing; we have to set the diameter of the filament and multiplier of extrusion. The commercial filaments are prepared usually 2.5-5 mm diameter, but to measure the accurate diameter is recommended. With modifying the parameter (for example, add 3% more material) we can influence the connections between the lines and layers.

## **6.3. Printer Settings**

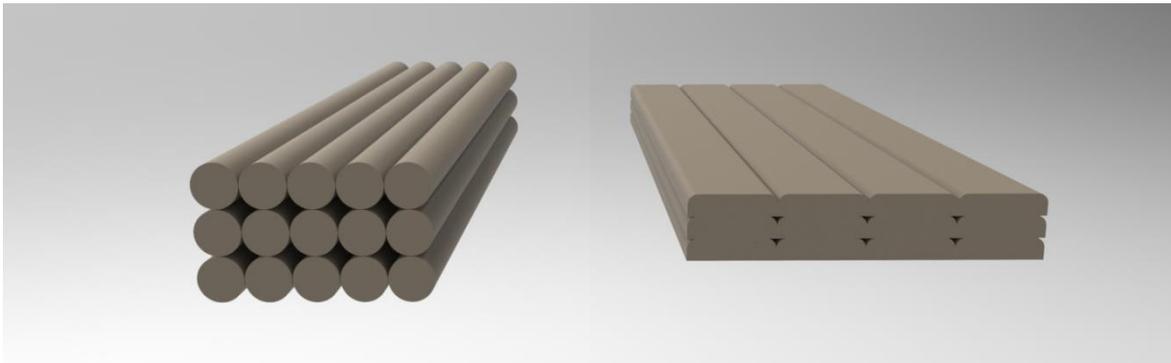
By printer setting we can define mainly the start G-code and end G-code, and the diameter of the nozzle. In our printer this size is 0.35 mm. The number of lines in one layer depends on this parameter. For the basic specimens I set 0.3 and 0.35 mm also. The difference between this two size, that the printer create more or less lines in one layer. If we set smaller value, the printer will print more lines. In the basic specimen the result are the following:

- nozzle diameter: 0.35 – 28 lines in the middle part of the specimen
- nozzle diameter: 0.30 – 37 lines in the middle part of the specimen

To use smaller diameter means that we push more material in the same object, causes better connection between the layers and lines. So the result is better quality specimens.

## 7. Printing from neat ABS

To find the accurate settings for the proper quality I printed four test-cubes and more than 15 specimens. The quality of the printing depends on the connection between the layers and lines. This line deposited in raster patterns (in a pattern that is composed in parallel lines). If we set the printer with the basic parameters, the results are going to be the following. The printer will push just enough material for the object (so we don't waste material) but at the same time the connection between lines and layers are going to be a bit weaker because of the voids which are between the lines as illustrated in Figure 8. Between these parallel lines there are voids that can significantly decrease the mechanical properties. Therefore this phenomenon causes highly anisotropic 3D printed object, the strength of the printed object depends on the direction of loading and printing. [9] If we modify the setting and use more material for the same model, we can decrease the number and the size of the voids in the printed object as illustrated in Fig. 9.



**Figure 8** Lines with the original settings

**Figure 9** Decreasing the size of the voids

The question is, what can we set for the better quality. We have several setting to modify:

- nozzle diameter: We can push more material by aforementioned factors.
- filament diameter: Use smaller diameter in the setting means that we can push more material while printing.
- extrusion multiplier: The original value is one, we can set it to 1.03 which means we push 3% more material.
- bed temperature: The bed temperature can be set between 0-100 Celsius degree. Because of dilatation the temperature difference is an important factor in the connection between the layers. If the printed object can cool down at the end of printing it leads better result than printer create a new warm layer above a cold layer.
- nozzle temperature: Every FDM-compatible material has a recommended printing temperature range. In case of ABS this range is 240-260 Celsius degree. If we set the

temperature from the higher part of the range it means the more molten printed lines can connect more to each other. The higher temperature can influence the color of the material.

In one line the material continuity is given by the specificity of printing process, the mechanical properties are much better in the direction of printing. In this case we have three methods to print a specimen.

To investigate the mechanical properties of specimens I had to print at least seven pieces from each form for the tensile strength test. I put a mirror above the surface of the bed to save it. To fix the first layer of the object I used strong hairspray. The “dog-bones” based on ASTM standard D638 Type I. and the dimensions of the specimens were illustrated in the Figure 10. The parameters that I used for printing are summarized in Table 3.

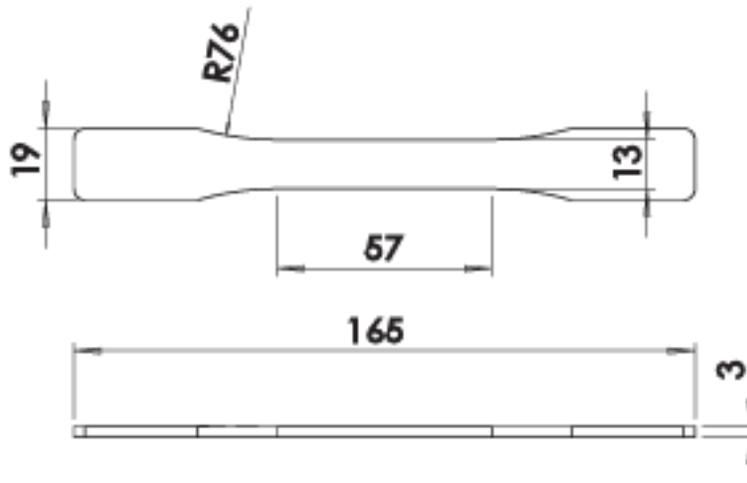


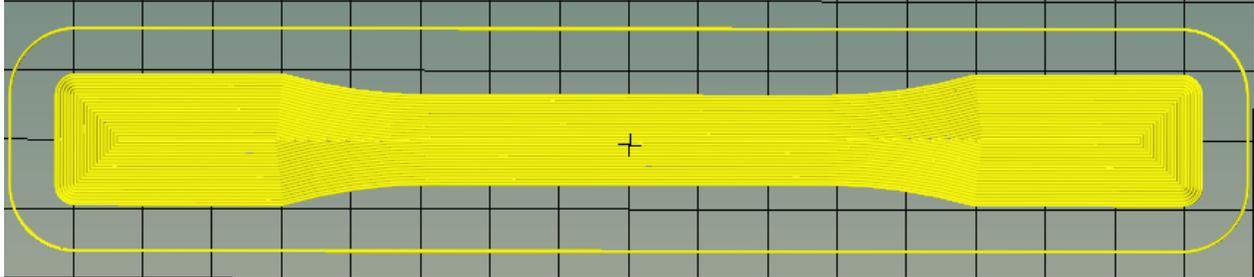
Figure 10 Dimensions of specimens, ASTM, D638 Type I.

Input variables	Value	Unit
Bed temperature-first layer	100	C
Bed temperature-other layers	95	C
Extruder temperature-first layer	250	C
Extruder temperature-other layers	246	C
Nozzle diameter	0,35	mm
Extrusion multiplier	1,03	-
First layer thickness	0,3	mm
Other layer thickness	0,2	mm
Velocity of perimeter printing	60	m/s
Velocity of first layer printing	30	m/s
Velocity of infill printing	80	m/s

Table 3 Printer parameters for ABS printing

## 7.1. First type of specimens

In the first case the lines are parallel to each other and the direction of loading and printing concur. This type is shown in the Figure 11.



**Figure 11** Direction of printing in the first type in the slicing software

First of all in generally the first layer can't stay on the bed without external help. It means, somehow we have to create a tacky surface on the bed. I prefer for this to use strong hairspray. The hairspray can fix the first layer on the bed and at the end of printing process one layer from the hairspray usually stuck on the first layer of specimen. After the specimen and the heated bed cooled down it's easy to remove the specimen from surface of bed than we can clean the first layer from the hairspray with water. Another viable method to use thermostable ducktape. The first layer is critically important in the printing process. As you can see in the following picture (Figure 12) if the first layer doesn't stuck (because the hairspray wasn't strong enough), the whole printing process can be false.



**Figure 12** Faulty specimen

On the right side of the specimen the connection between the line seems strong enough while on the left side the lines are broken and the connection between the layers are also faulty. Because this specimen was one of the first I didn't set the printer to print more material. In this case the link between the lines can't be strong enough causes by the distance among the lines. At the end of printing the specimen had this curved shape. This is the effect of dilatation. The liquid material hardens immediately after extrusion and becomes colder than 90-100 C degrees. Since the printer heats the bed there is a temperature difference among the first heated layer and the last

layer. The colder layer becomes a bit smaller it can constrict the top of the specimen and results this curved shape. If the hairspray is strong but the dilatation is stronger, it causes some cracks amid layers. In this case the first and the last layer are going to be suitable but the quality won't be appropriate, as shown on the Figure 12.



**Figure 12 Warping**

We can solve the problem of weak connection by using more material. If we push more material every line is going to be connected to the following one. From the other hand if we push too much material the dog-bones can inadequate. In the following pictures (Figure 13) you can see the result.



**Figure 13 Example for weak connection between the lines and for using too much material**

The parameters of fabrication process was summarized in the Table 4.

Specimen's number	Adjusted diameter	Extrusion multiplier	Temperature			
			Bed		Nozzle	
			First layer	Other layers	First layer	Other layers
1.	2,9 mm	1,03	100	95	250	245
2.	2,9 mm	1,05				
3.	2,9 mm	1				
4.	2,95mm	1				
5.	3 mm	1				
6.	3,1 mm	1				
7.	3 mm	1,02				
8.	3 mm	1,02	100	95	245	240
9.	3 mm	1,03	100	95	250	246
10.	3 mm	1,03				
11.	3 mm	1,03				
12.	3 mm	1,03				
13.	2,85 mm	1,03	100	95	250	246
14.	2,85 mm	1,03				
15.	2,85 mm	1,03				
16.	2,85 mm	1,03				
17.	2,85 mm	1,03				
18.	2,85 mm	1,03				
19.	2,85 mm	1,03				

**Table 4 Test the effect of parameters**

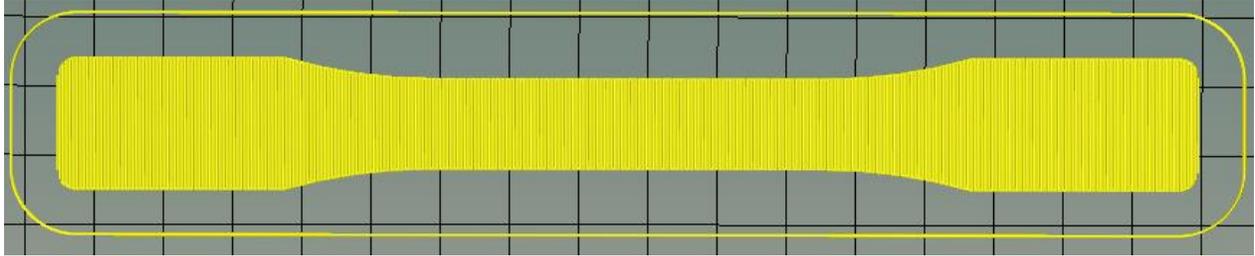
In the following picture (Fig. 14.) you can see the first type of specimens what I printed for the tensile strenght test. Interesting, that from 1 to 12 the color of the filament is white and from 13-19 it's "natural". At the end we tested just the last 7 specimens.



**Figure 14 Neat ABS, first type of specimens**

## 7.2. Second type of specimens

In the second case the lines are parallel to each other but the direction of printing is perpendicular to the direction of loading.



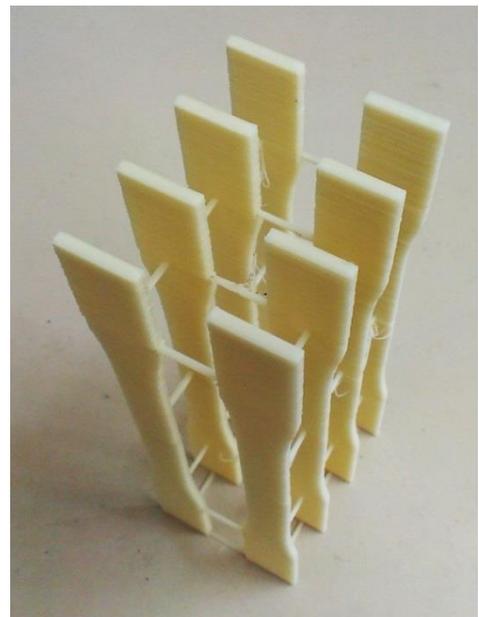
**Figure 15 Second type of specimens, the lines are perpendicular to the direction of loading**

As aforementioned the printer works by slicing software generated G-code. In the slicing program (Repetier Host) we have the possibility to modify the G-code that is already generated. With the basic setting we can slice the specimen but every second layer is going to be created in perpendicular to the previous layer. To reach the proper model I modified the G-code to print every layer like the first one. In the second type I could use the same parameters what I obtained from the experiment of first type thus the printing process was correct and accurate.

## 7.3. Third type of specimens

In this case we can investigate the connection between the layers. One specimen contains 825 layers. The layers are parallel to the surface of bed so the direction of the load is perpendicular to the printing direction. To print this type of dogbones I had to design a new model for printing. To stabilize the object in the first and second case I printer 8 specimens together. The specimens were connected to each other in the first case with sticks as you can see in the following picture. (Fig. 16) The idea to print the specimens together with stick came from the stabilization. It's easy to remove the support-sticks and they are strong enough to fix the model. Even though the result are not suitable for the test. I had the following problems:

- Printing time (18 hour)
- Dilatation
- Model size
- Quantity of specimens



**Figure 16 Third type of specimens with sticks**

The estimated printing time was more than 18 hours so the temperature difference is too big between the night and daytime in the laboratory of the university. (The radiators start to heat the rooms at 6 am.) Because of this circumstances the previous layers were too cold while printing and the connection between the solid and melted material was too weak. To reach the better quality I had four options:

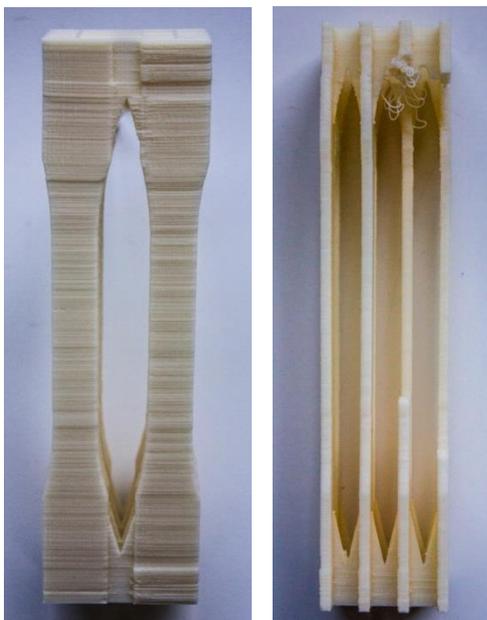
- Decrease the printing time
- Design a more stable model
- Use more support material
- Secure the constant temperature

I had two possibilities to decrease the printing time. The first one is to enhance the printing speed. The problem is with this that the surface of the layer is approximately small so the dynamic effects can be stronger. The other solution is to create a more stable model. In this model I reduced the distance among two specimens (so the printer had not move the nozzle needlessly long time). To stabilize the model I



designed walls among the specimens. It didn't enhance the printing time and I thought with this method I can decrease the dynamic effect. Because these walls were related to the side surface of specimens, I had to decrease the size of the wall in the area of specimen (Figure 17). With this little modification easier to remove the support wall without ruining the side surface of the

specimen. You can see the result on following pictures.



**Figure 18-19. Cracks and broken parts in the third type**

As you can see two of the eight specimens are broken. One of them broke in the night while printing so the printer pushed melted material in the air. This phenomenon is also a sign for dilatation so I searched another way to reach the perfect model. Because the solution of walls was a suitable method I designed the same model but with just only four specimens. The estimated printing time was only nine hours. I printed 8 specimens with this method. The first model was printed at nighttime. The results are better than the previous but some layers aren't suited perfectly to the previous layer.

Because the model was already proper, the printing time didn't take a long time I had to stabilize the temperature. To reach the stabil temperature I build a box around the printer from paper. Then I put a thermometer in the box. The temperature in the laboratory was 17 C degrees, inside of the box it was 26 C degrees. Too high temperature can harm the electrical parts of the printer so I have cut a hole on the top of the box to let the air flow ththrough to box.

## 8. Printing from carbon fiber reinforced ABS

I used ColorFabb XT-CF20 filament for printing. As we can see on the site of the company, it's highly recommended to use stainless steel nozzle and its diameter must be at least 0,4 mm. "A special point of attention is the abrasive nature of the carbon fibers. In general these fibers will accelerate the nozzle-wear of brass nozzles, much faster than unfilled filaments." [10] Because of this reasons I designed a new nozzle shown in the Figure 21.

I needed to face many challenges beneath the manufacturing of specimens. The carbon fibers in the molted material could clog the extrusion nozzle while printing at lower temperature. [9] Some of the users on specialized sites recommend even bigger hole diameter for the nozzle to avoid the problem of clogging so I chose 0.5 mm nozzle hole. The biggest problem was that some molted material stuck on surface of the nozzle then this little, already solid pieces could stuck on the last layer. In my case after the first layer the printing process was stopped by this phenomenon. You can see the result in the following picture.

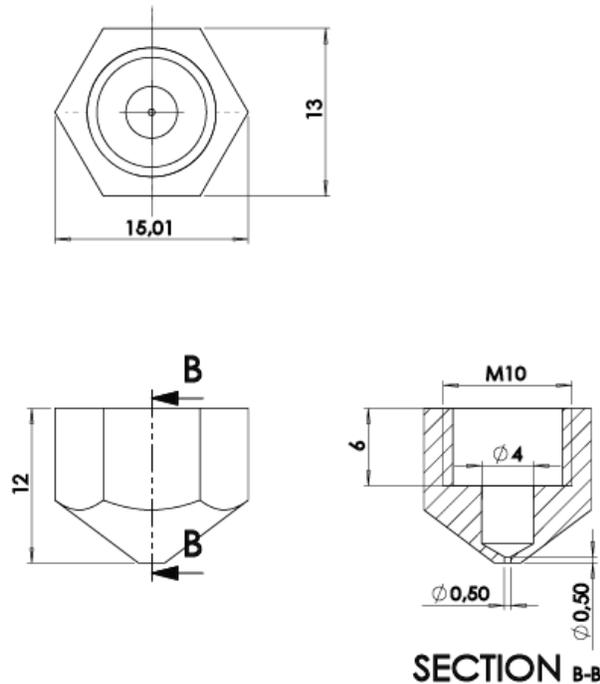


Figure 21 Nozzle's technical drawing



Figure 22 Printing was not possible with bigger thickness

After failed at printing of 18 specimens I found the solution. The most important modifications (compare to neat ABS parameters) are in the velocity, extrusion multiplier, layer thickness and extruder temperature. To avoid the aforementioned problems the higher temperature was needed with slower velocity. I used 20% more material to avert the void between the lines and layers. I made the molted material stuck on the surface of the last layer by decreasing the thickness of the layers. This way the nozzle was close enough the last layer and because I used more filament, the material could not stuck on the nozzle.

The settings are summarized in the following table. (Table 5)

Input variables	Value	Unit
Bed temperature-first layer	100	C
Bed temperature-other layers	100	C
Extruder temperature-first layer	265	C
Extruder temperature-other layers	265	C
Nozzle diameter	0,45	mm
Extrusion multiplier	1,2	-
First layer thickness	0,15	mm
Other layer thickness	0,1	mm
Velocity of perimeter printing	30	m/s
Velocity of first layer printing	30	m/s
Velocity of infill printing	30	m/s

**Table 5 Parameters for carbon fiber reinforced ABS printing**

Unfortunately with this parameters the real thickness of the specimen was only 2.4 mm instead of 3 mm. To solve this problem I designed a new model and the model's thickness was 3.5 mm. After printing the real thickness was 3 mm. To compare the materials to each other I printed all the three types of specimens on the same way as in case of the neat ABS with the proper parameters.

### **8.1. Observations with microscope**

To investigate the accuracy of the printer I checked the layers with an electrical microscope (500x magnification). In the first type of specimens the lines were not linked to each other in every case (Fig. 20) and from the other side there were some cracks between the layers as I mentioned before.

In the second type of specimens the perpendicular lines were short so the dynamic effect was significant from the point of accuracy as you can see in the Fig. 21. The first layer was a bit bigger than the others in every case.

In the third type of neat ABS the biggest problem was the cracks between the layers. This cracks makes stress concentration points on the surface of the specimen and this phenomenon decrease significantly the strength of the specimen.

In case of CF-ABS the problems were the same but the degree of accuracy was higher. In Fig. 23 you can see next to the void a little material bubble that first stucked on the surface on the nozzle, after it was big enough reached the surface of the layer and stucked on it. Since the thickness of the layers were smaller and the hole of the diameter was bigger thus the surface of the specimens was more coherent. It means the connections between the layers are better I

predict the mechanical properties of the third type of the CF-ABS will be higher than in case of neat ABS.



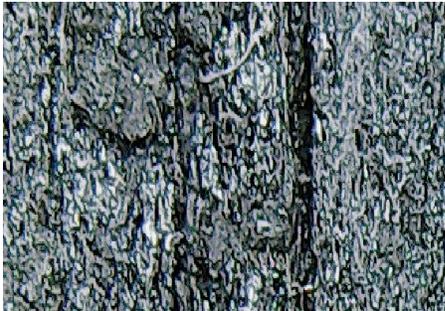
**Figure 20 Voids between the lines**



**Figure 21 Difference between layers**



**Figure 22 Small cracks between layers**



**Figure 23 Voids between lines, CF-ABS**

## 9. Effect of acetone surface treatment

To use acetone for surface treatment is a very popular method to reach a smooth and shiny surface. The basis of the idea is that the acetone solve the ABS by breaking the secondary bonds between the ABS polymer chains. This way the chains are able to glide past each other and move to more stable positions. The imperfect surface of the 3D printed object is a common problem at design objects. My opinion is that the original surface looks nicer, but I was interested in the effect of acetone from the point of mechanical properties. [11]

We have more possibility to do this treatment. Because the acetone as a liquid can totally destroy our printed object we have to put them into acetone vapor. The effect of the treatment depends on the time and the temperature. I will write the whole method step by step.

The equipment mainly consist of a can or jar and a piece of aluminium (or foil) and we can put our printed object on it. Because the acetone vapor is heavier than the air it is recommended to use a ventilator to circular the acetone vapor inside of the can so te acetone-humadity will be equable in every part of the can. (The specimens were too big for one can so I fixed 2 together with a ducktape. In every case I put the same types of specimens together in the can.)



**Figure 24 Equipment for acetone surface treatment**

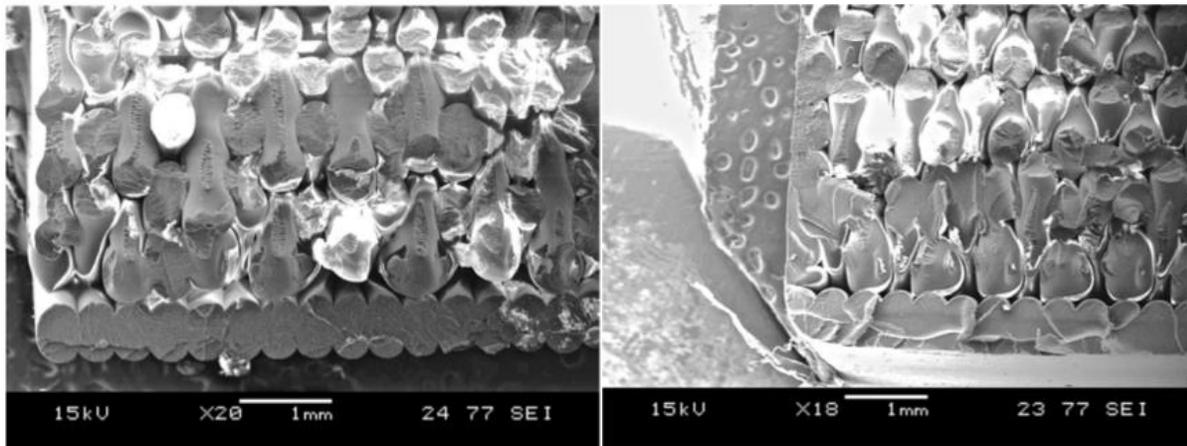
To fix the specimens I used Blinder Clips without handles then I put them into the can. I took some acetone inside of the can then closed the whole system. If we have not enough time for this method we can put our can on the bed of the printer thus we can heat them to reach higher humadity. (I did not use heating for the treatment.) To reach the optimum time for the treatment I put the failed and broken specimens into the vapor.

In case of neat ABS after 25 minutes we can see the difference and the surface is shiny and smooth, the treatment is effective and controllable. When I left the specimens in the vapor for 1 our and 20 minutes the surface was still shiny but the outer lines/beads were too much molted furthermore there stucked some air while molting so we can see some bubble

under the molted surface. Therefore I limited the treatment time at 50 minutes. Thus I was able to compare the difference between the two treatment time (25 min / 50 min).

The effect of acetone depends on the direction of printing too. The printed object highly anisotropic so we can not improve the mechanical skills in every direction because we can not make the lines stronger than originally they were, just the connection between the layers and

lines. In the following pictures of SEM microscope I would like to show the difference before and after treatment (Fig. 25 and Fig. 26).

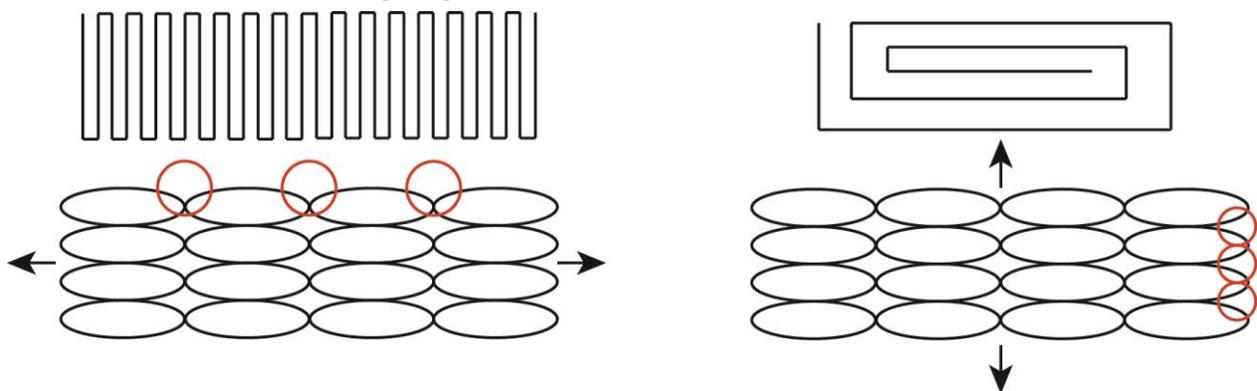


**Figure 25-26 SEM pictures before and after acetone treatment [11]**

As we can see on the left side of the right picture the outer lines of the layers are melted and bonded together. In the printed objects it would be important to ignore the cracks between the layers. Because these cracks and warps are stress concentrations I predict we can enhance the mechanical properties by removing these stress points.

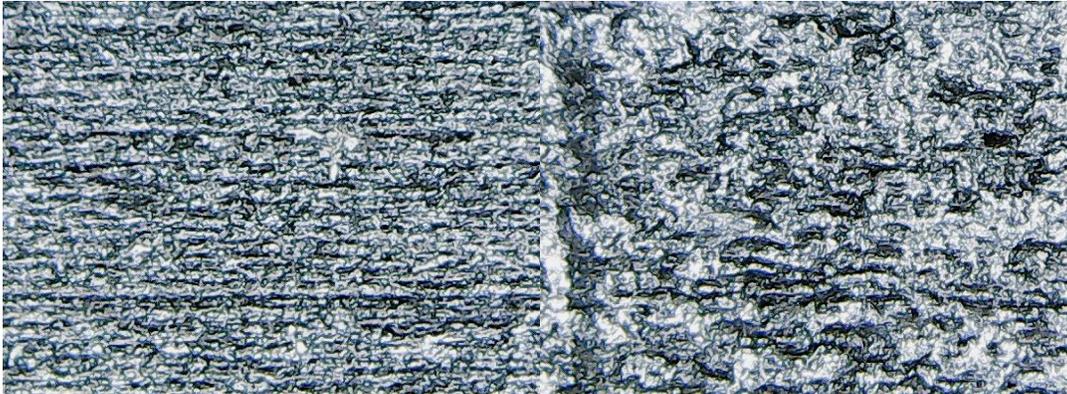
In the first type the tensile strength depends on the strength of the lines so if we use acetone we can only destroy the outer surfaces of the specimens but we cannot improve the strength of the lines.

Because the layer thickness was 0.2 mm and in case of neat ABS and 0.1 mm in case of CF-ABS these values can influence the result of the test. To illustrate the effect on the cross sections I created this drawing (Fig. 27).



**Figure 27 Cross sections in the second and third type**

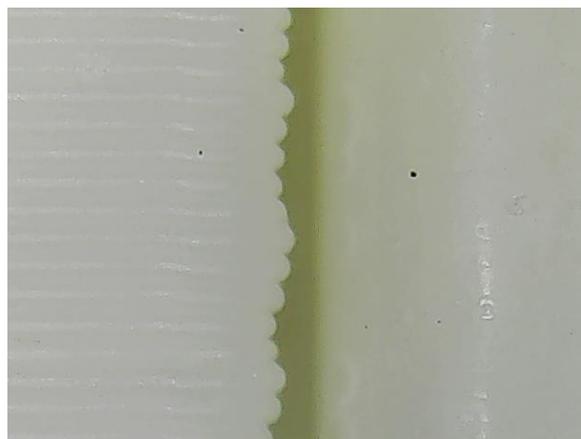
The red circles mark the places of the stress concentrations (meeting points of layers and lines). I draw the toolpath above the cross sections of the specimens. The arrows mean the direction of loading. For printing the CF-ABS I changed the nozzle as I mentoined. The hole of the nozzle is bigger thus the printer use less and bigger liner in one layer. I suppose in case of CF-ABS the acetone can solve the ABS part but not the carbon fibers so the acetone can make more stress concentrations on the surface of the specimen. I took photos about the surface of CF-ABS specimen after and before acetone treating (Fig. 28 and Fig. 29).



**Figure 28-29 Surface of the third type of specimen from CF-ABS, before and after acetone treatment**

We can see the acetone wapor didn't make uniformly related surface as in case of neat ABS. The errors on the surface can decrease the mechanical properties.

In the following picture (Fig. 30) we can see the effect of the acetone in the third type of specimens from neat ABS. The outer surface of the specimen is completely melted without cracks.



**Figure 30 Third type of neat ABS, before and after treatment**

## 10. Results of printing

The quality and the mechanical properties in my case depends on 3 things:

- quality of material
- direction of printing
- surface treatment method

Because I would like to investigate the effect of the acetone surface treatment, the difference between the two material and the effect of printing direction I printed 42 specimens and then I created 16 types as you can see in the following sheet. In the last row the numbers means of the printed specimens. In case of neat ABS without acetone in the third type one specimen broke while preparing for the tensile strength test. For the same reason I tested only one specimen after the 25 minutes acetone treatment in case of carbon fiber reinforced ABS's third type I summarized the types in the following table (Table 6).

Specimens															
Without-Acetone						Acetone-25						Acetone-50			
ABS			CF-ABS			ABS			CF-ABS			ABS		CF-ABS	
I.	II.	III.	I.	II.	III.	I.	II.	III.	I.	II.	III.	II.	III.	II.	III.
5	3	4	5	2	4	2	2	2	2	2	1	2	2	2	2

**Table 6** Types of the specimens. The numbers in the last row mean the number of the tested specimen.

### 10.1. Tensile strength test

For the tensile strength test I followed the principles of the ASTM D638-10 standard. First of all the thickness of the specimens were measured by a micrometer at three sections of the specimen then the average thickness was used for the calculating. In case of width of these three parts the measuring method was the same. For the test we used a MTS Insight (Electromechanical – 100 kN Standard length) machine. For measuring the axial displacement and the transversal deformation a biaxial extensometer was used. As the standard recommends the speed of testing, it was set to 5 mm/min. One of the specimens (16-0088 ABS 3\_3) broke while preparing the test. Originally we should have tested at least 5 specimens from each type but because of the time unfortunately I had not possibilities to print bigger quantity.

From the tensile strength test we can obtain the following parameters.

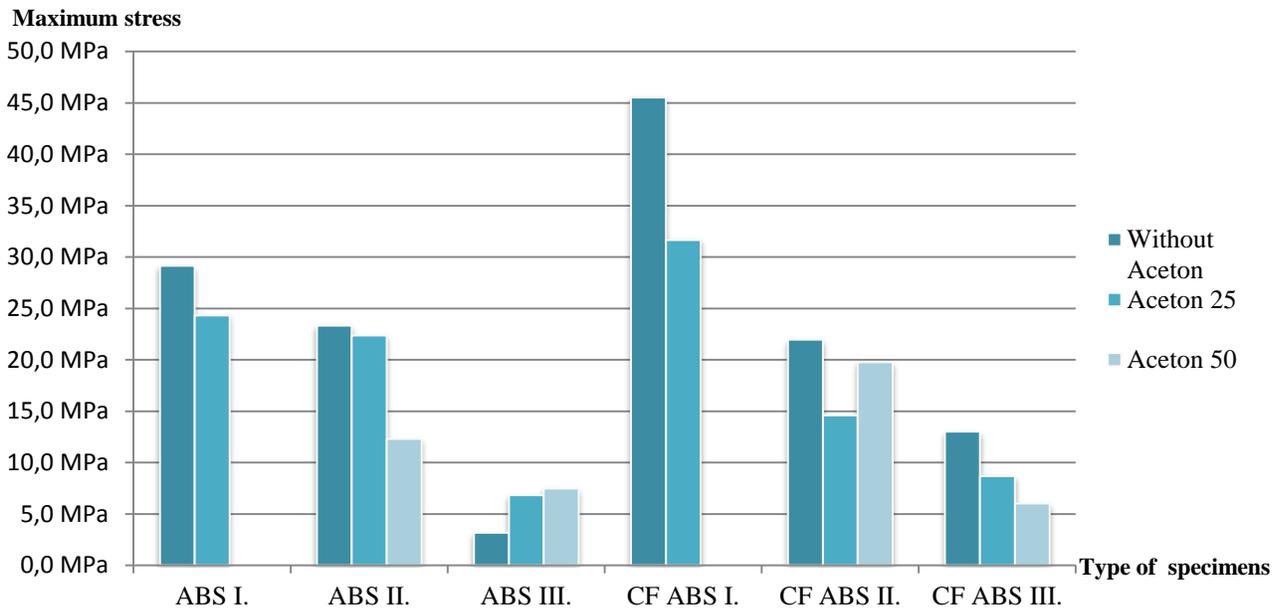
1. Ultimate axial force,  $F$  [N]

2. Maximum stress [MPa]
3. Strength at failure, [MPa]
4. Young modulus [GPa]
5. Poisson ratio [-]
6. Strain at failure,  $\epsilon$ , [%]

The sheets of the results can be found in the appendix.

### 10.1.1. Comparison of specimens I. – Maximum stress

To compare the result I created the following diagrams.

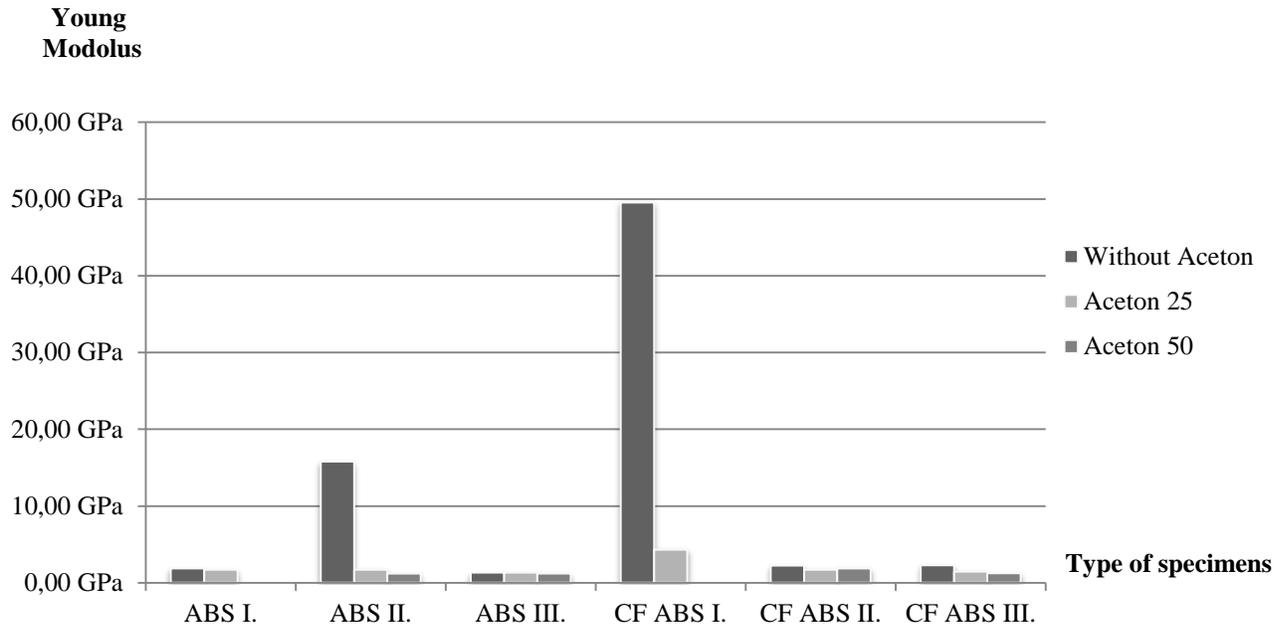


The printed objects (especially the fiber reinforced printed object) are highly orthotropic. In case of maximum stress we can see the significant effects of the carbon fibers and the difference between the printing direction. The tendencies are the same in both of the materials and the characteristics look like as I predicted. If the loading and printing direction are the same the tensile strength is much higher than in case of other directions.

In the third type in case of neat ABS the specimens act like as I mentioned before in the part of effect of the acetone.

In the second type the effect of acetone are not tested properly because of the scant number of the tested specimens. To obtain more accurate values I should test more specimens.

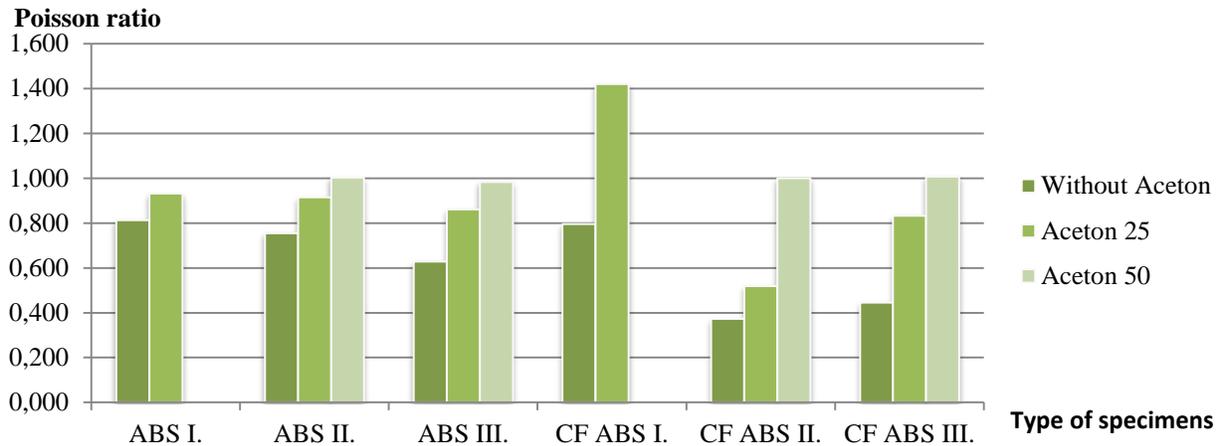
### 10.1.2. Comparison of specimens II. - Young modulus



Young's modulus (which is also known as the elastic modulus) is a mechanical property of linear elastic solid materials and it defines the connection between stress and strain in a material. The stiffer material have higher Young modulus. Most of the specimens were softly elastic independently form the acetone treatment.

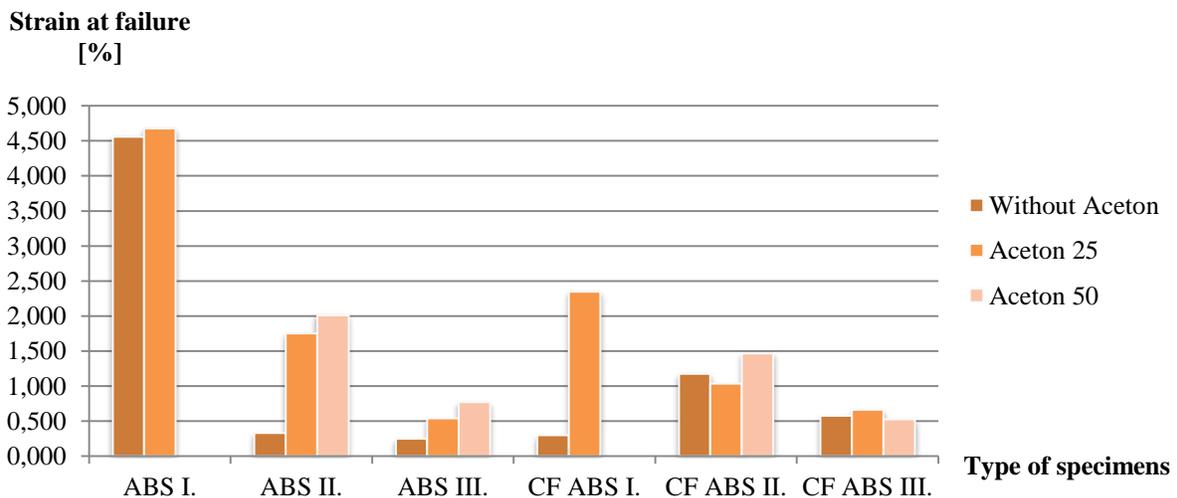
According to the Young modulus we can see the significant effect of the carbon fibers. Thanks to the orthotropic behavior the stiffness can not be the same in every direction, the connection was very strong between the lines in the second type of neat ABS so the stiffness of the specimens was higher then in other cases. This result doesn't fit for our experiences, I suppose there was a problem in the test. To clarify this problem I should print more specimens and repeat the test. The degree of rigidity is not the same in a line in different direction, so this value depends on the connenction between the lines because the lines are perpendicular to the direction of loading.

### 10.1.3. Comparison of specimens III. - Poisson ratio



When a specimen is loaded in one direction it generally tends to expand in the other two directions perpendicular to the direction of compression. This phenomenon is called the Poisson effect. [12] The acetone vapor increased the poisson ratio in every case. The original values are higher than the usual and in case of acetone they are even higher.

### 10.1.4. Comparison of specimens IV. - Strain at failure



As we can see the effect of the acetone and printing directions are important factors. The acetone typically increased the flexibility of specimens (except of case in third type at CF ABS, here this value more or less constant). The first type from the neat ABS was generally more flexible than the first type of CF ABS. At the second and third type the effect of acetone was

significant caused by the less stress concentration points. The first type of the CF ABS had higher degree of toughness than the other specimens. The behavior of carbon fiber is highly rigid but the acetone with the ABS solving can improve the flexibility.

## 11. Conclusions

The FDM technology is deservedly the most populist rapid prototyping method. Nowadays, thanks to the quality and price of the technology and materials we can create any kind of object quasi without boundaries. With this technology we are able to print the final product that is a big step in the history of manufacturing.

To reach the desired quality in printing we have to set all of the parameter properly thus we have to understand to whole process. In my study I printed more than 60 specimens with several parameters and investigated the effect of the settings to obtain the best setting for the best results. After I experimented the printing options in case of neat ABS I used this knowledge to examine the printing with carbon fiber reinforced ABS. After I reached the proper settings in printing of both materials I printed more than 40 specimens in 3 directions to investigate the effect of the printing direction.

Independently from the thickness of the layers the surface of the printed object never will be perfectly smooth. To reach the smooth surface to use acetone vapor as a surface treatment is a feasible way. In my study I examined the effect of acetone, the necessary time for the treatment and the effect from the point of mechanical properties in case of 25 and 50 minutes of treatment.

After I prepared all of the specimens we tested them with a tensile test machine. With this experiment we were able to obtain the following mechanical properties: tensile stress, Young's modulus, Yield strength and Poisson ratio.

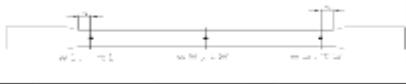
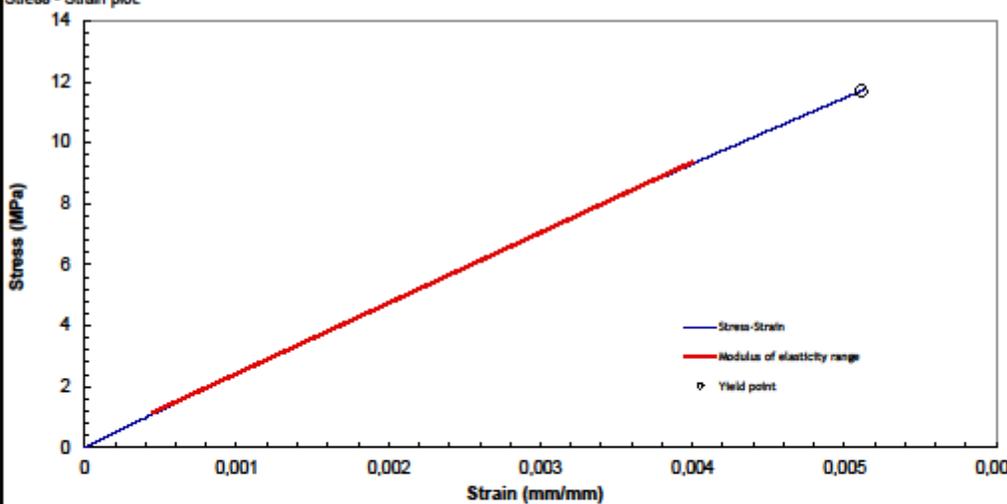
In my study I found the best parameters for the desired quality and understood the whole printing process. I convinced that the parameters can significantly influence the quality and the mechanical properties of printed object.

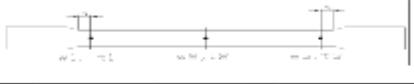
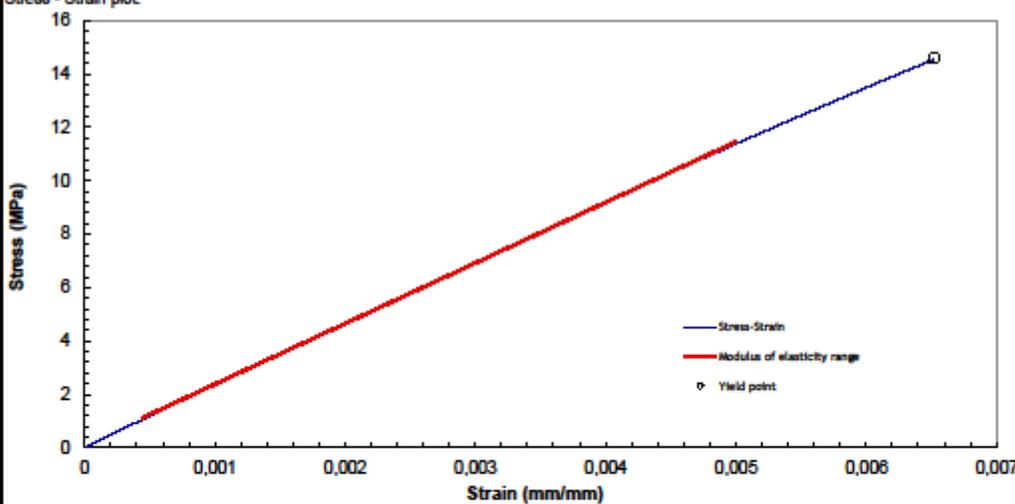
## 12. Bibliography

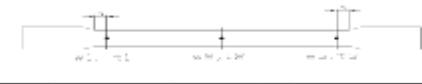
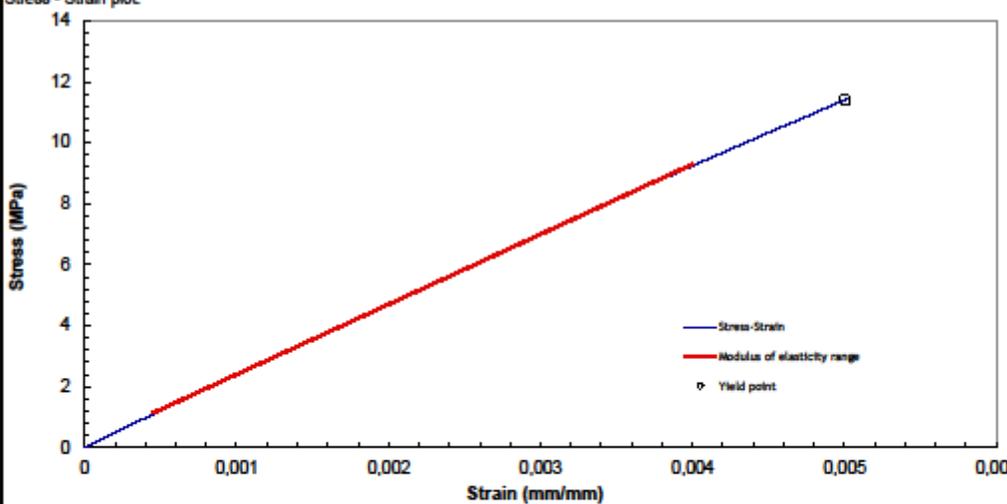
- [1] [https://en.wikipedia.org/wiki/Fused\\_deposition\\_modeling](https://en.wikipedia.org/wiki/Fused_deposition_modeling) (2016. 01. 18.)
- [2] Dudek, P., 2013, "FDM 3D Printing Technology in Manufacturing Composite Elements," Archives of Metallurgy and Materials, 58(4), pp. 1415-1418.
- [3] [https://en.wikipedia.org/wiki/Acrylonitrile\\_butadiene\\_styrene](https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene) (2016. 01. 14.)
- [4] <http://www.absmaterial.com/> (2016. 01. 14.)
- [5] <http://www.matweb.com/search/DataSheet.aspx?MatGUID=3a8afcddac864d4b8f58d40570d2e5aa&ckck=1> (2016. 01. 14.)
- [6] <http://www.matweb.com/search/DataSheet.aspx?MatGUID=3a8afcddac864d4b8f58d40570d2e5aa&ckck=1> (2016. 01. 4.)
- [7] Fu-da Ning, Junhua Wei, Shiren Wang Additive manufacturing of CFRP Composites using fused deposition Modeling: effects of carbon fiber Content and length
- [8] <https://en.wikipedia.org/wiki/G-code> (2016. 01. 18.)
- [9] Halil L, Vlastimil K, Gregorio M. V, Chad E. D, Lonnie J. L, Amit K. N, Craig A. B, Soydan O. Highly oriented carbon fiber–polymer composites via additive manufacturin
- [10] <http://learn.colorfabb.com/colorfabb-xt-cf20/> (2016. 01. 15.)
- [11] <https://benchapman4.wordpress.com/2014/05/08/increasing-toughness-of-3d-printed-plastic-using-acetone-vapor/> (2016. 01. 22.)
- [12] [https://en.wikipedia.org/wiki/Poisson%27s\\_ratio](https://en.wikipedia.org/wiki/Poisson%27s_ratio) (2016. 01. 24.)
- [13] Vlastimil Kunc<sup>1</sup>, Brett Compton<sup>1</sup>, Srdjan Simunovic<sup>1</sup>, Chad Duty<sup>1</sup>, Lonnie Love<sup>1</sup>, Brian Post<sup>1</sup>, Craig Blue<sup>1</sup>, Farid Talagani<sup>2</sup>, Renly Dutton<sup>2</sup>, Cody Godines<sup>2</sup>, Saber DorMohammadi<sup>2</sup>, Harsh Baid<sup>2</sup>, Frank Abdi<sup>2</sup>; 1. Oak Ridge National Laboratory, 2. Alpha Star Corporation  
Corresponding author: Vlastimil Kunc, [kuncv@ornl.gov](mailto:kuncv@ornl.gov), (865) 919 - 4595  
Modeling of Large Scale Reinforced Polymer Additive Manufacturing;

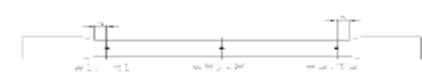
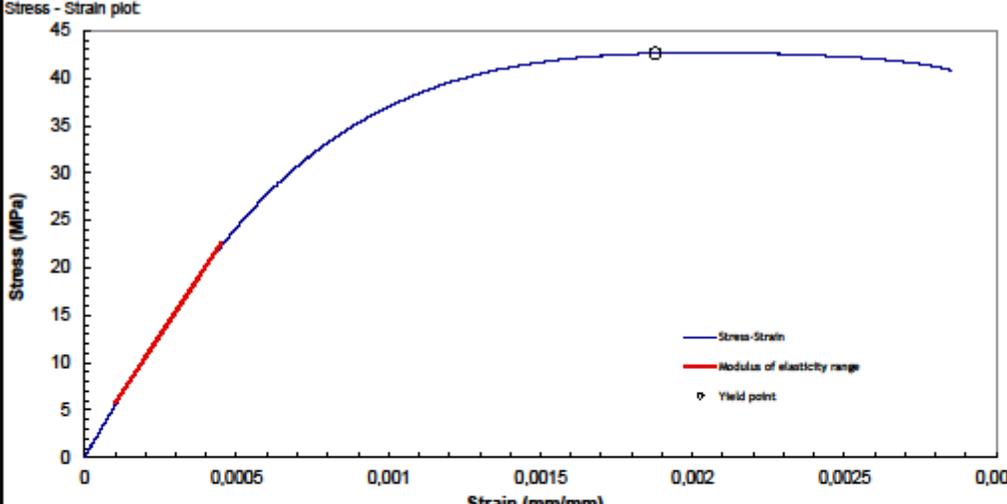
### 13. Appendix A – Test results

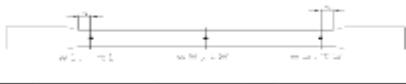
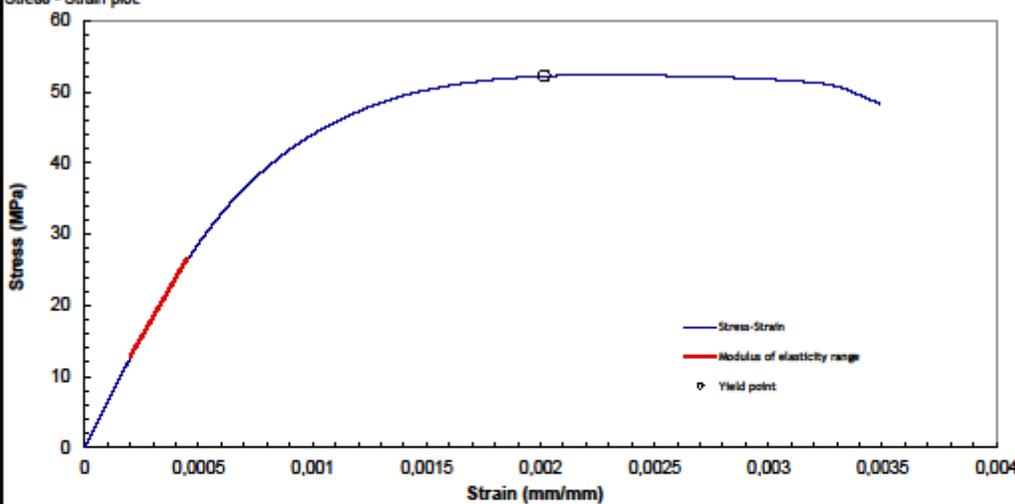
Results Report		External code:	CF_3-4
Tensile test- ASTM638-10		Internal code:	16-0139
Validated by:		JRE	Validation date:
			2014.01.14
<b>SPECIMEN MATERIAL</b>			
Material Type:	Carbon fiber reinforced ABS		Batch:
Manufacturer:	3D Printed		Orientation:
<b>SPECIMEN DIMENSIONS</b>			
Specimen:	CF 3-4		Date:
			2016.01.22
Technicians:	CMA/DPI		
Tool used:	MICROMETRE/02	MICROMETRE/02	
(mm)	Width	Thickness	
1	13,389	3,520	
2	13,467	3,702	
3	13,476	3,650	
Mean Width:	13,44	Mean thickness:	3,624
		Area:	48,72 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
<b>STRAIN GAUGE/EXTENSOMETER</b>			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
<b>TEST DATA</b>			
Specimen:	CF 3-4		Date:
			2016.01.26
Technicians:	YBA		
Speed (mm/min):	0,5	Lab Temperature (°C):	24,2
Test Machine:	MTS Insight	Load Cell/Range:	10 KN/100 %
Chamber:	-	Test temperature (°C):	0,0
Temperature measured by:	-		
<b>TENSILE TEST RESULTS</b>			
	Result	Unit	
Strength at failure:	10,2	MPa	Stress at yield:
Young Modulus:	2,3	GPa	10,2
Poisson ratio:	0,41		MPa
Strain at failure:	0,45	%	Strain range:
			450
			4000
			με
			Strain range:
			1000
			3000
			με
			Elongation at yield:
			0,4
			%
Date:	2016.01.27	Technician:	YBA/BGA
		Data file:	16-0139.xlsx
Stress - Strain plot			
<b>COMMENTS</b>			

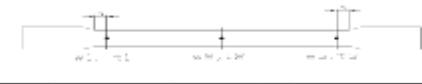
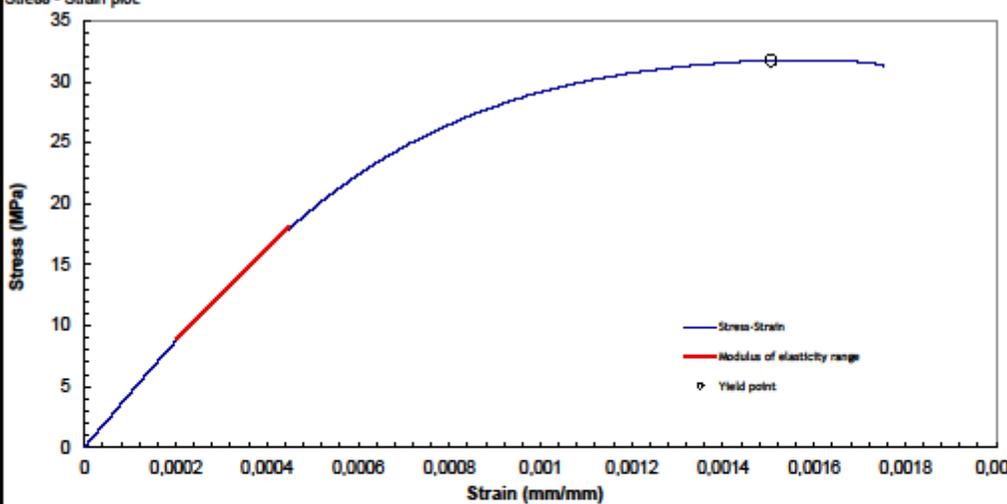
 <b>Results Report</b>		External code:	CF_3-5	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0140	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-5		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,539	3,680		
2	13,520	3,679		
3	13,398	3,496		
Mean Width:	13,49	Mean thickness:	3,618	Area: 48,80 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-5		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,3	Rel.Hum. (%): 45,6
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	11,7	MPa	Stress at yield:	11,7 MPa
Young Modulus:	2,3	GPa	Strain range:	450 4000 με
Poisson ratio:	0,41		Strain range:	1000 3000 με
Strain at failure:	0,51	%	Elongation at yield:	0,5 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0140.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

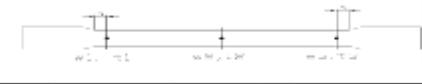
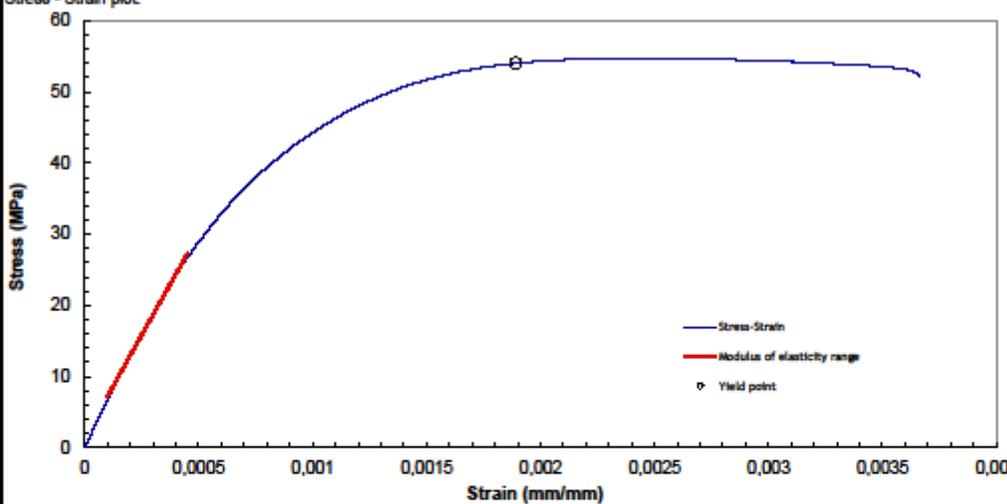
 <b>Results Report</b>		External code:	CF_3-6	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0141	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-6		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,425	3,510		
2	13,499	3,720		
3	13,436	3,751		
Mean Width:	13,45	Mean thickness:	3,660	Area: 49,24 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-6		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,3	Rel.Hum. (%): 46,0
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	14,6	MPa	Stress at yield:	14,6 MPa
Young Modulus:	2,3	GPa	Strain range:	450 5000 με
Poisson ratio:	0,40		Strain range:	1000 3000 με
Strain at failure:	0,65	%	Elongation at yield:	0,7 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0141.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

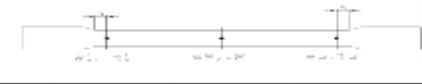
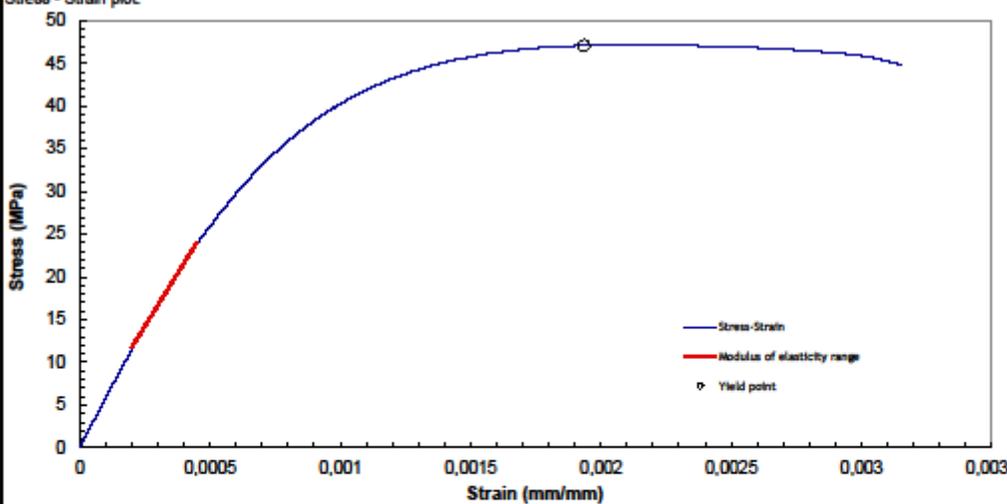
 <b>Results Report</b>		External code:	CF_3-7	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0142	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-7		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,471	3,495		
2	13,591	3,718		
3	13,590	3,662		
Mean Width:	13,55	Mean thickness:	3,625	Area: 49,12 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-7		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,9	Rel.Hum. (%): 46,3
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	11,4	MPa	Stress at yield:	11,4 MPa
Young Modulus:	2,3	GPa	Strain range:	450 4000 με
Poisson ratio:	0,49		Strain range:	1000 3000 με
Strain at failure:	0,50	%	Elongation at yield:	0,5 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0142.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

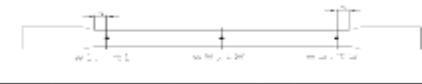
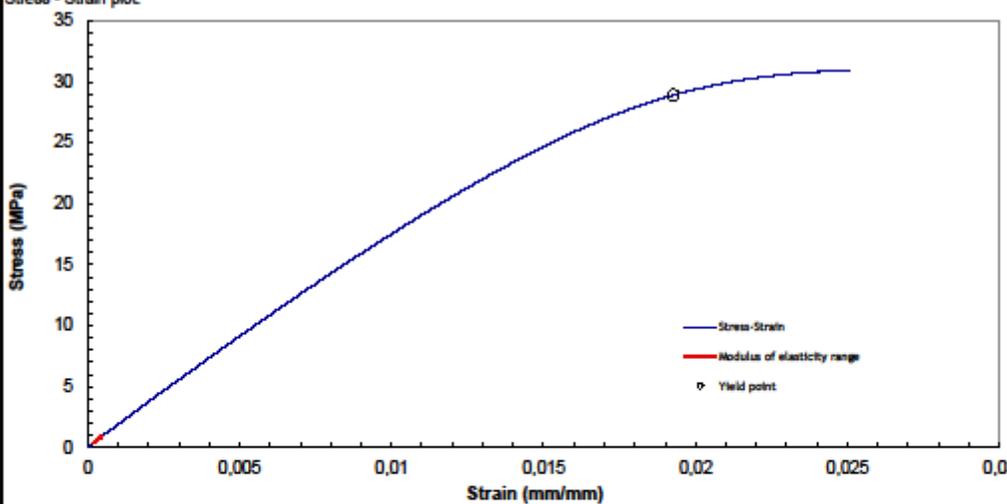
 <b>Results Report</b>		External code:	CF_1-1
Tensile test- ASTM638-10	Validated by:	JRE	16-0073
		Internal code:	16-0073
		Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>			
Material Type:	Carbon fiber reinforced ABS		Batch: CF
Manufacturer:	3D Printed		Orientation: 1
<b>SPECIMEN DIMENSIONS</b>			
Specimen:	CF 1-1	Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians: CMA/DPI
(mm)	Width	Thickness	
1	13,391	3,065	
2	13,303	3,001	
3	13,415	3,045	
Mean Width:	13,37	Mean thickness:	3,037
		Area:	40,60 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
<b>STRAIN GAUGE/EXTENSOMETER</b>			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
<b>TEST DATA</b>			
Specimen:	CF 1-1	Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	25,0
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %
Chamber:	-	Test temperature (°C):	25,0
Temperature measured by:	-		
<b>TENSILE TEST RESULTS</b>			
	Result	Unit	
Strength at failure:	40,8	MPa	Stress at yield: 42,6 MPa
Young Modulus:	48,3	GPa	Strain range: 100 450 με
Poisson ratio:	0,772		Strain range: 1000 3000 με
Strain at failure:	0,28	%	Elongation at yield: 0,2 %
Date:	2016.01.27	Technician:	YBA/BGA
		Data file:	16-0073.xlsx
<b>Stress - Strain plot</b> 			
<b>COMMENTS</b>			

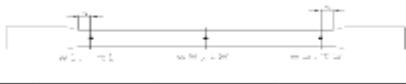
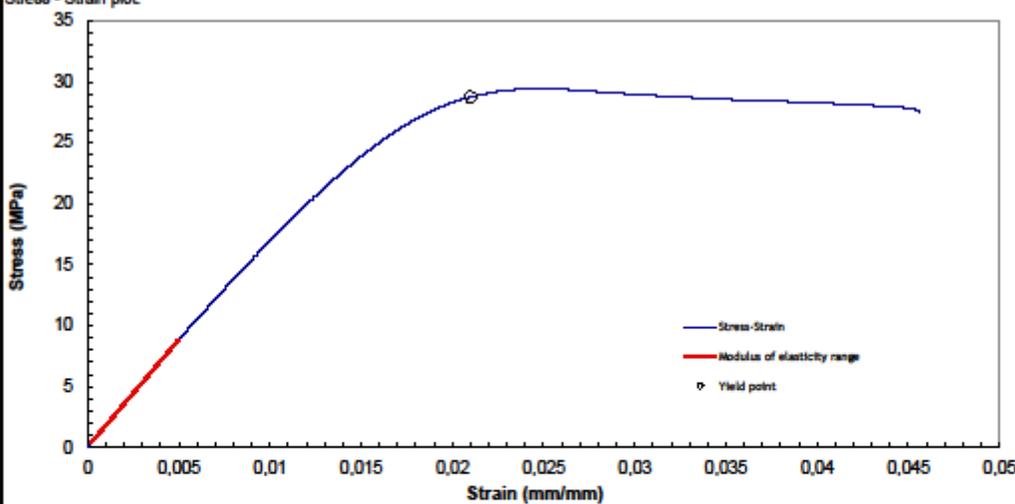
 <b>Results Report</b>		External code:	CF_1-2	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0074	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 1-2		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,495	3,054		
2	13,257	3,024		
3	13,442	3,028		
Mean Width:	13,40	Mean thickness:	3,035	Area: 40,67 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 1-2		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,8	Rel.Hum. (%): 45,8
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	24,8	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	48,3	MPa	Stress at yield:	52,2 MPa
Young Modulus:	55,5	GPa	Strain range:	200 450 µε
Poisson ratio:	0,84		Strain range:	1000 3000 µε
Strain at failure:	0,35	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0074.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	CF_1-3	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0075	2014.01.14
Validated by:		JRE	Validation date:	
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 1-3		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,251	2,931		
2	13,134	2,931		
3	13,353	2,940		
Mean Width:	13,25	Mean thickness:	2,934	Area: 38,87 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:				
Resistance (Ω):	-	Dimension (mm):	-	
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	
Transverse Sensitivity:	-	Other information:		
<b>TEST DATA</b>				
Specimen:	CF 1-3		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,9	Rel.Hum. (%): 45,8
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	24,9	Soak time (min): -
Temperature measured by:				
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	31,2	MPa	Stress at yield:	31,7 MPa
Young Modulus:	37,2	GPa	Strain range:	200 450 με
Poisson ratio:	0,75		Strain range:	1000 3000 με
Strain at failure:	0,18	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0075.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

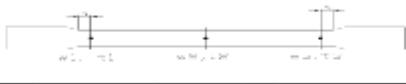
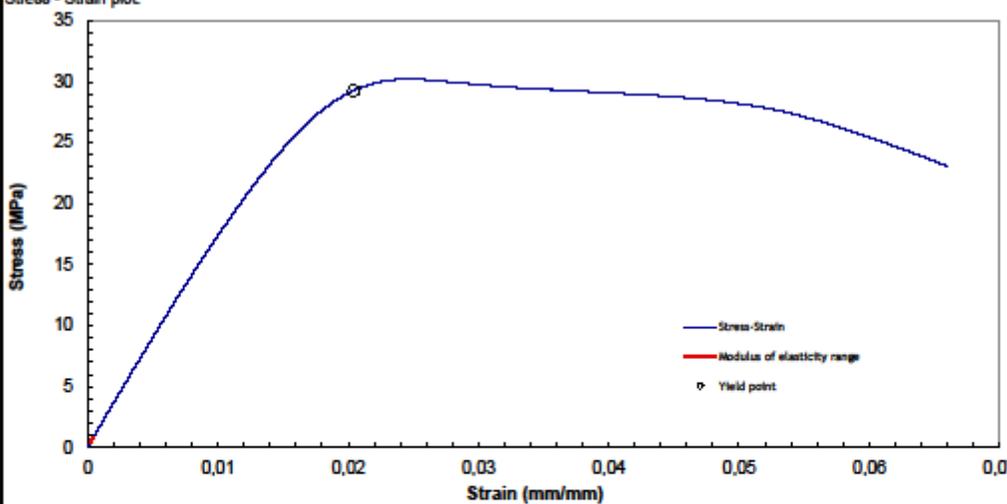
 <b>Results Report</b>		External code:	CF_1-4	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0076	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 1-4		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,367	2,996		
2	13,222	2,971		
3	13,417	3,052		
Mean Width:	13,34	Mean thickness:	3,006	Area: 40,09 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 1-4		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,7	Rel.Hum. (%): 45,6
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	24,7	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	52,1	MPa	Stress at yield:	54,0 MPa
Young Modulus:	57,3	GPa	Strain range:	100 450 με
Poisson ratio:	0,79		Strain range:	1000 3000 με
Strain at failure:	0,37	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0076.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

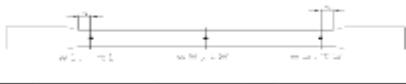
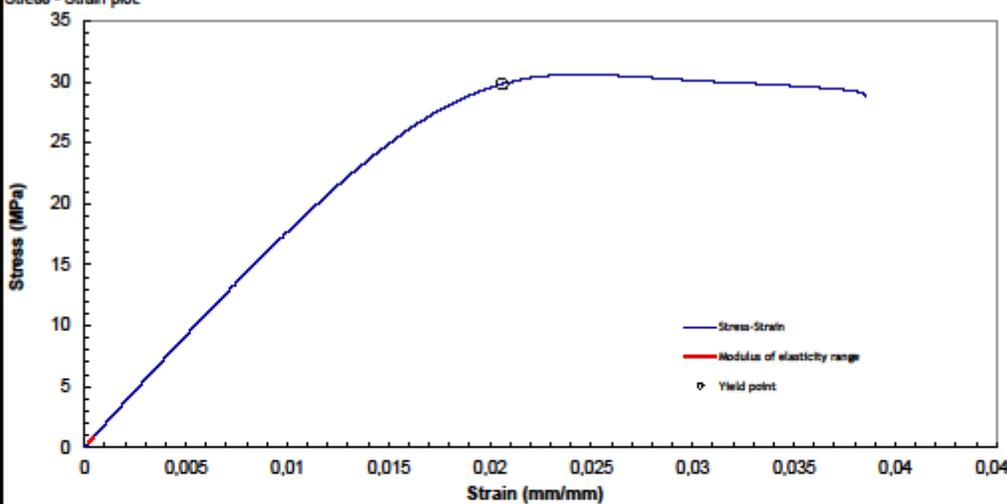
 <b>Results Report</b>		External code:	CF_1-5
Tensile test- ASTM638-10	Validated by:	JRE	16-0077
		Internal code:	16-0077
		Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>			
Material Type:	Carbon fiber reinforced ABS		Batch: CF
Manufacturer:	3D Printed		Orientation: 1
<b>SPECIMEN DIMENSIONS</b>			
Specimen:	CF 1-5		Date: 2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians: CMA/DPI
(mm)	Width	Thickness	
1	13,338	2,996	
2	13,200	2,960	
3	13,444	3,053	
Mean Width:	13,33	Mean thickness:	3,003
		Area:	40,02 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
<b>STRAIN GAUGE/EXTENSOMETER</b>			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
<b>TEST DATA</b>			
Specimen:	CF 1-5		Date: 2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,4
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %
Chamber:	-	Test temperature (°C):	24,4
Temperature measured by:	-		
<b>TENSILE TEST RESULTS</b>			
	Result	Unit	
Strength at failure:	44,9	MPa	Stress at yield: 47,1 MPa
Young Modulus:	49,4	GPa	Strain range: 200 450 με
Poisson ratio:	0,82		Strain range: 1000 3000 με
Strain at failure:	0,32	%	Elongation at yield: 0,2 %
Date:	2016.01.27	Technician:	YBA/BGA
		Data file:	16-0077.xlsx
Stress - Strain plot			
			
<b>COMMENTS</b>			

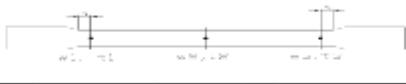
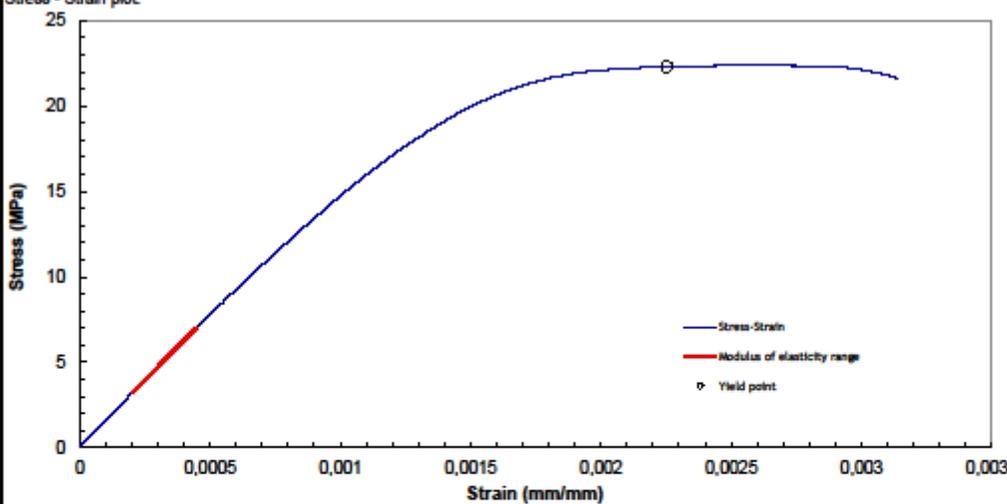
 <b>Results Report</b>		External code:	1_3	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	1 3		Date:	2016.01.22
Tool used:	MICROMETRE/D2	MICROMETRE/D2	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,385	2,768		
2	13,173	2,680		
3	13,257	2,716		
Mean Width:	13,27	Mean thickness:	2,721	Area: 36,12 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	1 3		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	24,2
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	24,2
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
Result		Unit		
Strength at failure:	30,9	MPa	Stress at yield:	28,9
Young Modulus:	1,879	GPa	Strain range:	200 450
Poisson ratio:	0,79		Strain range:	1000 3000
Strain at failure:	2,509	%	Elongation at yield:	1,9
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0078.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

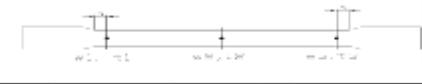
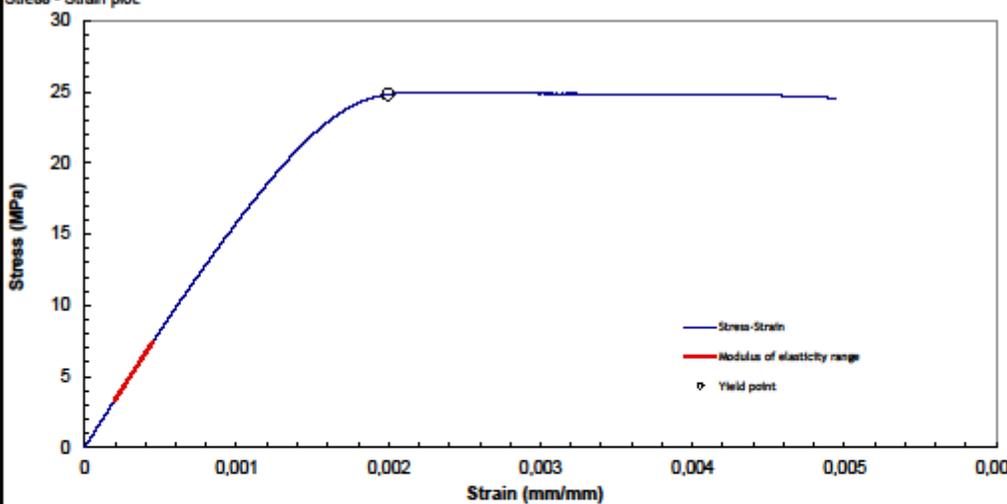
 <b>Results Report</b>		External code:	1_4
Tensile test- ASTM638-10		Validated by:	JRE
		Internal code:	16-0079
		Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>			
Material Type:	Carbon fiber reinforced ABS		Batch: CF
Manufacturer:	3D Printed		Orientation: 1
<b>SPECIMEN DIMENSIONS</b>			
Specimen:	1 4	Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians: CMA/DPI
(mm)	Width	Thickness	
1	13,889	2,866	
2	13,642	2,742	
3	13,791	2,927	
Mean Width:	13,77	Mean thickness:	2,845
		Area:	39,19 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
<b>STRAIN GAUGE/EXTENSOMETER</b>			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
<b>TEST DATA</b>			
Specimen:	1 4	Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,7
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %
Chamber:	-	Test temperature (°C):	24,7
Temperature measured by:	-	Soak time (min):	-
<b>TENSILE TEST RESULTS</b>			
	Result	Unit	
Strength at failure:	27,5	MPa	Stress at yield: 28,7 MPa
Young Modulus:	1,8	GPa	Strain range: 200 5000 με
Poisson ratio:	0,77		Strain range: 1000 3000 με
Strain at failure:	4,57	%	Elongation at yield: 2,1 %
Date:	2016.01.27	Technician:	YBA/BGA
		Data file:	16-0079.xlsx
<b>Stress - Strain plot</b> 			
<b>COMMENTS</b>			

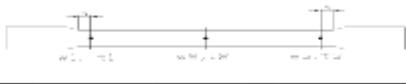
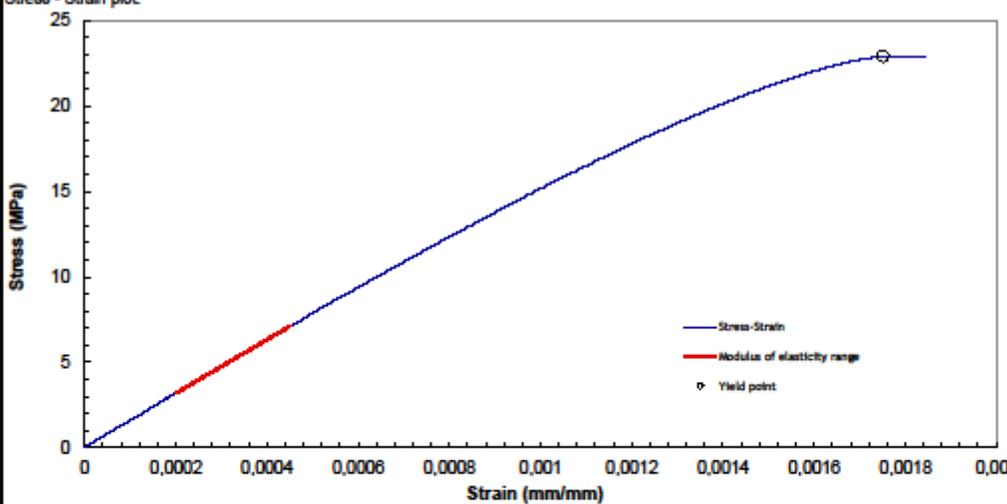


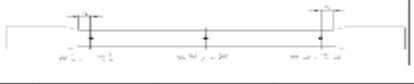
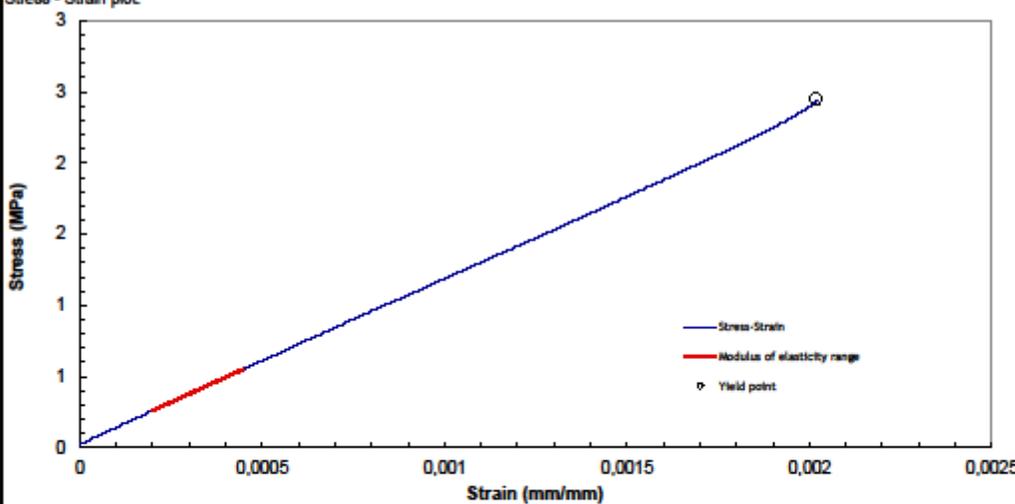
 <b>Results Report</b>		External code:	1_6
Tensile test- ASTM638-10		Internal code:	16-0081
Validated by:		JRE	Validation date:
Page 1 of 1 2014.01.14			
SPECIMEN MATERIAL			
Material Type:	Carbon fiber reinforced ABS		Batch:
Manufacturer:	3D Printed		Orientation:
SPECIMEN DIMENSIONS			
Specimen:	1 6	Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:
(mm)	Width	Thickness	
1	13,633	2,897	
2	13,489	2,870	
3	13,642	2,909	
Mean Width:	13,59	Mean thickness:	2,892
		Area:	39,30 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
STRAIN GAUGE/EXTENSOMETER			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
TEST DATA			
Specimen:	1 6	Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	24,5
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %
Chamber:	-	Test temperature (°C):	24,5
Temperature measured by:	-		
Soak time (min):	-		
Technicians:	YBA		
Rel.Hum. (%):	46,2		
TENSILE TEST RESULTS			
	Result	Unit	
Strength at failure:	23,1	MPa	Stress at yield:
Young Modulus:	1,8	GPa	29,3
Poisson ratio:	0,86		Strain range:
Strain at failure:	6,60	%	200
Date:	2016.01.27	Technician:	Strain range:
		YBA/BGA	1000
			3000
			Elongation at yield:
			2,0
			%
			Data file:
			16-0081.xlsx
Stress - Strain plot			
			
COMMENTS			

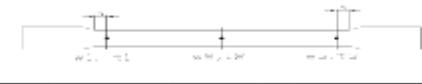
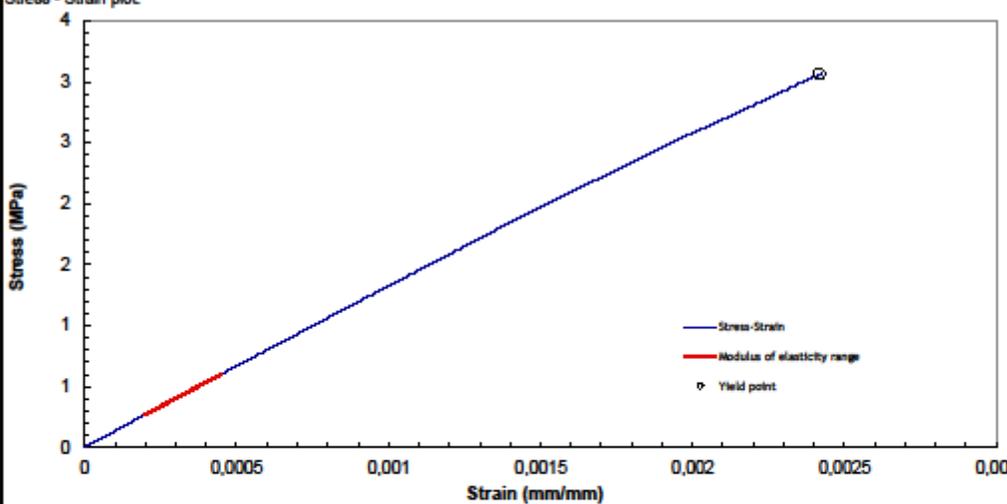
 <b>Results Report</b>		External code:	1.7	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0082	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	1.7		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,605	2,848		
2	13,284	2,879		
3	13,469	2,931		
Mean Width:	13,45	Mean thickness:	2,886	Area: 38,82 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:				
Resistance (Ω):	-	Dimension (mm):	-	
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	
Transverse Sensitivity:	-	Other information:		
<b>TEST DATA</b>				
Specimen:	1.7		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	24,7
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	24,7
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	28,8	MPa	Stress at yield:	29,8 MPa
Young Modulus:	1,9	GPa	Strain range:	200 450 με
Poisson ratio:	0,81		Strain range:	1000 3000 με
Strain at failure:	3,86	%	Elongation at yield:	2,1 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file:
				16-0082.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

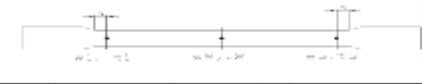
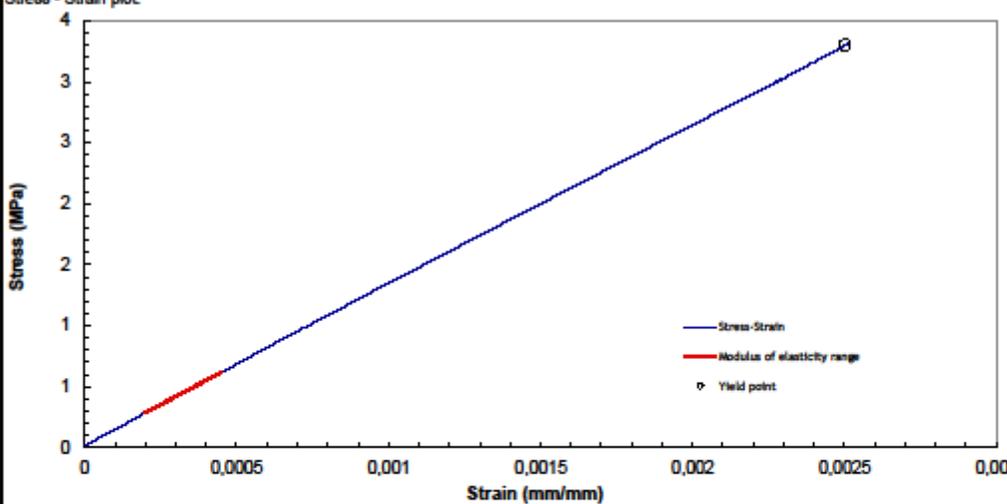
 <b>Results Report</b>		External code:	2_1	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0083	2014.01.14
Validated by:		JRE	Validation date:	
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	2 1		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	14,359	2,974		
2	14,355	2,894		
3	14,350	2,902		
Mean Width:	14,35	Mean thickness:	2,923	Area: 41,96 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:				
Resistance (Ω):	-	Dimension (mm):	-	
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	
Transverse Sensitivity:	-	Other information:		
<b>TEST DATA</b>				
Specimen:	2 1		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	24,7
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	24,7
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
Result		Unit		
Strength at failure:	21,6	MPa	Stress at yield:	22,3 MPa
Young Modulus:	15,351	GPa	Strain range:	200 450 µε
Poisson ratio:	0,735		Strain range:	1000 3000 µε
Strain at failure:	0,31	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0083.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

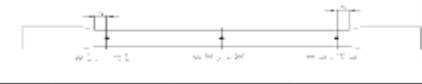
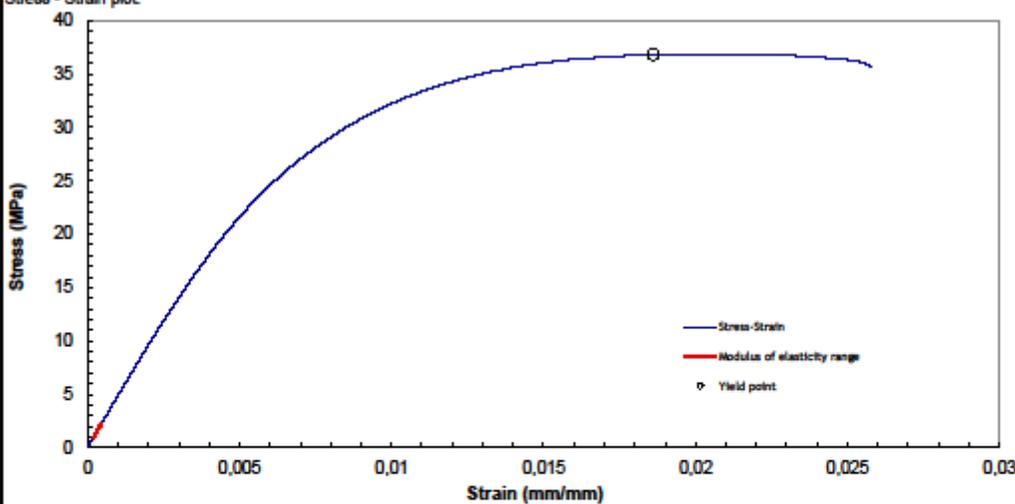
 <b>Results Report</b>		External code:	2_2	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0084	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	2 2		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	14,407	2,832		
2	14,067	2,887		
3	14,299	2,889		
Mean Width:	14,26	Mean thickness:	2,869	Area: 40,91 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	2 2		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	24,7
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	24,7
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	24,5	MPa	Stress at yield:	24,8 MPa
Young Modulus:	16,3	GPa	Strain range:	200 450 με
Poisson ratio:	0,78		Strain range:	1000 3000 με
Strain at failure:	0,49	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0084.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

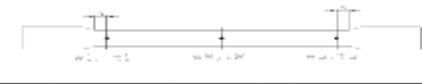
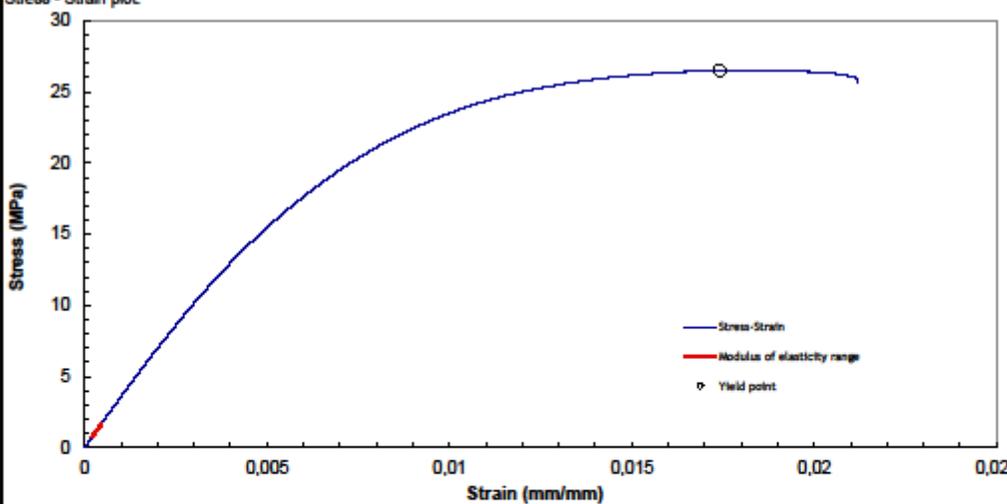
 <b>Results Report</b>		External code:	2_3	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0085	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	2 3		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	14,428	2,876		
2	14,156	2,909		
3	14,539	2,877		
Mean Width:	14,37	Mean thickness:	2,887	Area: 41,50 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	2 3		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	24,4
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	24,4
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
Result		Unit		
Strength at failure:	22,9	MPa	Stress at yield:	22,9
Young Modulus:	15,6	GPa	Strain range:	200
Poisson ratio:	0,74		Strain range:	1000
Strain at failure:	0,18	%	Elongation at yield:	0,2
Date:	2016.01.27	Technician:	YBA/BGA	Data file:
16-0085.xlsx				
Stress - Strain plot				
				
<b>COMMENTS</b>				

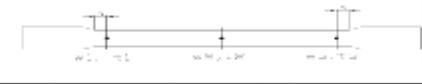
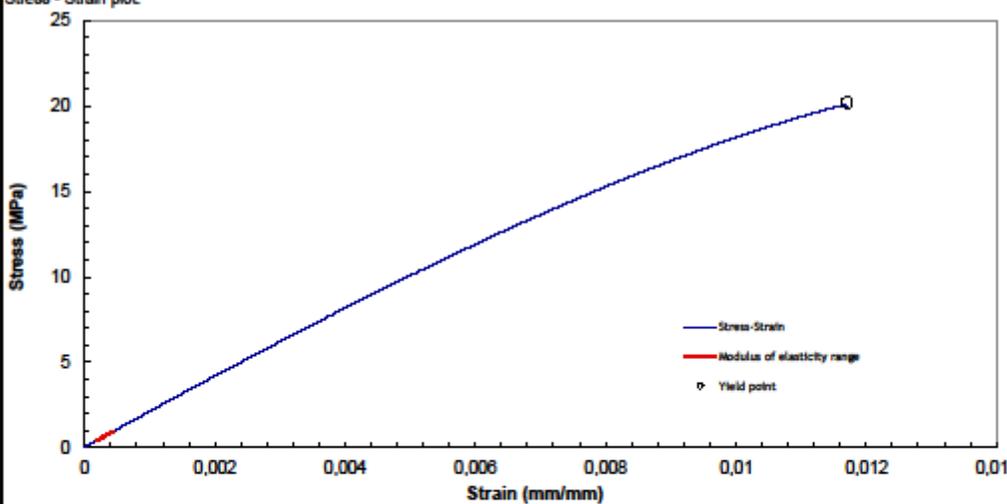
 <b>Results Report</b>		External code:	3_1	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0086	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3 1		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,385	3,081		
2	13,012	3,070		
3	13,270	3,091		
Mean Width:	13,22	Mean thickness:	3,081	Area: 40,73 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3 1		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,2	Rel.Hum. (%): 46,0
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,2	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	2,445	MPa	Stress at yield:	2,450 MPa
Young Modulus:	1,2	GPa	Strain range:	200 450 µε
Poisson ratio:	0,48		Strain range:	1000 3000 µε
Strain at failure:	0,20	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0086.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

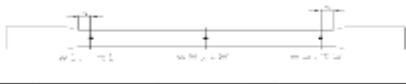
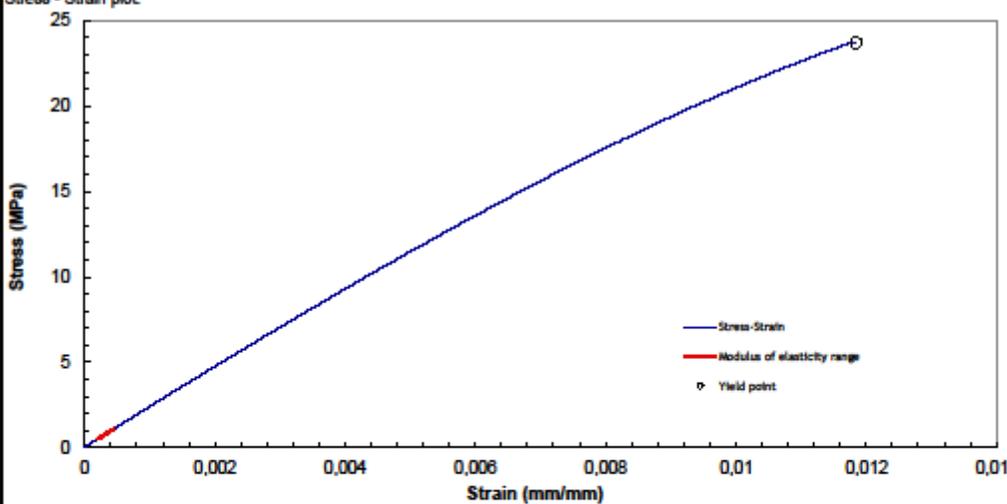
 <b>Results Report</b>		External code:	3_2	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3 2		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,476	3,064		
2	13,278	3,054		
3	13,446	3,100		
Mean Width:	13,40	Mean thickness:	3,073	Area: 41,17 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3 2		Date:	2016.01.25
Speed (mm/min):	0,5		Lab Temperature (°C):	23,0
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	23,0
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
Result		Unit		
Strength at failure:	3,1	MPa	Stress at yield:	3,1 MPa
Young Modulus:	1,3	GPa	Strain range:	200 450 με
Poisson ratio:	0,63		Strain range:	1000 3000 με
Strain at failure:	0,24	%	Elongation at yield:	0,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0087.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

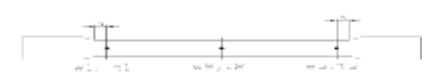
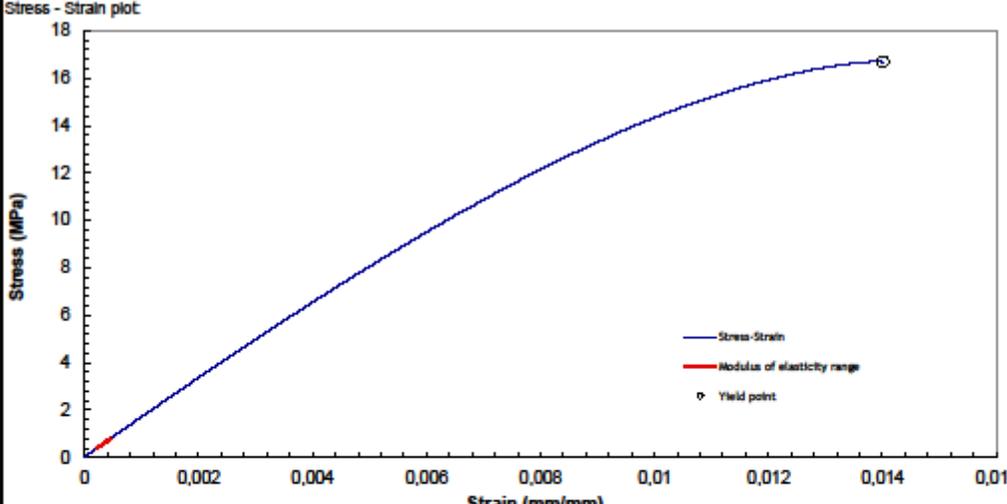
 <b>Results Report</b>		External code:	3_4	Page 1 of 1			
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:			
		Internal code:	16-0089	2014.01.14			
<b>SPECIMEN MATERIAL</b>							
Material Type:	Carbon fiber reinforced ABS			Batch:	CF		
Manufacturer:	3D Printed			Orientation:	1		
<b>SPECIMEN DIMENSIONS</b>							
Specimen:	3 4		Date:	2016.01.22	Technicians:	CMA/DPI	
Tool used:	MICROMETRE/02	MICROMETRE/02					
(mm)	Width	Thickness					
1	13,084	3,179					
2	12,829	3,149					
3	13,162	3,134					
Mean Width:	13,03	Mean thickness:	3,154	Area:	41,08 mm <sup>2</sup>		
Specimen reception conditions are according to the standard:					YES	Specify:	-
<b>STRAIN GAUGE/EXTENSOMETER</b>							
Type:	Biaxial extensometer		Biaxial extensometer				
Gage types and number:							
Resistance (Ω):	-	Dimension (mm):	-				
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-				
Transverse Sensitivity:	-	Other information:					
<b>TEST DATA</b>							
Specimen:	3 4		Date:	2016.01.25	Technicians:	YBA	
Speed (mm/min):	0,5		Lab Temperature (°C):	23,1	Rel.Hum. (%):	46,3	
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %			
Chamber:	-		Test temperature (°C):	23,1	Soak time (min):	-	
Temperature measured by:							
<b>TENSILE TEST RESULTS</b>							
	Result	Unit					
Strength at failure:	3,3	MPa	Stress at yield:	3,3	MPa		
Young Modulus:	1,3	GPa	Strain range:	200	με		
Poisson ratio:	0,63		Strain range:	1000	3000		
Strain at failure:	0,25	%	Elongation at yield:	0,3	%		
Date:	2016.01.27	Technician:	YBA/BGA	Data file:	16-0089.xlsx		
Stress - Strain plot							
							
<b>COMMENTS</b>							

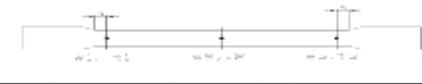
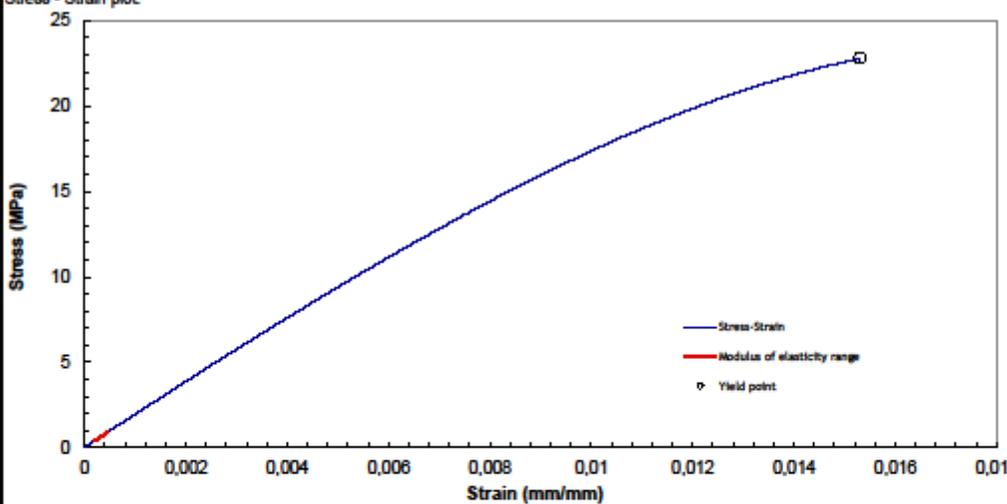
 <b>Results Report</b>		External code:	CF_1-6_A-25	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:
		Internal code:	16-0118	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 1-6 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,980	3,123		
2	12,961	3,101		
3	12,954	3,126		
Mean Width:	12,97	Mean thickness:	3,117	Area: 40,41 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 1-6 A-25		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	23,1	Rel.Hum. (%): 45,7
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,1	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	35,7	MPa	Stress at yield:	36,8 MPa
Young Modulus:	5,0	GPa	Strain range:	200 450 µε
Poisson ratio:	1,73		Strain range:	1000 3000 µε
Strain at failure:	2,58	%	Elongation at yield:	1,9 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0118.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

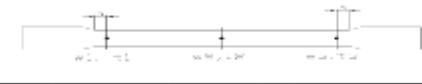
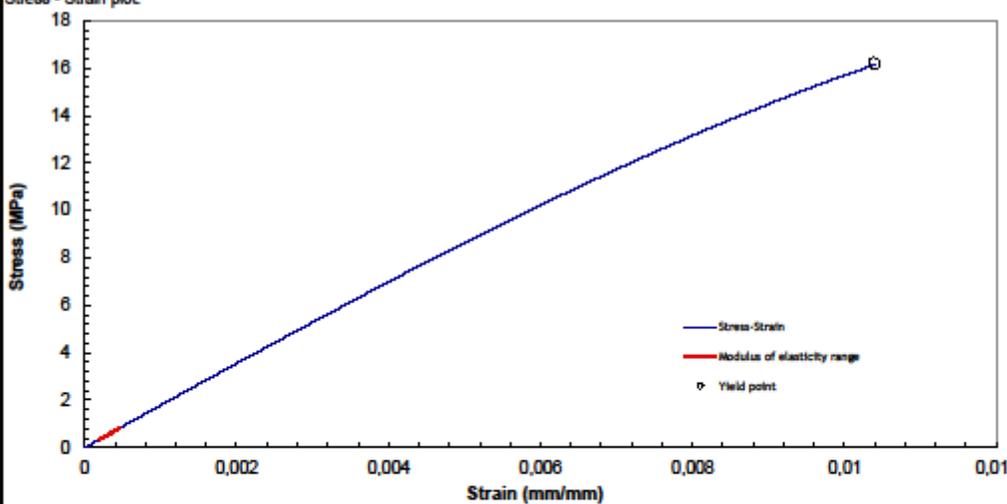
 <b>Results Report</b>		External code:	CF_1-7_A-25	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:
		Internal code:	16-0119	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 1-7 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,121	2,879		
2	13,106	2,859		
3	13,124	2,834		
Mean Width:	13,12	Mean thickness:	2,857	Area: 37,48 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 1-7 A-25		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	22,8	Rel.Hum. (%): 45,2
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	22,8	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	25,7	MPa	Stress at yield:	26,5 MPa
Young Modulus:	3,5	GPa	Strain range:	200 450 με
Poisson ratio:	1,11		Strain range:	1000 3000 με
Strain at failure:	2,12	%	Elongation at yield:	1,7 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0119.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

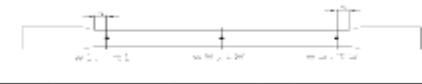
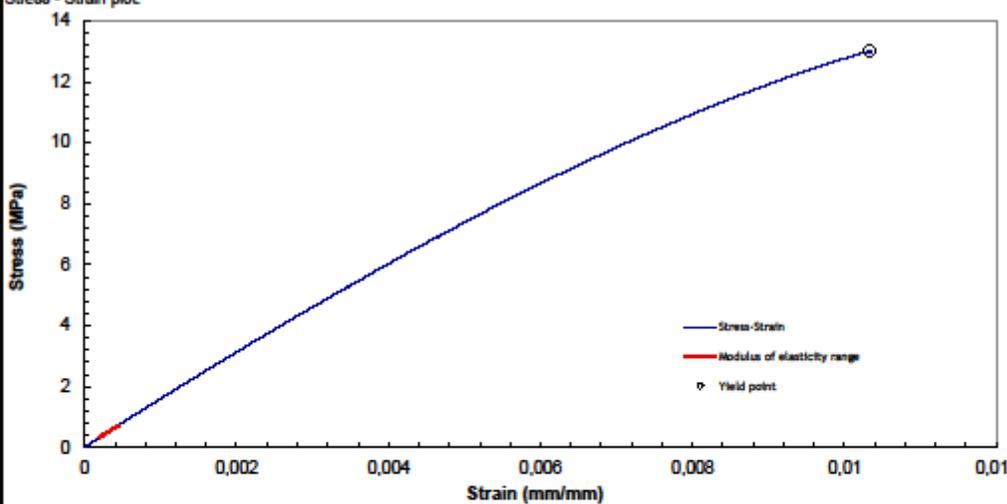
 <b>Results Report</b>		External code:	CF_2-1	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 2-1		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,754	3,298		
2	12,755	3,271		
3	12,850	3,255		
Mean Width:	12,79	Mean thickness:	3,275	Area: 41,87 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 2-1		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,3	Rel.Hum. (%): 46,1
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,3	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	20,0	MPa	Stress at yield:	20,2 MPa
Young Modulus:	2,1	GPa	Strain range:	200 450 µε
Poisson ratio:	0,38		Strain range:	1000 3000 µε
Strain at failure:	1,17	%	Elongation at yield:	1,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0120.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

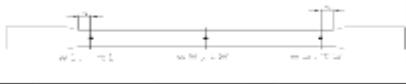
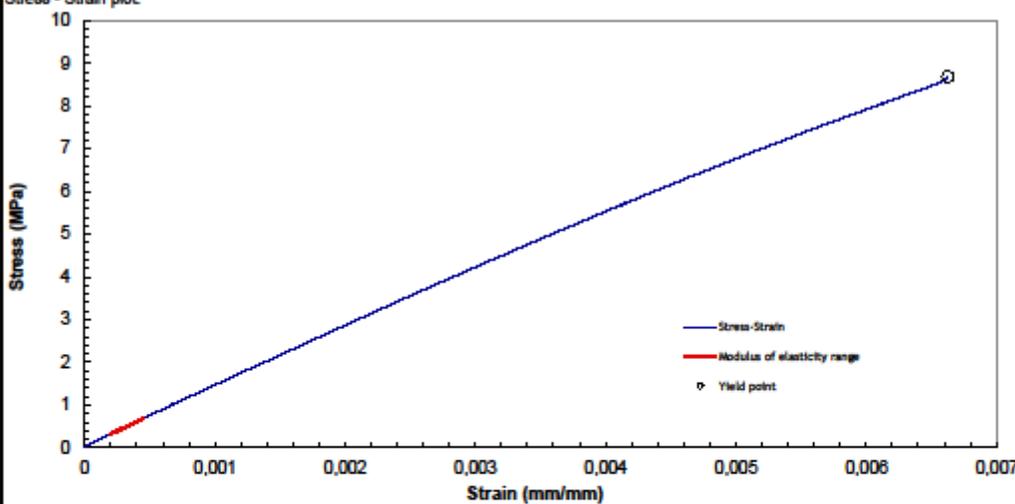
 <b>Results Report</b>		External code:	CF_2-2	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 2-2		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,972	3,299		
2	12,969	3,247		
3	13,118	3,224		
Mean Width:	13,02	Mean thickness:	3,257	Area: 42,40 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 2-2		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,3	Rel.Hum. (%): 46,0
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,3	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	23,7	MPa	Stress at yield:	23,7 MPa
Young Modulus:	2,4	GPa	Strain range:	200 450 με
Poisson ratio:	0,36		Strain range:	1000 3000 με
Strain at failure:	1,18	%	Elongation at yield:	1,2 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0121.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

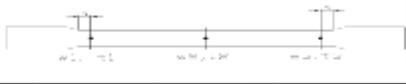
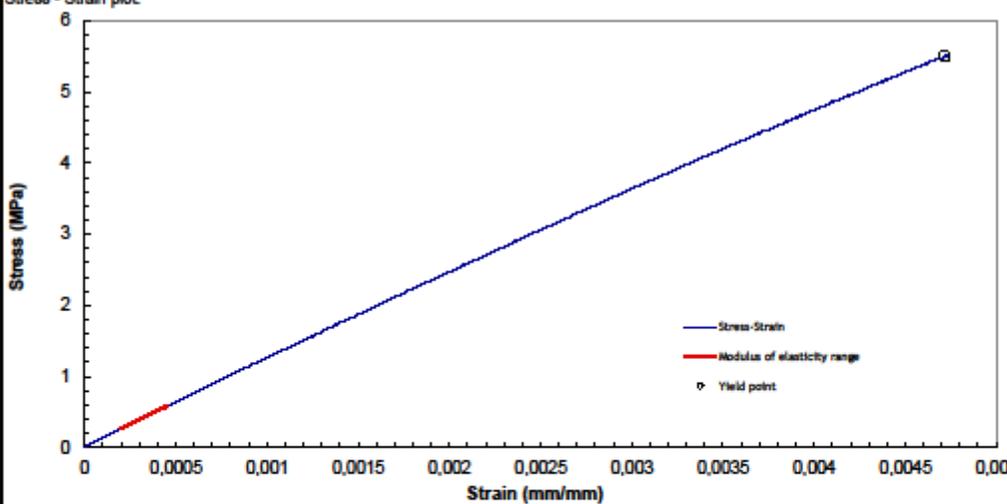
 <b>Results Report</b>		External code:	CF_2-3_A-50	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0122	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 2-3 A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,990	2,974		
2	12,953	2,922		
3	12,945	2,915		
Mean Width:	12,96	Mean thickness:	2,937	Area: 38,07 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 2-3 A-50		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,5	Rel.Hum. (%): 45,7
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,5	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	16,6	MPa	Stress at yield:	16,7 MPa
Young Modulus:	1,7	GPa	Strain range:	200 450 με
Poisson ratio:	1,37		Strain range:	1000 3000 με
Strain at failure:	1,40	%	Elongation at yield:	1,4 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0122.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

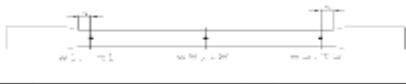
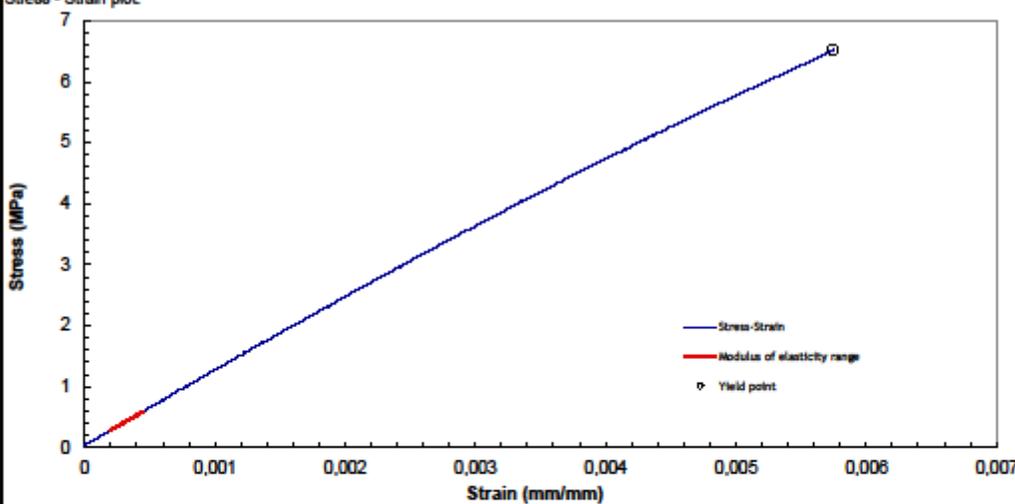
 <b>Results Report</b>		External code:	CF_2-4_A-50
Tensile test- ASTM638-10		Validated by:	JRE
		Internal code:	16-0123
		Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>			
Material Type:	Carbon fiber reinforced ABS		Batch: CF
Manufacturer:	3D Printed		Orientation: 1
<b>SPECIMEN DIMENSIONS</b>			
Specimen:	CF 2-4 A-50		Date: 2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians: CMA/DPI
(mm)	Width	Thickness	
1	12,988	3,071	
2	12,929	3,024	
3	12,937	2,996	
Mean Width:	12,95	Mean thickness:	3,030
			Area: 39,25 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -			
<b>STRAIN GAUGE/EXTENSOMETER</b>			
Type:	Biaxial extensometer		Biaxial extensometer
Gage types and number:	-		
Resistance (Ω):	-	Dimension (mm):	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-
Transverse Sensitivity:	-	Other information:	-
<b>TEST DATA</b>			
Specimen:	CF 2-4 A-50		Date: 2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,4
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %
Chamber:	-	Test temperature (°C):	23,4
Temperature measured by:	-		
<b>TENSILE TEST RESULTS</b>			
	Result	Unit	
Strength at failure:	22,8	MPa	Stress at yield: 22,8 MPa
Young Modulus:	2,0	GPa	Strain range: 200 450 με
Poisson ratio:	0,63		Strain range: 1000 3000 με
Strain at failure:	1,53	%	Elongation at yield: 1,5 %
Date:	2016.01.27	Technician:	YBA/BGA
			Data file: 16-0123.xlsx
Stress - Strain plot			
			
<b>COMMENTS</b>			

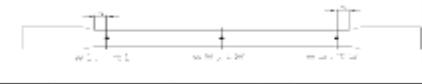
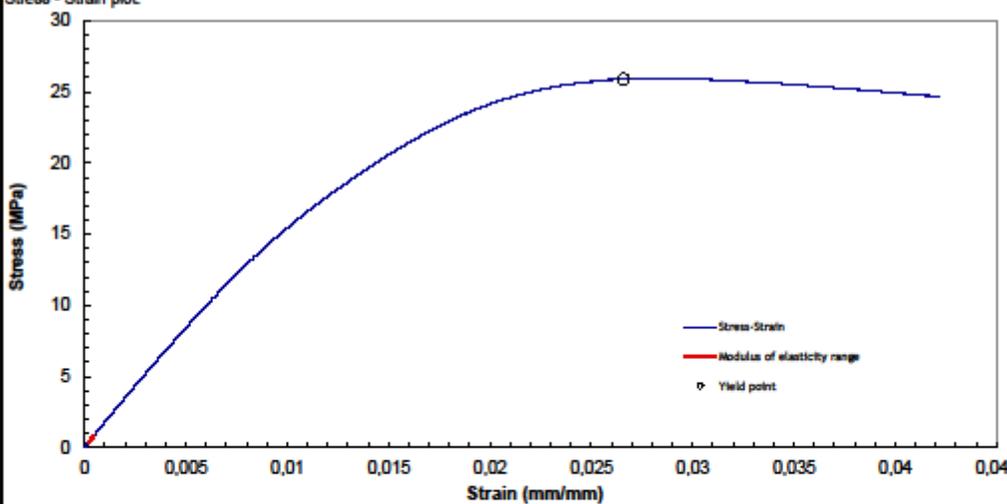
 <b>Results Report</b>		External code:	CF_2-5_A-25	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0124	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 2-5 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,774	3,309		
2	12,725	3,261		
3	12,821	3,214		
Mean Width:	12,77	Mean thickness:	3,261	Area: 41,66 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 2-5 A-25		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,5	Rel.Hum. (%): 45,3
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,5	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	16,1	MPa	Stress at yield:	16,2 MPa
Young Modulus:	1,8	GPa	Strain range:	200 450 µε
Poisson ratio:	0,55		Strain range:	1000 3000 µε
Strain at failure:	1,04	%	Elongation at yield:	1,0 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0124.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

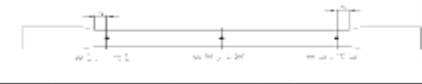
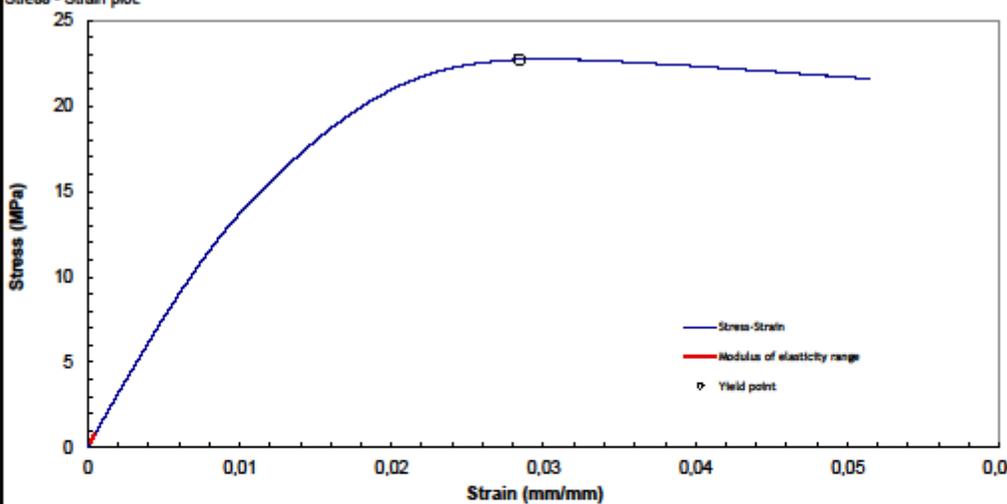
 <b>Results Report</b>		External code:	CF_2-6_A-25	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0125	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 2-6 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	12,690	3,055		
2	12,678	3,027		
3	12,686	3,070		
Mean Width:	12,68	Mean thickness:	3,051	Area: 38,70 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 2-6 A-25		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,3	Rel.Hum. (%): 45,5
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,3	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	12,9	MPa	Stress at yield:	13,0 MPa
Young Modulus:	1,5	GPa	Strain range:	200 450 με
Poisson ratio:	0,49		Strain range:	1000 3000 με
Strain at failure:	1,03	%	Elongation at yield:	1,0 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0125.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

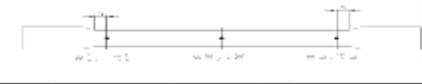
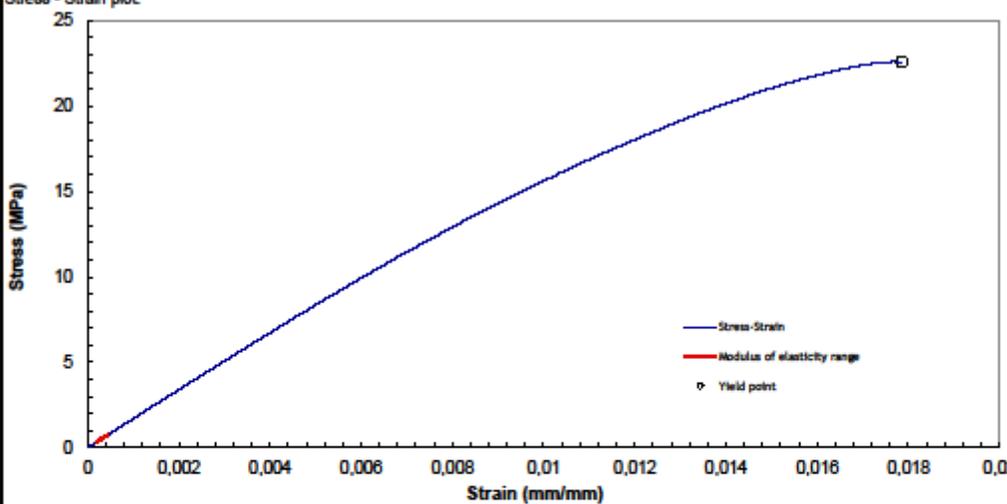
 <b>Results Report</b>		External code:	CF_3-1_A-25	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0126	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-1 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,314	3,207		
2	13,384	3,226		
3	13,347	3,286		
Mean Width:	13,35	Mean thickness:	3,240	Area: 43,24 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-1 A-25		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,5	Rel.Hum. (%): 46,1
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,5	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	8,68	MPa	Stress at yield:	8,68 MPa
Young Modulus:	1,4	GPa	Strain range:	200 450 με
Poisson ratio:	0,83		Strain range:	1000 3000 με
Strain at failure:	0,66	%	Elongation at yield:	0,7 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0126.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

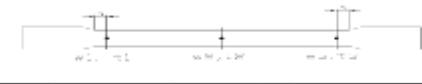
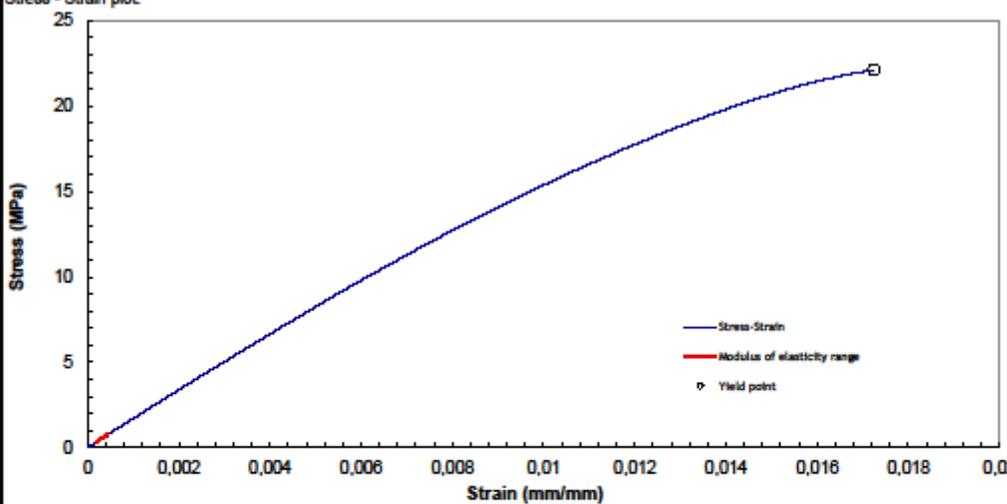
 <b>Results Report</b>		External code:	CF_3-2_A-50	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0127	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-2 A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,547	3,184		
2	13,622	3,237		
3	13,664	3,280		
Mean Width:	13,61	Mean thickness:	3,234	Area: 44,01 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-2 A-50		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,1	Rel.Hum. (%): 45,5
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,1	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	5,5	MPa	Stress at yield:	5,5 MPa
Young Modulus:	1,3	GPa	Strain range:	200 450 µε
Poisson ratio:	1,20		Strain range:	1000 3000 µε
Strain at failure:	0,47	%	Elongation at yield:	0,5 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0127.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

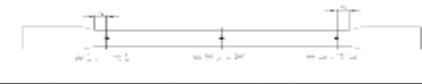
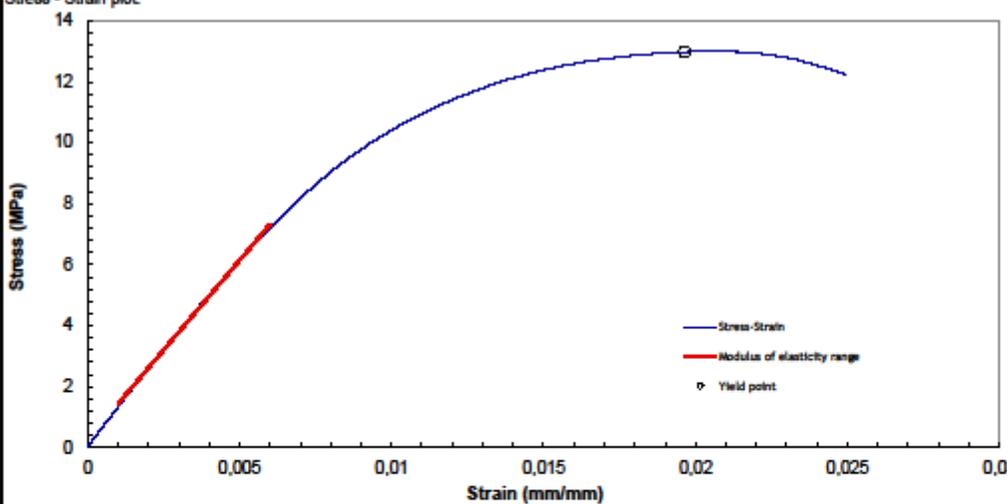
 <b>Results Report</b>		External code:	CF_3-3_A-50	Page 1 of 1
Tensile test- ASTM638-10	Validated by:	JRE	16-0128	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	CF 3-3 A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,487	3,350		
2	13,524	3,280		
3	13,585	3,242		
Mean Width:	13,53	Mean thickness:	3,291	Area: 44,53 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	CF 3-3 A-50		Date:	2016.01.25
Speed (mm/min):	0,5	Lab Temperature (°C):	23,5	Rel.Hum. (%): 45,3
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,5	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	6,5	MPa	Stress at yield:	6,5 MPa
Young Modulus:	1,2	GPa	Strain range:	200 450 με
Poisson ratio:	0,81		Strain range:	1000 3000 με
Strain at failure:	0,57	%	Elongation at yield:	0,6 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0128.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

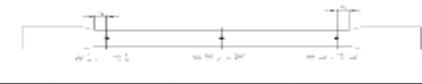
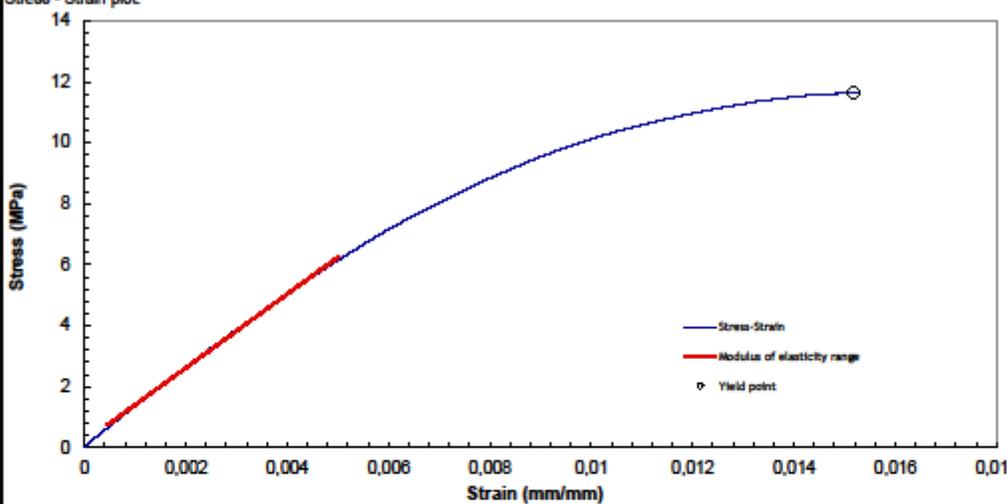
 <b>Results Report</b>		External code:	1-8_A-25	Page 1 of 1
Tensile test- ASTM638-10		Internal code:	16-0129	2014.01.14
		Validated by:	JRE	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	1-8 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,240	3,043		
2	13,110	3,047		
3	13,220	3,111		
Mean Width:	13,19	Mean thickness:	3,067	Area: 40,45 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:				
Resistance (Ω):	-	Dimension (mm):	-	
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	
Transverse Sensitivity:	-	Other information:		
<b>TEST DATA</b>				
Specimen:	1-8 A-25		Date:	2016.01.26
Speed (mm/min):	0,5		Lab Temperature (°C):	23,3
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	23,3
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	24,6	MPa	Stress at yield:	25,9 MPa
Young Modulus:	1,8	GPa	Strain range:	200 450 με
Poisson ratio:	0,95		Strain range:	1000 3000 με
Strain at failure:	4,22	%	Elongation at yield:	2,7 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0129.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

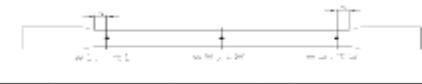
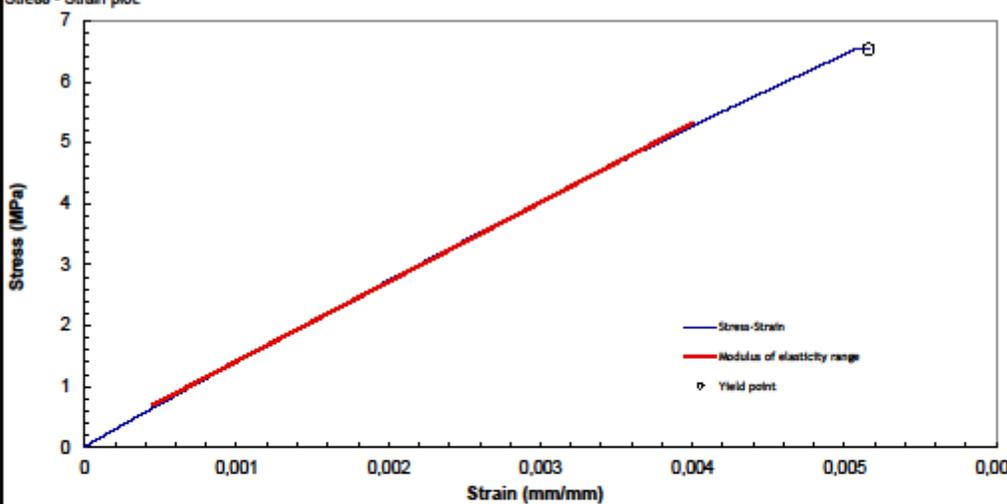
 <b>Results Report</b>		External code:	1-9_A-25	Page 1 of 1
Tensile test- ASTM638-10		Validated by:	JRE	2014.01.14
		Internal code:	16-0130	Validation date:
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	1-9 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,090	3,375		
2	12,950	3,373		
3	13,020	3,346		
Mean Width:	13,02	Mean thickness:	3,365	Area: 43,81 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	1-9 A-25		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	23,5	Rel.Hum. (%): 45,5
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,5	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	21,6	MPa	Stress at yield:	22,7 MPa
Young Modulus:	1,6	GPa	Strain range:	200 450 με
Poisson ratio:	0,91		Strain range:	1000 3000 με
Strain at failure:	5,14	%	Elongation at yield:	2,8 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0130.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

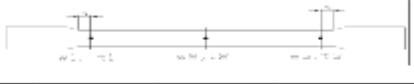
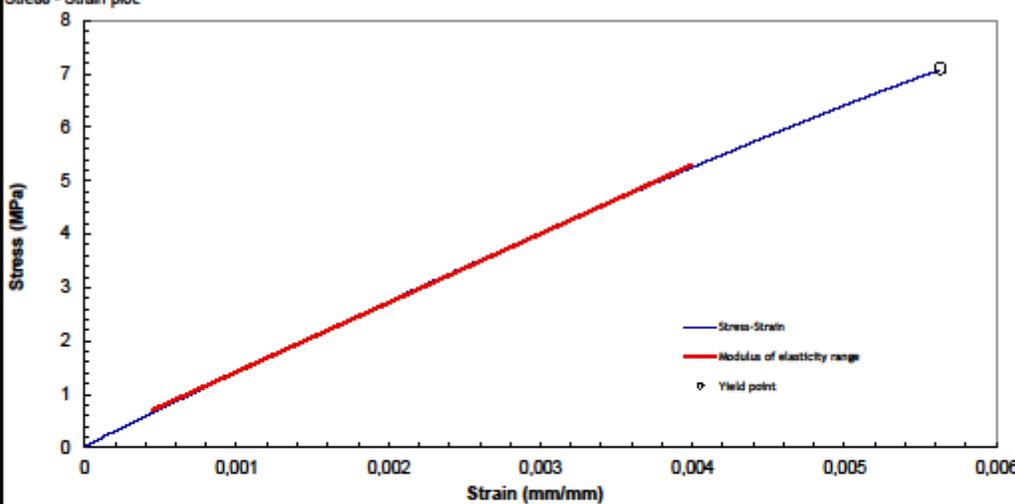
 <b>Results Report</b>		External code:	2_4_A_25			
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:	16-0131	
		Internal code:	16-0131		Page 1 of 1	
			2014.01.14			
<b>SPECIMEN MATERIAL</b>						
Material Type:	Carbon fiber reinforced ABS			Batch:	CF	
Manufacturer:	3D Printed			Orientation:	1	
<b>SPECIMEN DIMENSIONS</b>						
Specimen:	2_4_A_25		Date:	2016.01.22	Technicians:	CMA/DPI
Tool used:	MICROMETRE/D2	MICROMETRE/D2				
(mm)	Width	Thickness				
1	13,710	2,965				
2	13,680	2,963				
3	13,620	2,952				
Mean Width:	13,80	Mean thickness:	2,960	Area:	40,86 mm <sup>2</sup>	
Specimen reception conditions are according to the standard: YES Specify: -						
<b>STRAIN GAUGE/EXTENSOMETER</b>						
Type:	Biaxial extensometer		Biaxial extensometer			
Gage types and number:						
Resistance (Ω):	-	Dimension (mm):	-			
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-			
Transverse Sensitivity:	-	Other information:				
<b>TEST DATA</b>						
Specimen:	2_4_A_25		Date:	2016.01.26	Technicians:	YBA
Speed (mm/min):	0,5		Lab Temperature (°C):	23,8	Rel.Hum. (%):	46,0
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %		
Chamber:	-		Test temperature (°C):	23,8	Soak time (min):	-
Temperature measured by:						
<b>TENSILE TEST RESULTS</b>						
	Result	Unit				
Strength at failure:	22,5	MPa	Stress at yield:	22,6	MPa	
Young Modulus:	1,7	GPa	Strain range:	200	450	
Poisson ratio:	0,99		Strain range:	1000	3000	
Strain at failure:	1,79	%	Elongation at yield:	1,8	%	
Date:	2016.01.27	Technician:	YBA/BGA	Data file:	16-0131.xlsx	
Stress - Strain plot						
						
<b>COMMENTS</b>						

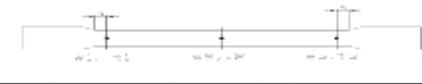
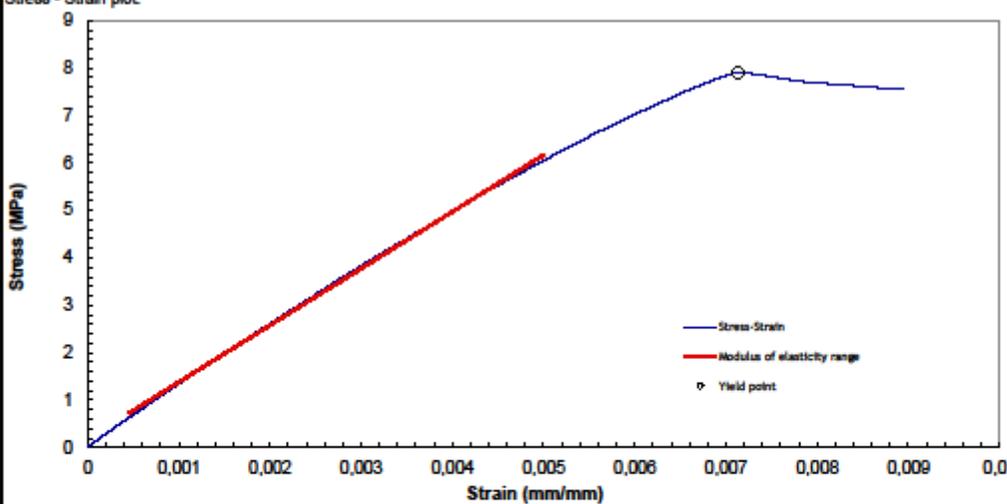
 <b>Results Report</b>		External code:	2_5_A-25		
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:	2014.01.14
		Internal code:	16-0132		Page 1 of 1
<b>SPECIMEN MATERIAL</b>					
Material Type:	Carbon fiber reinforced ABS			Batch:	CF
Manufacturer:	3D Printed			Orientation:	1
<b>SPECIMEN DIMENSIONS</b>					
Specimen:	2_5_A-25		Date:	2016.01.22	
Tool used:	MICROMETRE/02	MICROMETRE/02			
(mm)	Width	Thickness			
1	14,027	2,929			
2	13,881	3,009			
3	14,063	2,938			
Mean Width:	13,99	Mean thickness:	2,959	Area:	41,39 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -					
<b>STRAIN GAUGE/EXTENSOMETER</b>					
Type:	Biaxial extensometer		Biaxial extensometer		
Gage types and number:					
Resistance (Ω):	-	Dimension (mm):	-		
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-		
Transverse Sensitivity:	-	Other information:			
<b>TEST DATA</b>					
Specimen:	2_5_A-25		Date:	2016.01.26	
Speed (mm/min):	0,5		Lab Temperature (°C):	23,9	Rel.Hum. (%): 45,8
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %	
Chamber:	-		Test temperature (°C):	23,9	Soak time (min): -
Temperature measured by:					
<b>TENSILE TEST RESULTS</b>					
	Result	Unit			
Strength at failure:	22,1	MPa	Stress at yield:	22,1	MPa
Young Modulus:	1,7	GPa	Strain range:	200	με
Poisson ratio:	0,84		Strain range:	1000	3000
Strain at failure:	1,72	%	Elongation at yield:	1,7	%
Date:	2016.01.27	Technician:	YBA/BGA	Data file:	16-0132.xlsx
Stress - Strain plot					
					
<b>COMMENTS</b>					

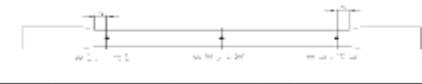
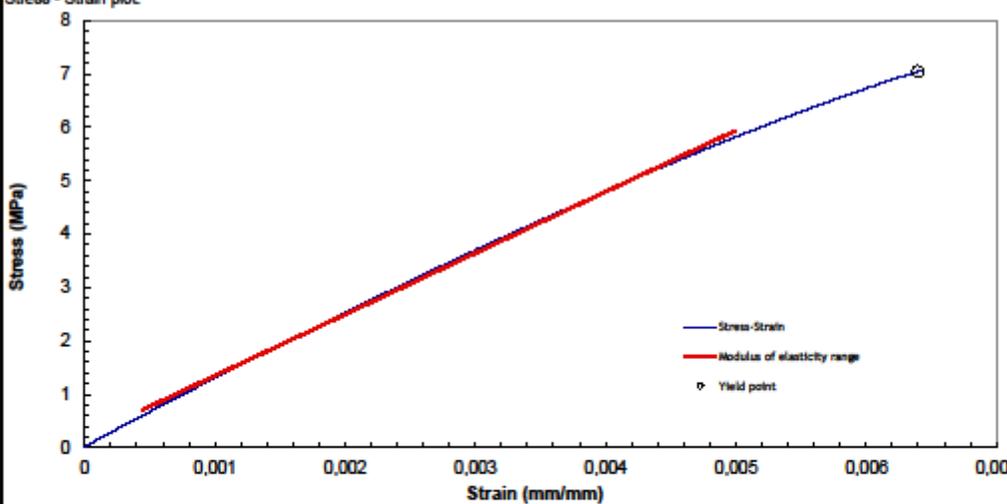
 <b>Results Report</b>		External code:	2_6_A-50	
Tensile test- ASTM638-10		Internal code:	16-0133	
Validated by:		JRE	Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	2_6_A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	14,001	3,169		
2	13,654	3,115		
3	14,530	3,062		
Mean Width:	14,06	Mean thickness:	3,115	Area: 43,81 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	2_6_A-50		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	23,9	Rel.Hum. (%): 45,8
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	23,9	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	12,2	MPa	Stress at yield:	12,974 MPa
Young Modulus:	1,2	GPa	Strain range:	1000 6000 µε
Poisson ratio:	0,99		Strain range:	1000 3000 µε
Strain at failure:	2,49	%	Elongation at yield:	2,0 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0133.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	2_7_A-50	
Tensile test- ASTM638-10		Internal code:	16-0134	
Validated by:		JRE	Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	2_7_A-50		Date:	2016.01.22
Tool used:	MICROMETRE/D2	MICROMETRE/D2	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	14,003	2,733		
2	13,705	2,696		
3	13,975	2,728		
Mean Width:	13,89	Mean thickness:	2,719	Area: 37,78 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	2_7_A-50		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,5	Rel.Hum. (%): 45,7
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	11,6	MPa	Stress at yield:	11,6 MPa
Young Modulus:	1,2	GPa	Strain range:	450 5000 με
Poisson ratio:	1,01		Strain range:	1000 3000 με
Strain at failure:	1,53	%	Elongation at yield:	1,5 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0134.xlsx
<b>Stress - Strain plot</b>  <p>The plot shows Stress (MPa) on the y-axis (0 to 14) and Strain (mm/mm) on the x-axis (0 to 0,018). A red line represents the modulus of elasticity range, and a blue line represents the rest of the stress-strain curve. A yield point is marked with a circled diamond at approximately (0,015, 11,6).</p>				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	3_5_A-25	
Tensile test- ASTM638-10		Internal code:	16-0135	
Validated by:		JRE	Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3 5 A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,207	3,114		
2	12,970	3,134		
3	13,333	3,145		
Mean Width:	13,17	Mean thickness:	3,131	Area: 41,24 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3 5 A-25		Date:	2016.01.26
Speed (mm/min):	0,5		Lab Temperature (°C):	24,6
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	0,0
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	6,5	MPa	Stress at yield:	6,5 MPa
Young Modulus:	1,3	GPa	Strain range:	450 4000 με
Poisson ratio:	0,96		Strain range:	1000 3000 με
Strain at failure:	0,52	%	Elongation at yield:	0,5 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0135.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	3_6_A-25	
Tensile test- ASTM638-10		Internal code:	16-0136	
Validated by:		JRE	Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3_6_A-25		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,557	3,054		
2	13,226	3,089		
3	13,515	3,069		
Mean Width:	13,43	Mean thickness:	3,071	Area: 41,25 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3_6_A-25		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,3	Rel.Hum. (%): 46,5
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	7,1	MPa	Stress at yield:	7,1 MPa
Young Modulus:	1,3	GPa	Strain range:	450 4000 με
Poisson ratio:	0,76		Strain range:	1000 3000 με
Strain at failure:	0,56	%	Elongation at yield:	0,6 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0136.xlsx
<b>Stress - Strain plot</b> 				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	3_7_A-50	
Tensile test- ASTM638-10		Validated by:	JRE	Validation date:
		Internal code:	16-0137	
			Page 1 of 1 2014.01.14	
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3_7_A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,567	3,176		
2	13,417	3,139		
3	13,605	3,136		
Mean Width:	13,53	Mean thickness:	3,150	Area: 42,62 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3_7_A-50		Date:	2016.01.26
Speed (mm/min):	0,5		Lab Temperature (°C):	24,3
Test Machine:	MTS Insight		Load Cell/Range:	10 kN/100 %
Chamber:	-		Test temperature (°C):	0,0
Temperature measured by:	-		Soak time (min):	-
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	7,5	MPa	Stress at yield:	7,9
Young Modulus:	1,2	GPa	Strain range:	450
Poisson ratio:	0,94		Strain range:	1000
Strain at failure:	0,89	%	Elongation at yield:	0,7
Date:	2016.01.27	Technician:	YBA/BGA	Data file:
				16-0137.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				

 <b>Results Report</b>		External code:	3_8_A-50	
Tensile test- ASTM638-10		Internal code:	16-0138	
Validated by:		JRE	Validation date:	2014.01.14
<b>SPECIMEN MATERIAL</b>				
Material Type:	Carbon fiber reinforced ABS		Batch:	CF
Manufacturer:	3D Printed		Orientation:	1
<b>SPECIMEN DIMENSIONS</b>				
Specimen:	3_8_A-50		Date:	2016.01.22
Tool used:	MICROMETRE/02	MICROMETRE/02	Technicians:	CMA/DPI
(mm)	Width	Thickness		
1	13,765	3,158		
2	13,550	3,152		
3	13,939	3,120		
Mean Width:	13,75	Mean thickness:	3,143	Area: 43,23 mm <sup>2</sup>
Specimen reception conditions are according to the standard: YES Specify: -				
<b>STRAIN GAUGE/EXTENSOMETER</b>				
Type:	Biaxial extensometer		Biaxial extensometer	
Gage types and number:	-			
Resistance (Ω):	-	Dimension (mm):	-	-
Strain gauge Factor:	-	Temp. Comp. (10 <sup>-6</sup> /°C):	-	-
Transverse Sensitivity:	-	Other information:	-	
<b>TEST DATA</b>				
Specimen:	3_8_A-50		Date:	2016.01.26
Speed (mm/min):	0,5	Lab Temperature (°C):	24,4	Rel.Hum. (%): 46,3
Test Machine:	MTS Insight	Load Cell/Range:	10 kN/100 %	
Chamber:	-	Test temperature (°C):	0,0	Soak time (min): -
Temperature measured by:	-			
<b>TENSILE TEST RESULTS</b>				
	Result	Unit		
Strength at failure:	7,1	MPa	Stress at yield:	7,1 MPa
Young Modulus:	1,1	GPa	Strain range:	450 5000 με
Poisson ratio:	1,03		Strain range:	1000 3000 με
Strain at failure:	0,64	%	Elongation at yield:	0,6 %
Date:	2016.01.27	Technician:	YBA/BGA	Data file: 16-0138.xlsx
Stress - Strain plot				
				
<b>COMMENTS</b>				