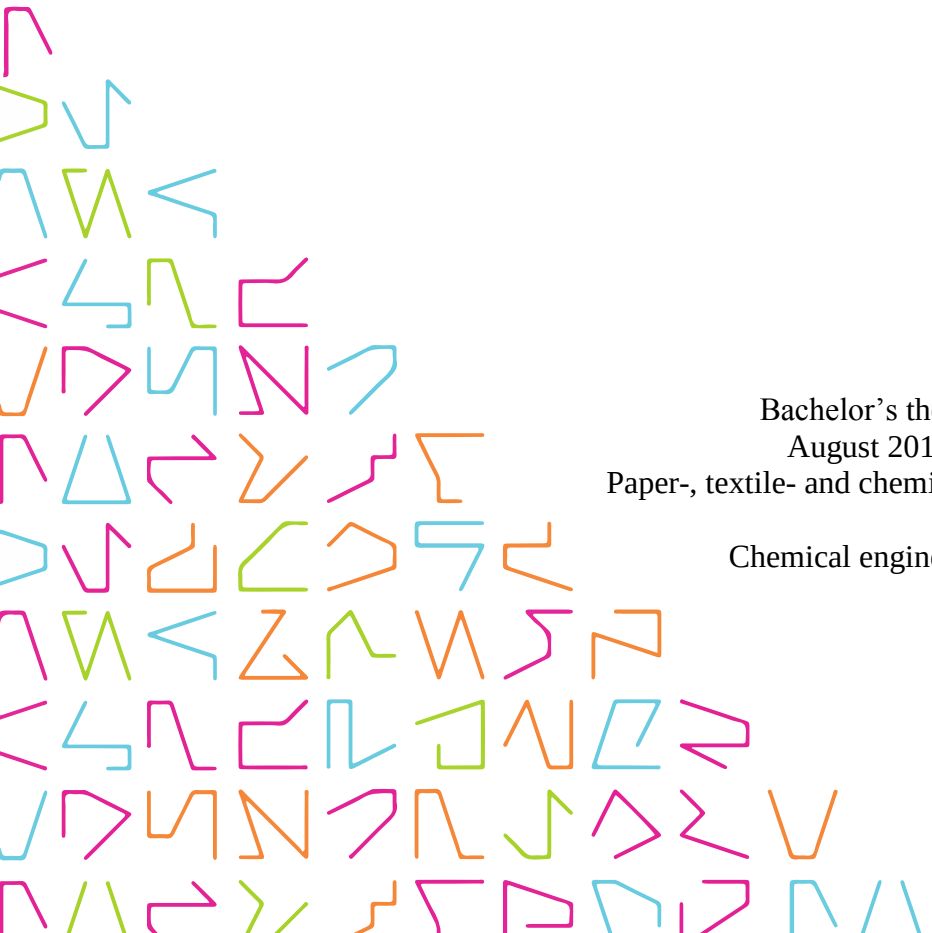
TAMPERE UNIVERSITY
OF APPLIED SCIENCES

THE EFFECT OF HUMIDITY AND TEMPERATURE ON PLA-CELLULOSE FIBRE COMPOSITE PROPERTIES

Sini-Tuuli Rauta



Bachelor's thesis
August 2016
Paper-, textile- and chemical engineering

Chemical engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Paper-, textile- and chemical engineering
Chemical engineering

RAUTA SINI-TUULI: The Effect of Humidity and Temperature on PLA-cellulose Fibre Composite Properties

Bachelor's thesis 107 pages, appendices 60 pages
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This Bachelor's thesis was conducted at VTT Technical Research Centre of Finland during summer 2016. Bachelor's thesis was made in Biocomposites and processing team, which research focus is in different sorts of natural material-based polymeric materials and their processability. The aim of this thesis was to study PLA composite samples placed in a climatic chamber where the humidity and temperature was constant during the full aging time and after that tested by various methods. Samples before exposure mean the original samples. The original sample were compared to aging sample results.

From the test results we can note that the amount of cellulose and additives has a lot importance of PLA composites. Based on mechanical tests such as impact test and tensile test and heat deflection temperature we can say that the additive epoxidized-linseed oil improved durability, strength and lengthened and slowed down aging. Sorbitol derivative as additive made the material more weak, which can be seen decreased material properties.

DSC analysis purpose was to determine glass transition temperature of original and aging samples and to find their differences. Determination of water absorption was one of the tests methods. In addition to the PLA composites there were three wood samples as references in the water absorption test. From the measurement result we can say that even though the PLA composites were absorbing much less water than wooden reference samples the materials may not be suitable for construction in constant contact with water such as quays. PLA composite with epoxy functional additive is suitable for many purposes like tables and chairs in indoors as a substitute for wood material. It is hard and long lasting.

Key words: PLA composite, cellulose, additives in PLA composites

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GLOSSARY

DP	degree of polymerization
DSC	Differential scanning calorimetry
T_c	Crystallization temperature
T_g	Glass transition temperature
T_m	Melting temperature
PLA	Polylactic acid
NDP	Never dried cellulose pulp
HDT	Heat deflection temperature
RH	Relative humidity
BSKP	Bleached softwood kraft pulp
CMC	Carboxymethyl cellulose
MFR	Melt flow rate
ELO	Epoxidized linseed oil

1. INTRODUCTION

At the beginning of this thesis there is a theoretical part, which prepares the experimental part. The theoretical part contains general information on biocomposites, polylactic acid (PLA) and cellulose pulp. In addition there is briefly presented additives those were used in research samples.

This work was conducted at VTT Biocomposites and processing team where different sorts of natural material-based polymeric materials and their processability is researched and developed. This work is a part of the wider research project Acel, which was partly funded by CLIC Innovations and Tekes. The purpose was to test and examine polylactide acid (PLA) - never dried cellulose pulp (NDP) composite samples. Nine different PLA-NDP composite samples were preapared and their aging was tested with and without humidity. PLA-NDP sample series contained different amounts of never dried cellulose pulp and additives.

In experimental part is presenting sample processing before tests and materials those were used in the work. It also introduces devices and working methods used in this work. The aim of the experimental part was to get information how the dof bone shaped samples react to aging test or what kind of changes it there occurs causes.

The methods used in material analysis were mechanical tests like impact tests and tensile tests. Material temperature behaviour was studied using heat deflection temperature (HDT) test and differential scanning calorimetry (DSC). The purpose of DSC analysis was to determine glass transition temperature (Tg) of original samples and samples after aging and to find their differences. Determination of water absorption was also one of the tests methods. In addition to the PLA-NDP composites three wooden reference samples were tested in the water absorption test.

2. THE WRITTEN PART

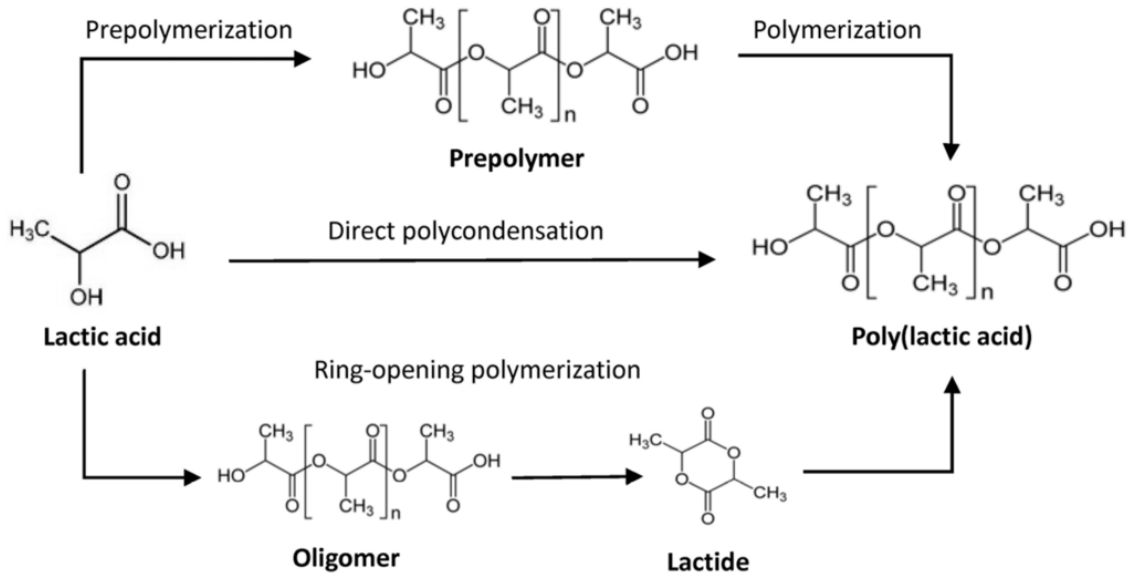
3.1 Polylactic acid

PLA is a biodegradable thermoplastic aliphatic polymer. It is a hard, renewable, biocompatible and resilient material, a set of highly attractive attributes for pharmaceutical, biological, medical applications and many other uses.

PLA is one of the strongest known biodegradable polymers and has therefore been found many applications in areas, such as orthopedics. Although organ transplantation has saved many lives, the harsh reality remains that the need for donor organs far outweighs the supply. It is recognized that tissue engineering may provide an alternative to organ transplantation. This may be achieved either by transplanting cells seeded into a porous material or, in some cases, by relying on ingrowth of tissue and by cells into such a material. PLA copolymers have been used as an artificial scaffold in cell transplantation and organ regeneration. (Chanda et al, 2009.)

Polylactic acid: $C_3H_6O_3$, can be synthesized by direct polycondensation of lactic acid, polymers with higher molecular weights. Lower polydispersity polymers are commonly obtained by ring opening polymerization of lactide (i.e. the cyclic dilactone of lactic acid). L- and D-lactide yield semi crystalline polymers named P(L)LA and P(D)LA, while lactide is used to synthesize amorphous polymers named P(LD)LA. On account of its attractive physico-chemical properties and its biodegradability, PLA is widely used as bio-based, large scale packaging material and in a number of biomedical applications, hence it represents a subject of extensive research. (Frediani et al, 2011.)

PLA synthesis generally. There are three routes to produce PLA polymers from lactic acid as shown in Picture 1. Direct condensation polymerization forms low molecular weight PLA. Two steps polymerization can achieve higher molecular weight, but is still limited by the equilibrium reaction of polycondensation due to hydrolysis of ester bonds. (Hu et al, 2016.)



PICTURE 1. Routes of poly(lactic acid) (PLA) synthesis from lactic acid. (Hu et al, 2016.)

The softening temperature point of PLA is about 60 °C so it may be used for example for 3D printing, but on the other hand, its low glass transition temperature makes many types of PLA unsuitable to applications for example cups holding hot liquid. Melting point is 150–160 °C. The raw material of PLA, L-lactic acid, can be produced by fermentation of renewable sugar resources such as starch and other polysaccharides.

Biopolymer Ingeo^{TM} PLA 3052D is a NatureWorks LLC product designed for injection molding applications where the requirements are clarity with heat deflection temperatures lower than 59°C. Applications include cutlery, cups, plates and saucers, and outdoor novelties, and this is just the beginning. (NatureWorks, Ingeo Biopolymer 3052D Technical Data Sheet Injection Molding Process Guide, 2016.)

The tables 1 and 2 are showing physical properties and mechanical properties for biopolymer grade PLA 3052D.

TABLE 1. Biopolymer PLA 3052D physical properties. (NatureWorks, Ingeo Biopolymer 3052D Technical Data Sheet Injection Molding Process Guide, 2016.)

PLA 3052D Physical properties	
Specific gravity	1.24
MFR, g/10 min (210°C,2,16 kg)	14
Relative Viscosity	3.3
Crystalline melt temperature (°C)	145-160
Glass transition temperature (°C)	55-60
Clarity	Transparent

TABLE 2. Biopolymer PLA 3052D mechanical properties (NatureWorks, Ingeo Biopolymer 3052D Technical Data Sheet Injection Molding Process Guide, 2016.)

PLA 3052D Mechanical properties	
Tensile yield strength, psi (MPa)	9,000 (62)
Tensile elongation, %	3.5
Notched izod impact, ft-lb/in (J/m)	0.3 (16.0)
Flexural strength (MPa)	80
Flexural modulus (MPa)	4,0
Heat distortion temperature (°C)	55

Carothers (at DuPont) discovered PLA or polylactide in 1932. He was only able to produce a low molecular weight PLA by heating lactic acid under vacuum while removing the condensed water. The problem at that time was to increase the molecular weight of the products; and, finally, by ring-opening polymerization of the lactide, high-molecular weight PLA was synthesized. PLA was first used in combination with polyglycolic acid (PGA) as suture material and sold under the name Vicryl in the U.S.A. in 1974. (Mehta et al, 2007)

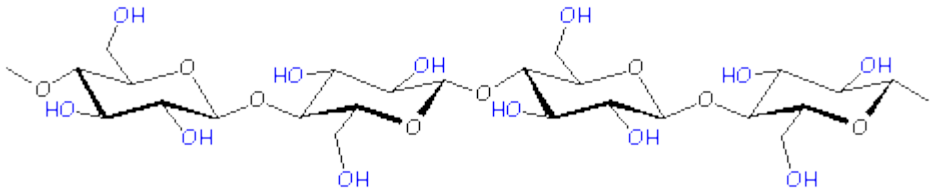
Briefly, PLA is based on agricultural (crop growing), biological (fermentation), and chemical (polymerization) sciences and technologies. It is classified as generally recognized as safe (GRAS) by the United State Food and Drug Administration (FDA) and is safe for all food packaging applications. (Conn et al, 1995.)

2.3 Cellulose

Wood is essentially composed of cellulose, hemicellulose, lignin and extractives. Table 3 presents chemical compositions of spruce. Each of these components contributes to fiber properties, which ultimately affect product properties. (Klemn et al, 2005.)

TABLE 3. Chemical composition of spruce. (Klemn et al, 2005.)

Constituent	Spruce
Cellulose (%)	39.5
Hemicellulose	
- Glucomannan (%)	17.2
- Glucuronoxylan (%)	10.4
- Other polysaccharides (%)	3.0
Lignin (%)	27.5
Total extractives (%)	2.1



PICTURE 2. The Structure of Cellulose (Cellulose, pslc.ws, 2016.)

Wood cellulose molecule has a length of about 5.2 micrometers and has an average of 10,000 glucose units. (Klemn et al, 2005.)

Cellulose, the major chemical component of fiber wall and contributing 40-45 % of the wood's dry weight, is composed of linear chains of D-glucose linked by β-1, 4-glycosidic bonds (picture 2). With the degree of polymerization from 10 000 in native wood to 1000 in bleached kraft pulps. Each D- anhydroglucopyranose unit possesses hydroxyl groups at C2, C3 and C6 positions, capable of undergoing the typical reactions known for primary and secondary alcohols. The molecular structure imparts cellulose with its characteristic properties: hydrophilicity, chirality, degradability and broad chemical variability initiated by the high donor reactivity of hydroxyl groups. (Klemn et al, 2005.)

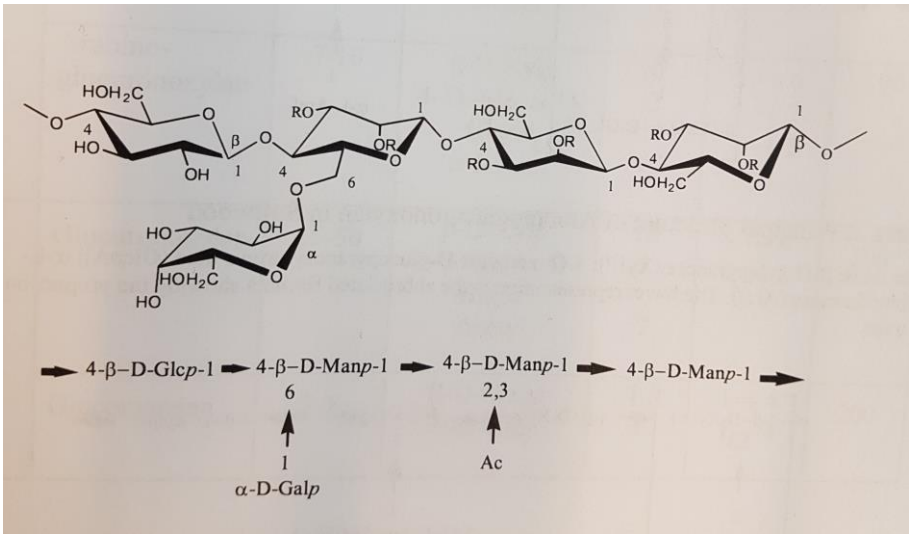
Cellulose has a strong tendency to form intra- and inter- molecular hydrogen bonds by the hydroxyl groups on these linear cellulose chains, which stiffen the straight chain and promote aggregation into a crystalline structure and give cellulose a multitude of partially crystalline fiber structures and morphologies. (Klemn et al, 2005.)

The ultrastructure of native cellulose (cellulose I) has been discovered to possess unexpected complexity in the form of two crystal phases: I_α and I_β. The relative amounts of I_α and I_β have been found to vary between samples from different origins. The I_α- rich specimens have been found in the cell wall of some algae and in bacterial cellulose, whereas I_β- rich specimens have been found in cotton, wood, and ramie fibers. (Klemn et al, 2005.)

The crystal and molecular structure, together with hydrogen- bonding system in cellulose I_α and I_β has been determined recently by Nishiama et. al. atomic- resolution synchrotron and neutron diffraction data recorded from oriented fibrous samples prepared by alignin cellulose microcrystals from the cell wall of the freshwater alga and tunicin. (Klemn et al, 2005.)

The presence of crystalline cellulose, with regions of less order, and the size of the elementary fibrils work together to produce interesting combination of contrary properties such as stiffness and rigidity on one hand and flexibility on the other hand. Crystalline cellulose has a very limited accessibility to water and chemicals. Chemical attack can therefore be expected to occur primarily on amorphous cellulose and crystalline surface. (Klemn et al, 2005.)

In the picture 3 below is shown sugar units: β- D- glucopyranose (GLc*p*); β- D- manno-pyranose (Man*p*); β- D- galactopyranose (Gal*p*). *R= CH3CO* or *H*. The lower representation is the abbreviated formula showing the proportions of the units (galactose- rich fraction). (Klemn et al, 2005.)



PICTURE 3. Principal Structure of Galactoglucomannans in Softwood. (Klemn et al, 2005.)

3.2 Biocomposites

A composite is defined as a system of materials, a mixture of two or more physical phases, which in combination yields properties very different to that of each individual species alone. An example is wood where cellulose fibrils reinforce a matrix consisting of lignin and hemicellulose. Other occurring fiber reinforcements are glass or carbon dispersed in a polymer plastic matrix, which gives property rise to a resulting material that is stiffer and stronger. If the fibers are continuous and oriented, the stiffness and strength can be calculated by the rule of mixture:

$$E_{composite} = \phi_m E_m + \phi_f E_f \quad \text{(Pa)} \qquad (1)$$

$$\sigma_{composite} = \phi_m \sigma_m + \phi_f \sigma_f \quad \text{(Pa)} \qquad (2)$$

Where Ø is the volume fraction of the matrix (m) or fiber (f) and their respective σ strength and E moludus (Pa). (Olof Gabrielsson, 2013.)

When a load is applied, shearing forces within the matrix is transferred to the stiff fiber that will improve the mechanical properties of the final product. In terms of composites the concept of the critical fiber length is an important factor to consider when determining the properties of the resulting composite. The critical fiber length is defined as the length (of the fiber) at which the tensile stress is able to reach its maximum without compromising the structural integrity of the composite. When the length of the fiber is lower than the critical fiber length the stress applied might be higher than the interface between the fiber and matrix can sustain, resulting in failure within the material. Whereas when the length of the fiber is higher in comparison to the critical fiber length the load may be more than the fiber can sustain which causes it to break. Interfaces where weak interactions between the fiber and the matrix are present act as internal defects. The interfacial strength is however not the ultimate solution since this could render a brittle composite since cracks will not be hindered through branching or interfacial delamination. The optimal way is therefore to create a controlled interfacial strength rather than the strongest. (Olof Gabrielsson, 2013.)

Composites are non-isotropic materials, meaning that they display directionality depending on the length and orientation of the fibers. Because of this, mechanical properties will be different depending on in which direction the test will be performed. (Olof Gabrielsson, 2013.)

A good example of biocomposites is UPM Formi, developed by UPM, whose composite granules are made of wood pulp and plastic. The material is ideally suited for manufacturing a wide range of industrial and consumer products, for example furniture and car parts. (Bioeconomy, 2016.)

Polylactide (PLA) based cellulose fibre compounds are finding their ways to different injection moulded applications. In addition to gain high performance PLA-cellulose pulp fibre composites there is also needed additives such as plasticizers and coupling agents in the compound. Renewable material based combined plasticizer-coupling agent as additive in PLA bleached softwood kraft pulp composite. (Immonen et al, 2016.)

2.4 Additives in PLA-cellulose composites

In the VTT, latest tests evidence the best performing additives in PLA-cellulose composites were epoxidized linseed oil (Vikoflex 7190) and sorbitol derivative (Tween 20 polysorbate, polyethylene glycol sorbitan monolaurate). (Immonen et al, 2016.)

ELO (epoxidized linseed oil) and other epoxidized vegetable oils are known plasticizers for PLA and thus compatible with it. It is also compatible with cellulose and due to epoxy functionality it can be react with cellulose hydroxyl groups forming covalent bond. This phenomenon can be utilised in processing with PLA in elevated temperature, when ELO modified cellulose can create true connections to PLA with improved dispersion. (Immonen et al, 2016.)

Vikoflex 7190 is a specialized premium-quality epoxidized linseed oil with superior performance properties distinguishing it from all currently available epoxidized linseed oils. Vikoflex 7190 epoxidized linseed oil is recommended for food contact packaging and medical applications where very little or no metallic stabilizer is used. Low odor properties also contribute to the high acceptance of Vikoflex 7190 epoxidized linseed oil in these critical areas. (Immonen et al, 2016.)

3. THE EXPERIMENTAL PART

3.1 Aim of the study

Aim of the work was to research PLA-NDP composites and neat PLA 3052D samples behavior in the climatic chambers on the conditions of 80 RH % and temperature 50 °C within two weeks and six weeks of aging time. This procedure is called aging test. The samples were tested with different methods and compared them to each other and also with original samples. It was also wanted to find out how additives epoxy- linseed oil and sorbitol derivative contributed to durability.

Purpose of the work was also to develop materials for totally bio-based products, wildlife friendly and cheap to produce as well as durable and long lasting in normal use temperature.

3.2 Materials and methods

PLA is widely used as a polymer matrix in cellulose fibre composites, due to its good availability, sensible price, wide selection of grades for different processing and good mechanical properties.

Wood cellulose is a good option for the reinforcement of composites, because it does not require fields for growing, it is widely available in uniform quality and has a good price compared to agro fibresand. Short fibres give better processability.

3.2.1 Materials

Polylactic acid (PLA Ingeo 3052D, NatureWorks LLC) was used a matrix polymer for the preparation of the PLA/ Never dried cellulose pulp (NDP) composites. Never dried cellulose (NDP) (Stora Enso) was chosen because the pre-treatment of fibres is easy and it is easy to add additives. It is made from spruce and available straight from pulp process in dry material content 32.6 %. As additive was used, epoxy functional linseed oil Vicoflex 7190. According to manufacturer Vikoflex 7190 is linseed oil based material and is recommended for food contact packaging and medical applications. In Vikoflex 7190 the double bonds of linoleic oil, α-linolenic oil and oleic acid are epoxidized to contain several oxirane rings (minimum 9 % of oxirane oxygen) able to react further. Its high compatibility and superior heat and light stability enable Vikoflex 7190 epoxidized linseed oil to function as a primary, polymeric type, plasticizer-stabilizer. Additives are needed as plasticizers and coupling agents in the compound.

To some sample compounds were prepared with sorbitol derivative (polyethylene glycol sorbitan monolaurate), Tween 20 (Sigma Aldrich), as additive to compare the plasticizing effect with a non-reactive additive.

3.2.2 Experiments

In the table 4 is presented biocomposite sample series, which were studied by several methods. Samples contained different amounts of pulp. Two samples are only pulp and PLA plastic and the other two samples contain additive, sorbitol derivative (Tween). Rest of the samples contain an ELO (Vikoflex 7190.)

TABLE 4. PLA-NDP- sample series on experiments. Additive and fibre contents.

	Sample name	Fibre w-%	Additive	Additive w-%
1	PLA 3052D (a matrix polymer)	0		
2	NDP 40	40		
3	NDP 50	50		
4	NDP 40 + Epox(5)	40	Epox-linseed oil Vikoflex 7190	5
5	NDP 50 + Epox(5)	50	Epox-linseed oil Vikoflex 7190	5
6	NDP 40 + Sorbitol(5)	40	Sorbitol derivative, Tween	5
7	NDP 50 + Sorbitol(5)	50	Sorbitol derivative, Tween	5
8	NDP 40 + Epox(8)	40	Epox-linseed oil Vikoflex 7190	8
9	NDP 40 + Epox(12)	40	Epox-linseed oil Vikoflex 7190	12

3.3 Samples processing

Cellulose came to VTT in never dried form in dry matter content 32 %. Never dried cellulose pulp blending with additives was made in Forberg-type blender. The additive ELO was added on fibre in amounts of 5, 8 or 12% of fibre dry material content. After additive mixing the cellulose was densified in a compactor device to form a pellet type material. The compactor device is a modified pelletizing equipment that allows low water content (50-15%) cellulose fibre material processing to loose pellets without increasing the friction temperature during processing too high for sensitive carbohydrate materials. After compacting the pellets were dried in a flow through dryer.

Additive containing bleached softwood kraft pulp with PLA composite were prepared with fibre content of 40 wt-% using a co-rotating twin-screw extruder (Berstorff GmbH ZE 25x33 D). Diameters and lengths of the screws of the twin-screw extruder were 25 mm and 870 mm respectively. The extruder zone temperatures ranged from 60 to 195 °C. After compounding, the PLA/BSKP samples were injection moulded with an injection moulding machine (Engel ES 200/50 HL) to test specimens according to ISO 527.

The target fibre content for biocomposite mixtures was to add 50% cellulose for compounds targeted to injection moulding without losing properties of PLA. In my test series the cellulose fibre contents were 40% and 50%.

3.4 Test methods

Original sample bars were tested by physical methods like tensile strength, impact strength and heat deflection temperature. Other test methods were differential scanning calorimetry (DSC) and determination of water absorption.

The samples were aged in climatic chambers (picture 4) for two weeks and six weeks. The humidity of the climatic chambers was 80 RH % (relative humidity percentage) and temperature 50 °C.

PICTURE 4. Climatic chamber (WTB Binder Labortechnik GmbH, Germany)

Tensile strength test, impact strength test and DSC run was made for temperature and humidity aging samples.

Water absorption test for PLA-NDP composites was performed together with three reference samples. The reference samples were three different types of woods; pressure saturated pine, spruce batten and wood birch.

PLA composite samples were in the water at 23°C for total four months. Wooden reference samples were two months in the water bath.

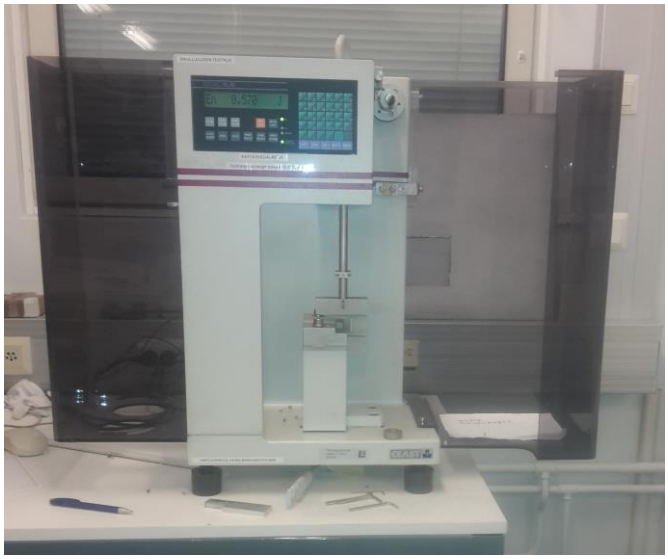
All the test specimens were kept in standard conditions (23 °C, 50% relative humidity) for at least five days before testing. It is better to conduct the test in the same atmosphere as that used for conditioning, if that is possible. Mechanical properties of the composite materials were evaluated.

3.4.1 Charpy impact tests

Charpy impact strength test was made according to ISO-179 standard. Impact strengths were measured for unnotched specimens in a three-point bend configuration and using a Charpy Ceast Resil machine. CEAST S.p.a., made in Torino, Italy (Picture 5). In this case all samples were tested with a two-joule hammer.

The test specimen, supported near its ends as a horizontal beam, is impacted by a single blow of a striker, with the line of impact midway between the supports, and bent at a high, nominally constant, velocity.

The definition impact strength means energy absorbed in breaking a specimen, referred to the original cross-sectional area of the specimen. It is expressed in kilojoules per square metre (kJ/m^2).



PICTURE 5. Impact strength machine (CEAST S.p.a., Torino, Italy).

3.4.2 Tensile tests

Tensile tests were performed using an Instron 4505 Universal Tensile Tester (Instron Corp., Canton, MA, USA) and an Instron 2665 Series High Resolution Digital Automatic Extensometer (Instron Corp., Canton, MA, USA) with a 10 kN load cell and a 5 mm/min cross-head speed. The tensile tests were performed according to ISO-527 (picture 6).

The test specimen is extended along its major longitudinal axis at constant speed until the specimen fractures or the stress (load) or the strain (elongation) reaches some predetermined value. During this procedure the load sustained by the specimen and the elongation are measured.

Grips for holding the test specimen shall be attached to the machine so that the major axis of the test specimen coincides with the direction of pull through the centreline of the grip assembly. The extensometer shall be capable of determining the relative change in the gauge length on the test specimen at any time during the test.

A minimum of five-test specimen shall be tested for each of the required directions of testing and for the properties considered. The number of measurements may be more than five if greater precision of the mean value is required.

Tensile testing most important result values are:
tensile stress at max load (MPa), tensile strain at max load (%), stress at break (MPa), strain at break (%), modulus (Auto Young's) (MPa).

PICTURE 6. Tensile tester and digital automatic extensometer (left) and grips for holding the test specimen (right).

3.4.3 Heat deflection temperature

The heat deflection temperature (HDT) is the temperature at which a polymer sample reform under a specified load and it is used to determine the short-term heat resistance. Heat deflection temperature was measured according to the ISO-75 standard using method A, where the outer stress is 1.80 MPa. HDT was determined by using the Ceast HDT 3 VICAT P/N 6911.000 apparatus. CEAST S.p.a., made in Torino, Italy (Picture 7). All samples were also measured with the method B, where the stress on the sample is 0.45 MPa.

Samples for testing are in the flatwise position. Three parallel test specimens are set to the silicone oil at a same time and device begins to raise the temperature of heating oil. Heat deflection temperature test was measured only for original sample series, not for the climatic chambers exposed samples.

PICTURE 7. Picture of the heat deflection temperature device (left) and sample points of the device when the samples are in oil (right).

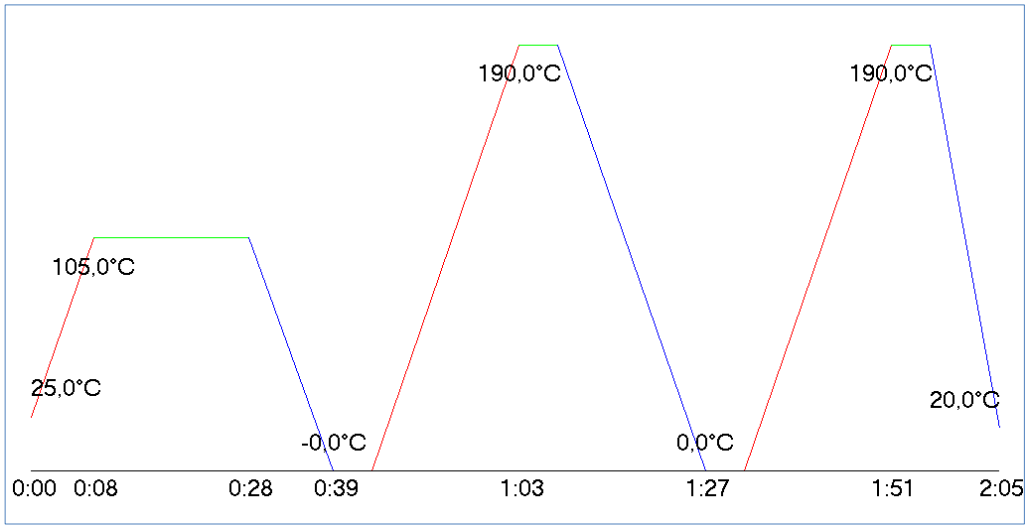
3.4.4 Differential scanning calorimetry

Differential scanning calorimetry Netzsch DSC 204 F1 made in Phoenix Germany (picture 8) is a thermal analysis technique which measures the temperature and heat flow associated with transitions in materials as a function of temperature and time. Such measurements provide qualitative and quantitive information about chemical and physical changes that include exothermic/endothermic processes or changes in heat capacity. Specific information that can be obtained include: glass transition temperatures, melting- and boiling points, crystallization time and reaction, Specific heat, oxidative stability, rate of cure, degree of cure, reaction kinetics, purity and thermal stability. DSC method is used most especially in polymer research. (Leonard C.Thomas. TA Instruments,Inc.)

The injection moulded samples were sawn to small slices and then slices with the weight of typically 10 mg were set on aluminum crucible and placed in the differential scanning calorimetry. Measurements are made in normally in nitrogen atmosphere.

PICTURE 8. Differential scanning calorimetry (Netzsch DSC 204 F1)

At first run parameters were set in the device. Samples were set preheated from 25 °C to 105 °C in about 30 minutes because sample wanted to be dried at first and then it was cooled back. For the actual measurement the first heating was 10 °C per minute to 190 °C followed by cooling and then second heating 10 °C per minute to 190 °C to see if any physical changes has occurred in sample, which can be seen by comparing the first and second run results. Then the last cooling was 20 °C per minute. In the picture 9 below is presented heating time, marked in red color and cooling time is marked in violet color. Green color means how long does the device keeps the temperature constant.

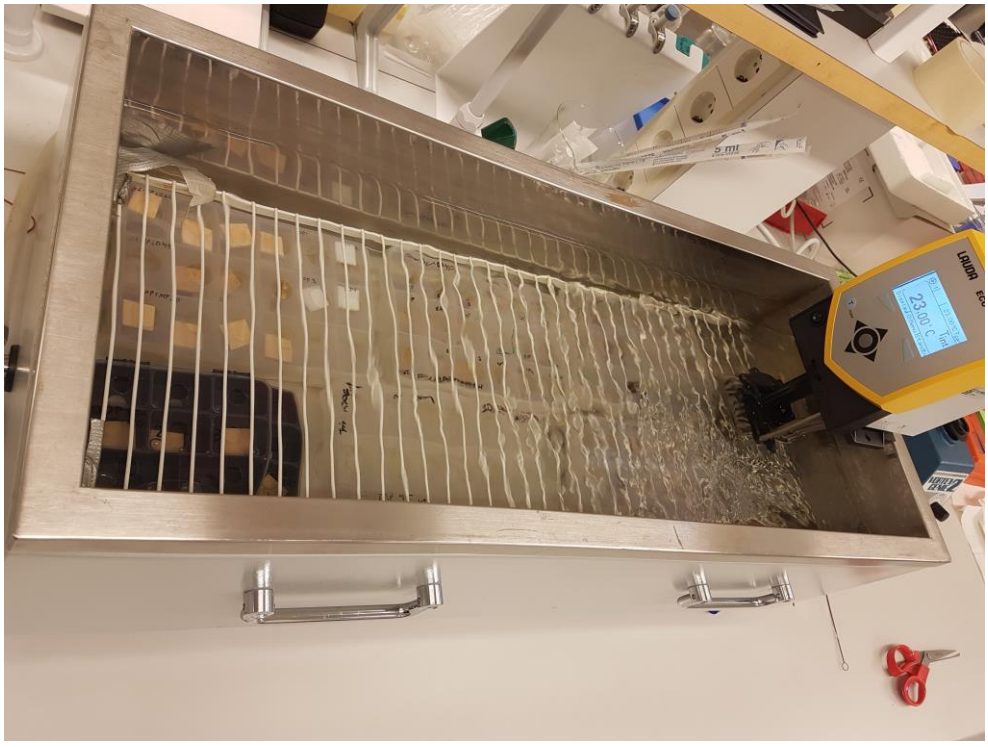


PICTURE 9. Differential scanning calorimetry (Netzsch DSC 204 F1) set values for PLA 3052D and NDP sample series.

3.4.5 Determination of water absorption

Determination of water absorption was performed according to ISO 62. The water absorption of the injection moulded samples was tested for samples immersed in a water bath in a temperature of 23 °C. Three parallel samples of each trial point were cut from the injection moulded test bars to 20 x 20 mm pieces with a thickness of 4 mm. The cut end of the sample was sanded smooth. The samples were dried overnight in the oven at 50 °C and the heat was evaporated in the desiccator. Then the samples were weighted. During the test the weight changes and sample area changes were measured. Water absorption is reported as percentages of weight and area change of sample.

Water absorption samples were in the reverse osmosis water bath. The samples were weighed before putting in the water and after 24 and 48 hours, one week, two weeks, three weeks, four weeks, two months, three months and four months watering periods. (Picture 10).

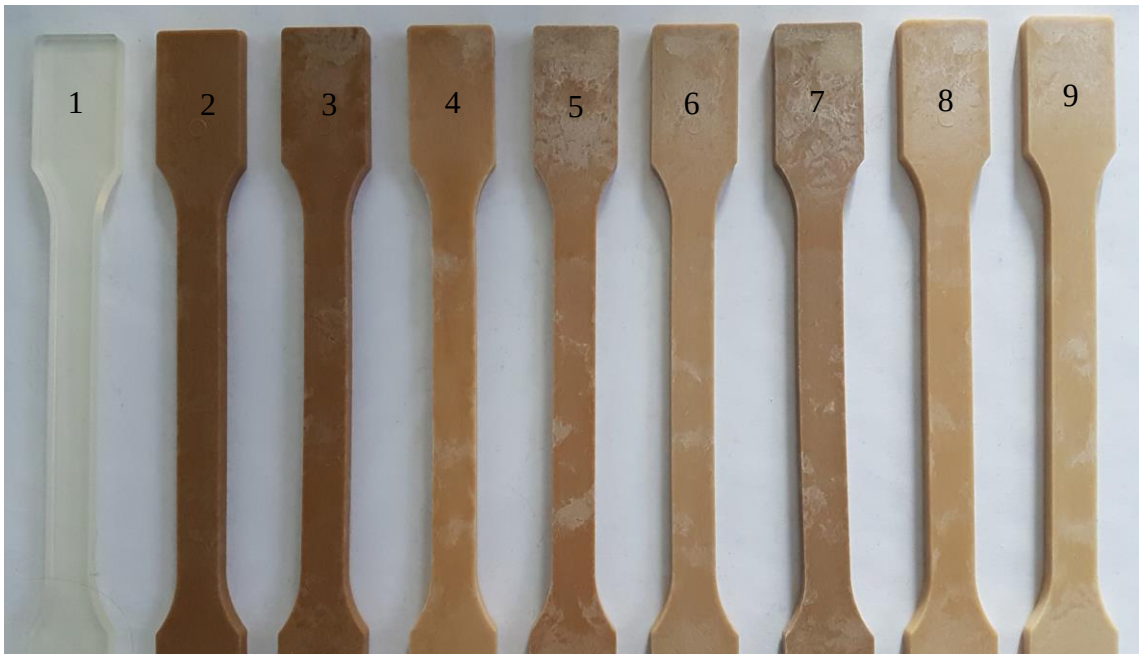


PICTURE 10. Device for determination of water absorption. In the picture samples are in the 23 °C water bath.

4 RESULTS AND DISCUSSION

In to the biocomposite samples series that was tested included nine samples. In the picture 11 below is original PLA 3052 sample, number 1 in the left side and next to it is sample rods in numerical order from the smallest number (1) to the largest (9) from left to right. Last sample number 9- NDP 40 + additive Epox 12 % in the right side.

Samples color difference is depending on of the amount of cellulose or additives and manufacturing temperatures.



PICTURE 11. Picture of the injection molded test rods. Neat PLA 3052 sample bar (left) and next to it is sample rods in numerical order from the smallest number (1) to the largest (9) from left to right. Last sample is NDP 40 + Epox 12 % (right).

For determination of water absorption the biocomposite samples were under water for four months and the picture 12 shows that their colors are faded quite a lot during that period. The picture shows the original undetermined samples placed in upper row and after water absorption test in lower row.

PICTURE 12. Determination of water absorption. At the upper row of the picture are original samples and below are samples after the water absorption test.

Picture 13 shows the wooden samples used in the water absorption test. Top of the picture is spruce list, in the middle is log of birch and the bottom is pressure-saturated pine. In the left side of the picture are the sawn samples used in the water absorption test.

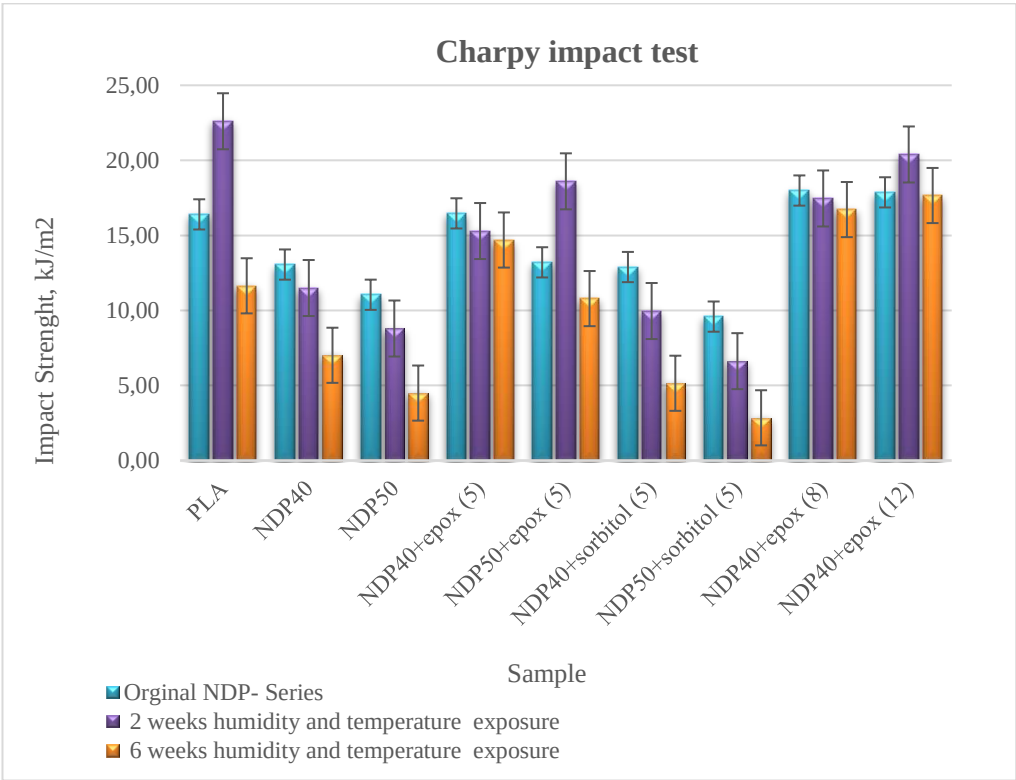
PICTURE 13. Wooden reference samples for the water absorption test. Top of the picture is spruce list, in the middle is log of birch and the bottom is pressure-saturated pine.

In the picture 14 is presented raw materials and composite compounds. On the left side of the picture 14 is never dry cellulose pulp and next to it are PLA-cellulose fibre compounds with NDP 40%, NDP 50% + sorbitol (5) and NDP 40% + epox (8) .On the right side is PLA 3052D granulates. Of the picture can be noted the color difference of the samples and granular size difference.

PICTURE 14. On the left side of the picture is never dry cellulose pulp and next to it are PLA-cellulose fibre compounds with NDP 40%, NDP 50% + sorbitol (5) and NDP 40% + epox (8). On the right side is PLA 3052D granulates.

Below are presented all result graphs which include Charpy impact test, heat deflection temperature test, differential scanning calorimetry test, determination of water absorption test and tensile test including graphs: tensile strength, strain at max load and young's modulus.

Charpy impact strength test results is presented in picture 15 and in Appendix 1, 2 and 3 (pages 48-50).



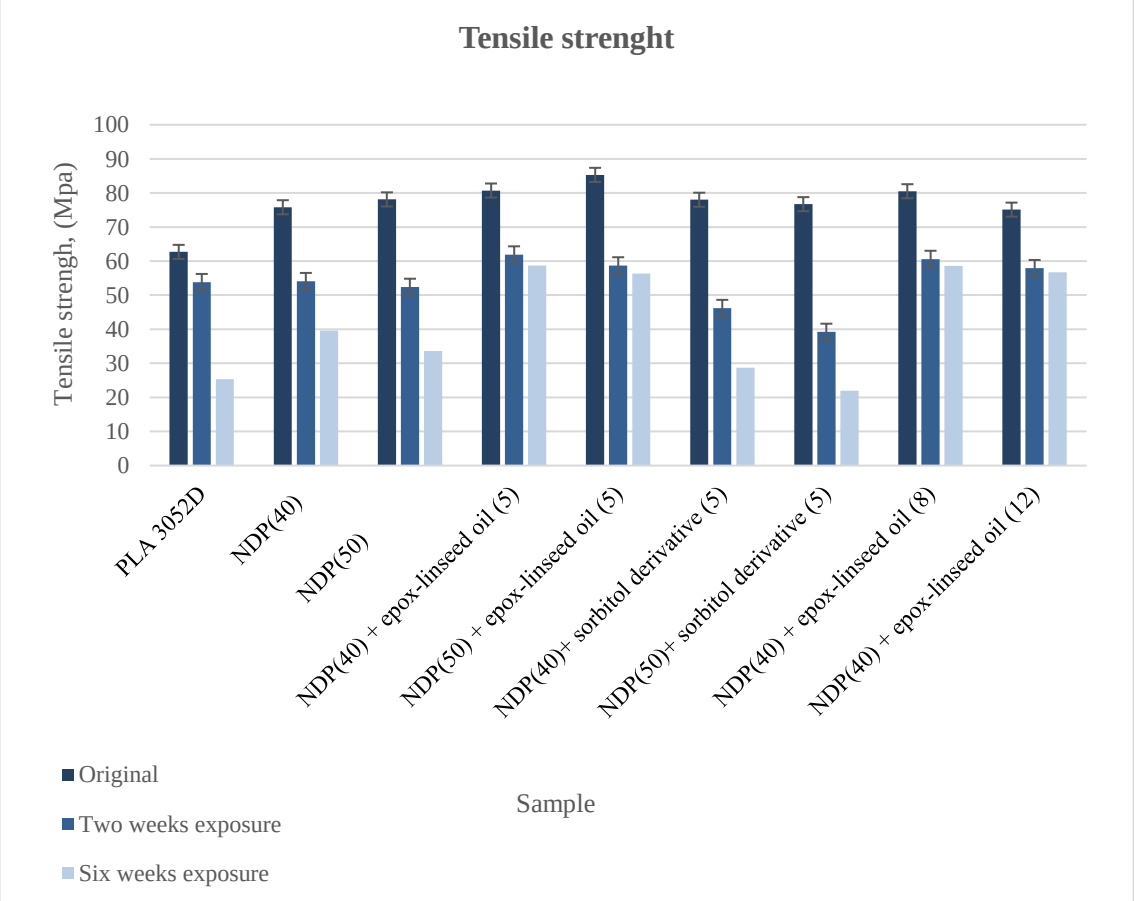
PICTURE 15. Charpy impact test results including the original tests series and after two- and six weeks aging series.

From impact test results can be seen that after six weeks in the climatic chambers aging impact strength results have completely collapsed especially in samples where sorbitol derivative (Tween) at the amount of 5 w-% in fibre, was added.

When looking at the sample results, where epox- linseed oil was added, we can note that the difference is very small between original, after two weeks aging and after six week aging.

Exceptional samples are PLA, NDP 50 + epox 5 % and NDP 40 + epox 12 %. Strange is for these samples that after two weeks aging the impact strengths are higher than in original sample (picture 15).

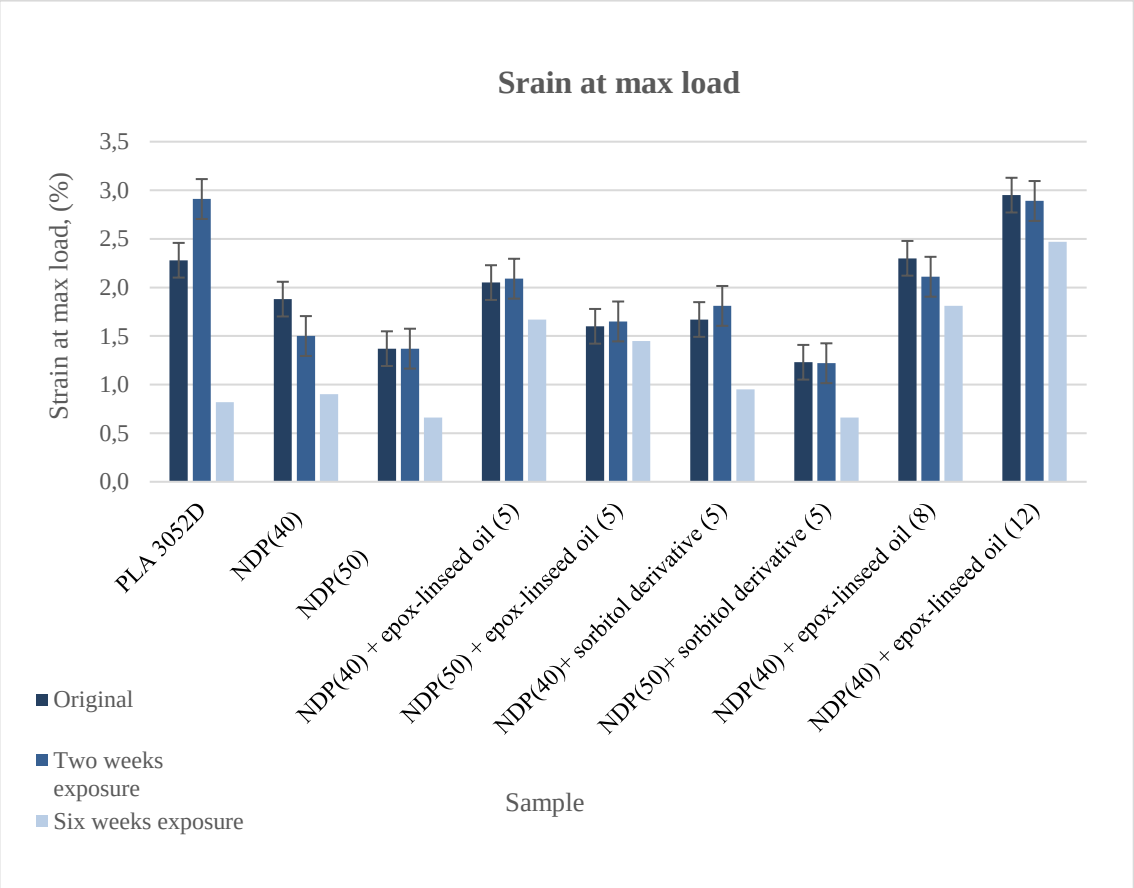
Results from tensile strength tests are presented in pictures 16-18 and in Appendix 4, 5 and 6 (pages 51-77).



PICTURE 16. Tensile strength test results including the original tests series and after two and six weeks aging.

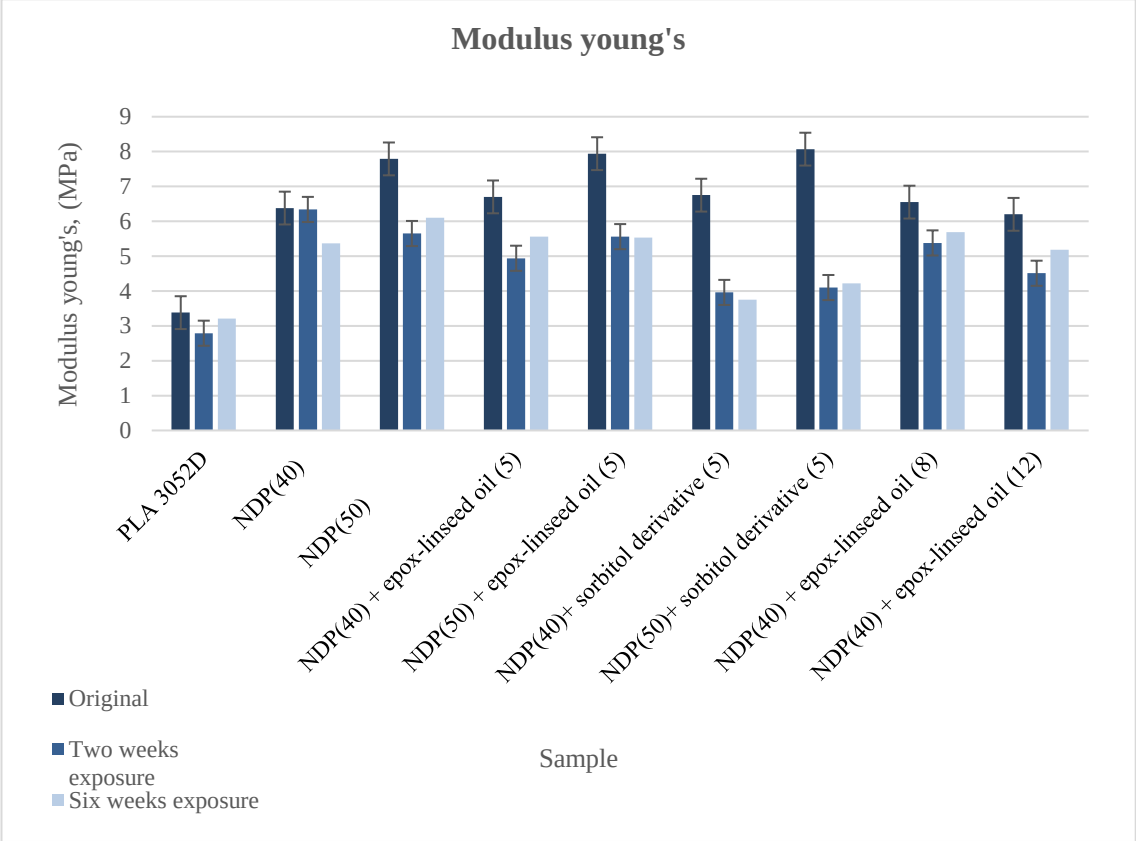
From tensile strength test results can be noticed the samples, which contained epox- linseed oil. The difference is very small between two weeks aged and six week aged samples.

In other samples the test results show quite steady tensile strength fall from the original samples to the six weeks aged samples (picture 16).



PICTURE 17. Strain at max load results including the original tests series and series after two- and six weeks aging test.

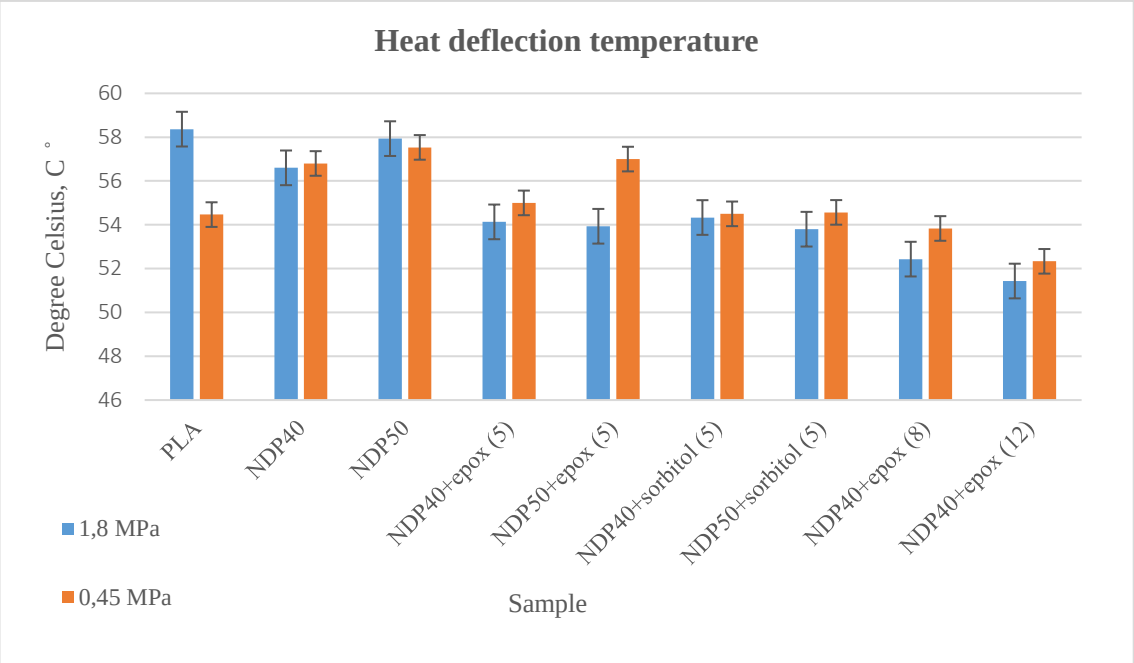
The results for Strain at max load are showing very small changes in all samples series especially between original samples and two weeks exposed samples. The collapse in strain is happening after six weeks exposure except for samples were epox-linseed oil is added. In samples that has epox-linseed oil the change is very small even in the strain at max load result (picture 17).



PICTURE 18. Results for Young's Modulus including the original tests series and after two and six weeks aging test.

Young's modulus results in picture 18 are showing that the biggest drop is happening in samples where sorbitol derivative was added and the smallest change is in samples, which has epoxy additives.

Heat deflection temperature (HDT) results are presented in picture 19 and Appendix 7 and 8 (pages 78-95).

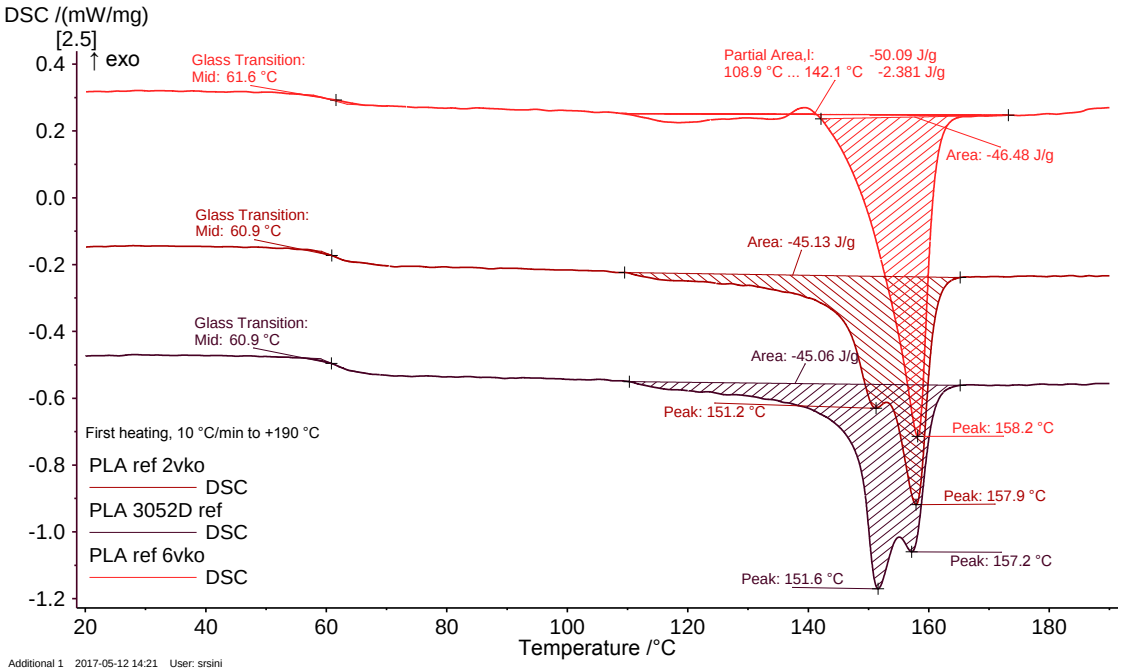


PICTURE 19. Heat deflection temperature tests measured by method A, where the outer stress is 1.80 MPa and method B, where the outer stress is 0.45 MPa.

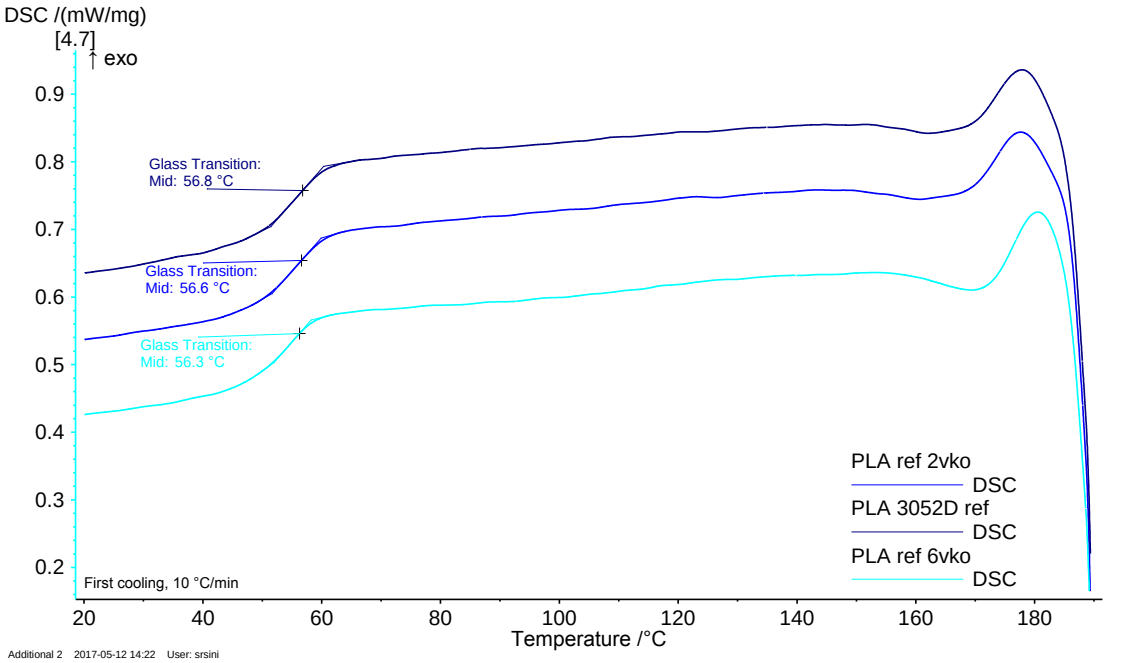
Heat deflection temperature tests were measured using method A, where the outer stress is 1.80 MPa and method B, where the outer stress is 0.45 MPa. In the picture 19 PLA 3052D and NDP 50 + epox 5% has a bigger difference between method A and B than the others. Heat deflection temperature test was measured only for original samples without aging.

Pictures 20-35 are presenting the differential scanning calorimetry (DSC) results including matrix polymer PLA 3052D samples, NDP 50 % cellulose, NDP 50 % cellulose + epox 5 % and NDP 50 % cellulose + sorbitol 5 %. All samples has own graphs for first heating, first cooling, second heating and second cooling runs. In the figures is presented original sample, two weeks and six weeks aged sample results and they are compared to each other. The rest of the DSC sample results are presented in Appendix 49 (pages 96-105).

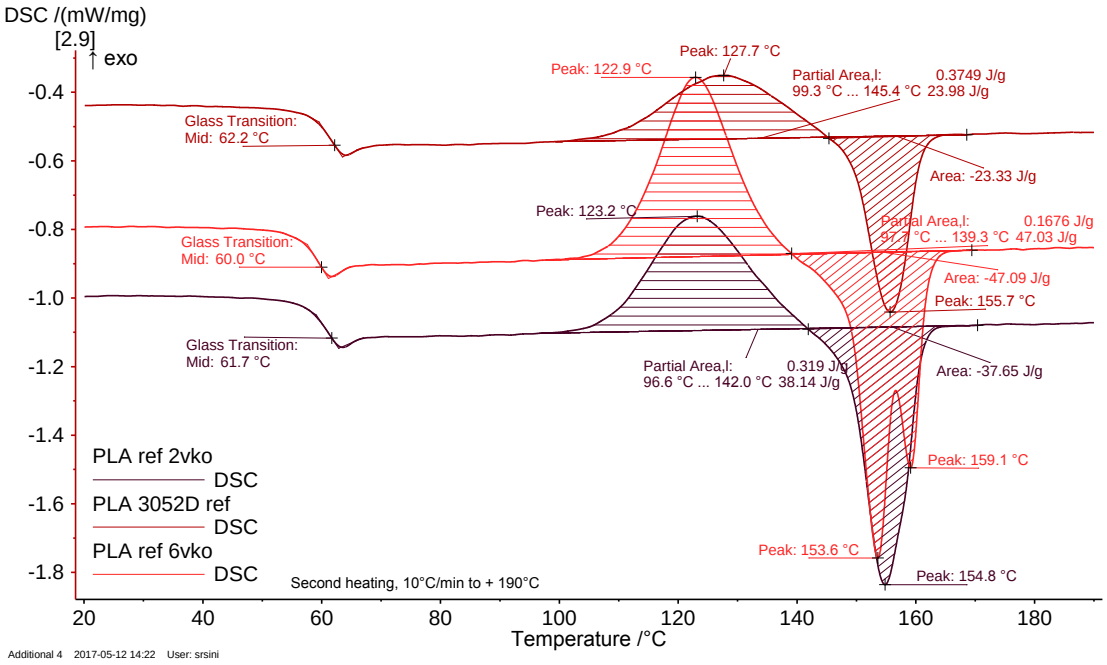
Pictures 20-23 contains DSC heating and cooling curves for neat PLA 3052D samples after two and six weeks of aging time and original sample.



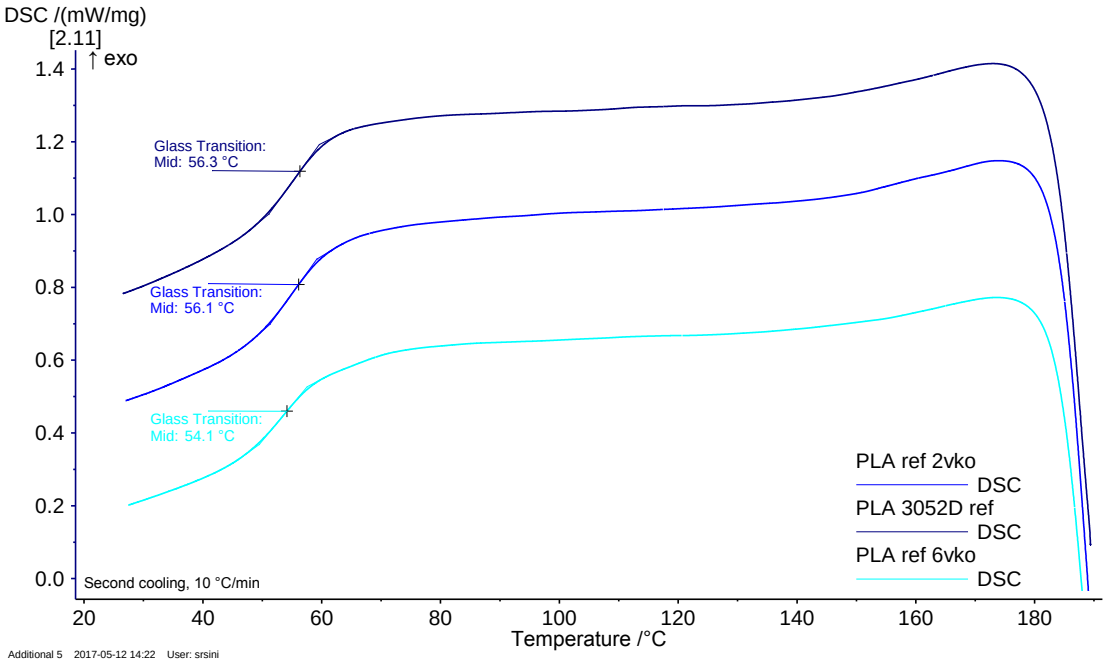
PICTURE 20. DSC results for neat PLA 3052D original sample and sample after two weeks and six week aging. Presented are the results of the first heating run.



PICTURE 21. DSC results for neat PLA 3052D original sample and sample after two weeks and six week aging. Presented are the results of the first cooling run.



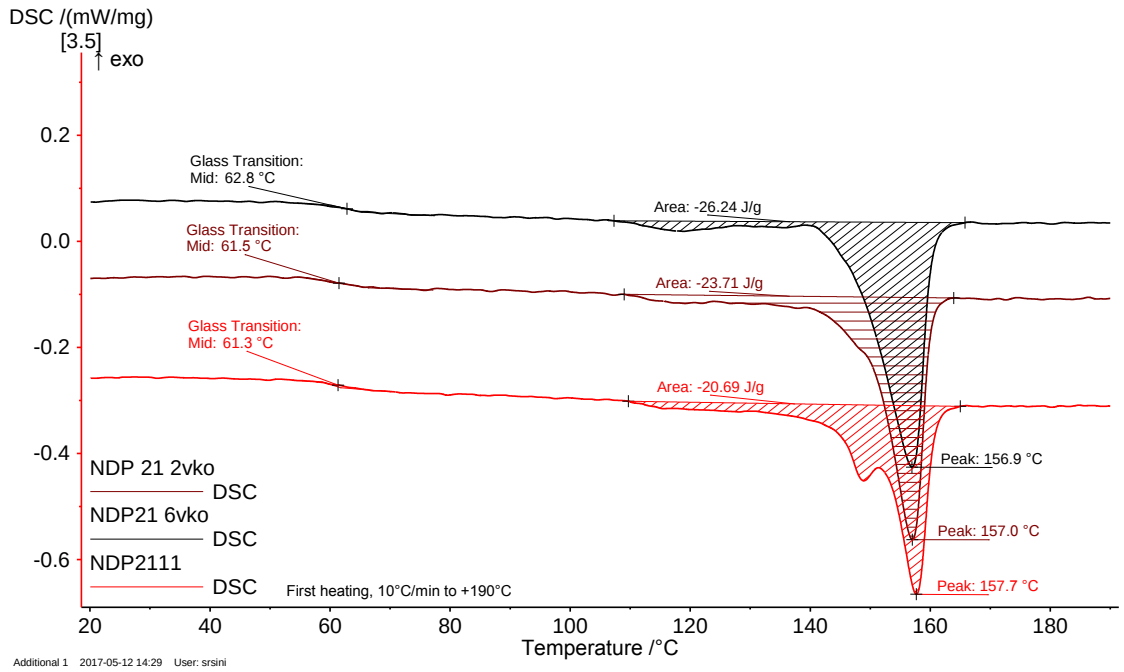
PICTURE 22. DSC results for neat PLA 3052D original sample and sample after two weeks and six week aging. Presented are the results of the second heating run.



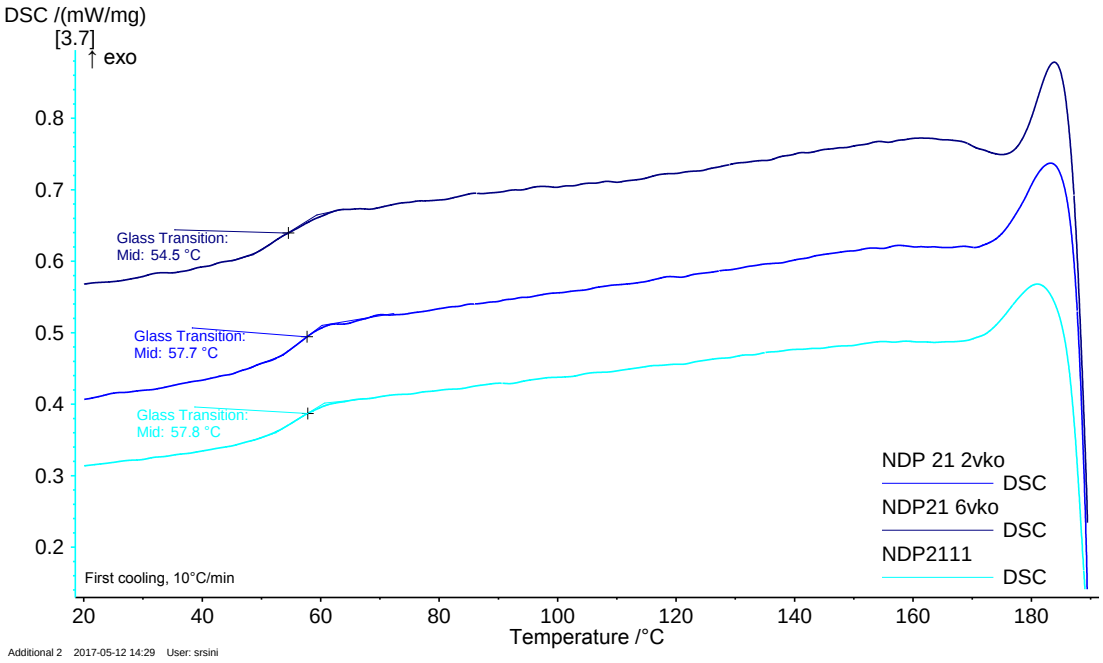
PICTURE 23. DSC results for neat PLA 3052D original sample and sample after two weeks and six week aging. Presented are the results of the second cooling run.

In picture 20 first heating stage shows that the area for glass transition logically rises the longer sample have been exposed. In picture 21 showing the first cooling stage the glass transition temperature for crystallization decreases the longer the sample is aging. In picture 22 for second heating stage there occurs noticeable exothermic cold crystallization. The longer the exposure time was the higher is the cold crystallization before melting and changes in glass transition temperature compared to the picture 20. In picture 23 there is no major changes compared to picture 21.

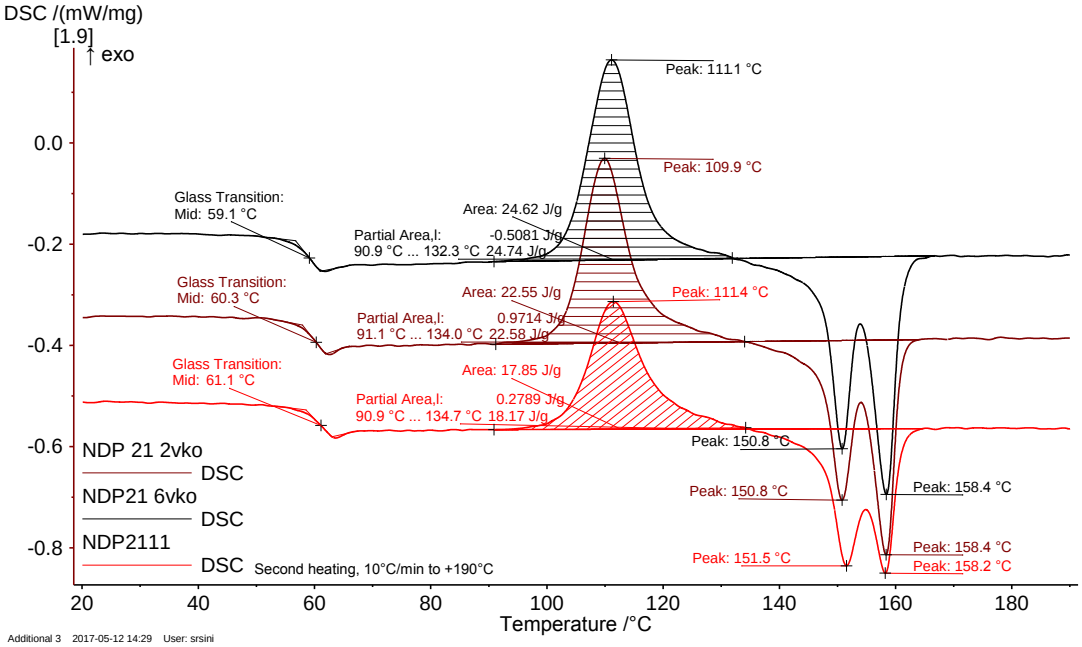
Pictures 24-27 contain DSC results for sample PLA-NDP 50 %, heating and cooling curves for two and six weeks aged samples and the original sample.



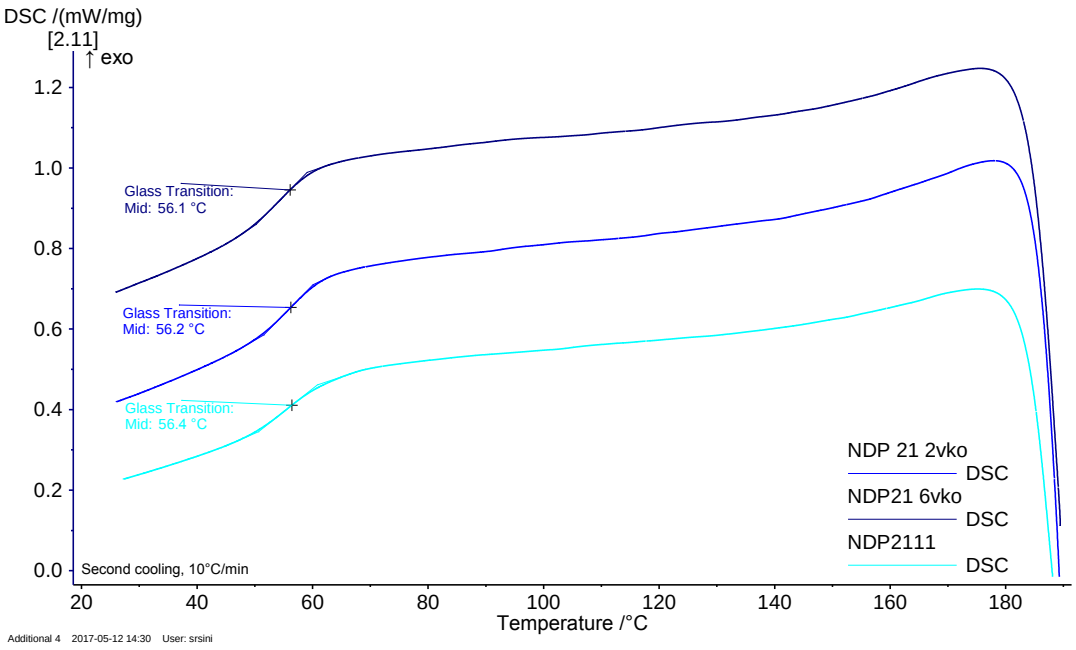
PICTURE 24. DSC results for non-aged PLA-NDP 50 % and sample after two weeks and six week aging. Presented are the results of the first heating run.



PICTURE 25. DSC results for non-aged PLA-NDP 50 % and sample after two weeks and six week aging. Presented are the results of the first cooling run.



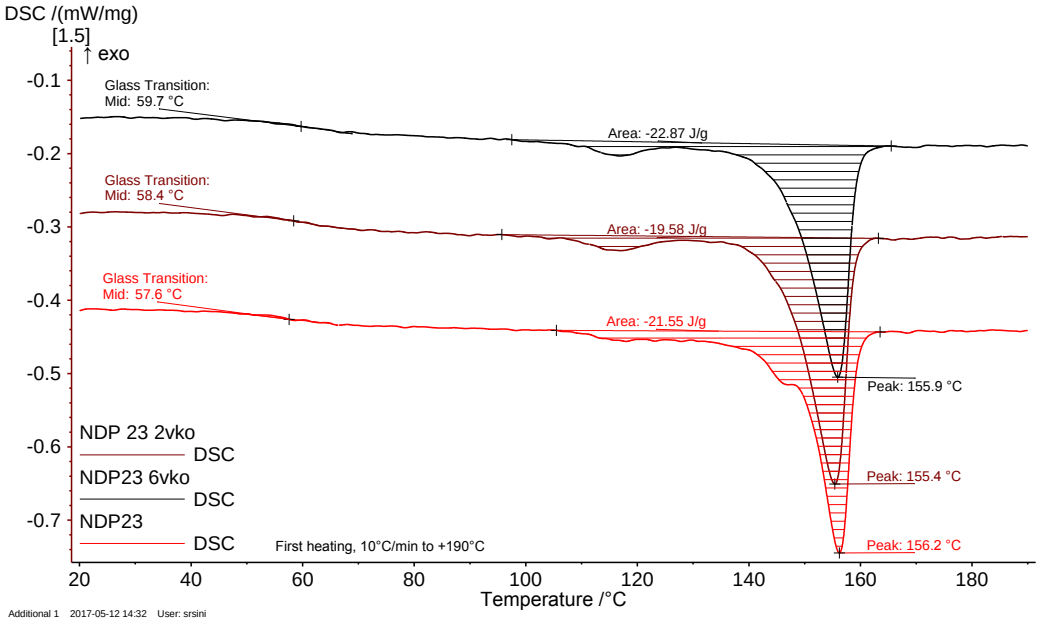
PICTURE 26. DSC results for non-aged PLA-NDP 50 % and sample after two weeks and six week aging. Presented are the results of the second heating run.



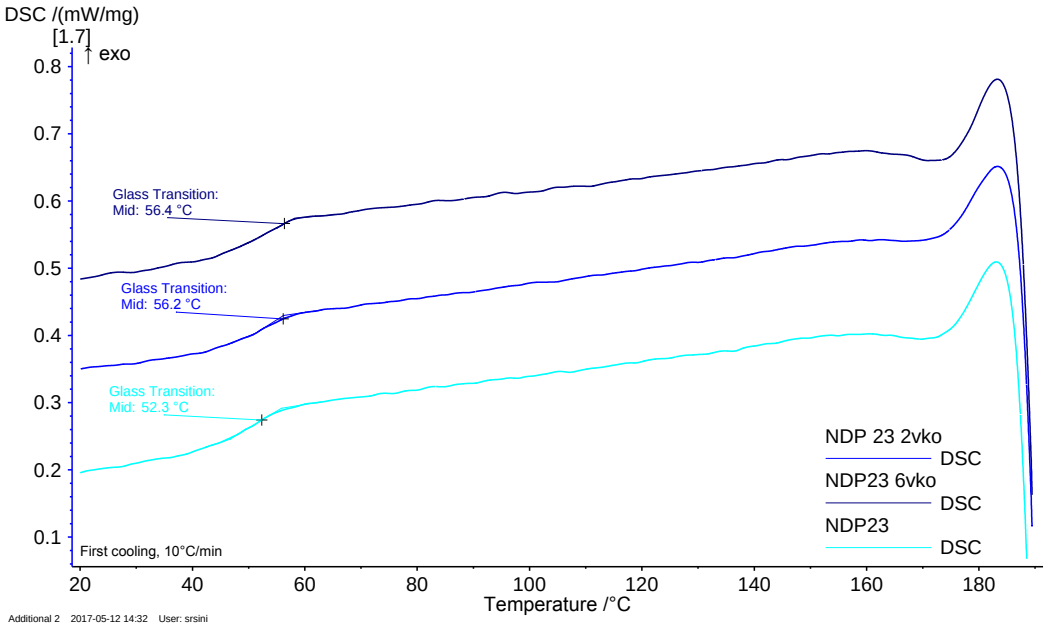
PICTURE 27. DSC results for non-aged PLA-NDP 50 % and sample after two weeks and six week aging. Presented are the results of the second cooling run.

In pictures 24-27 the heating and cooling stages have almost similar phenomena like with neat PLA 3052D where the area of glass transition logically rises the longer sample have been aged. Also in the second heating run there can be found a noticeable exothermic cold crystallization. The longer the aging time the higher the cold crystallization before melting occurs in the second heating run. In PLA 3052D and PLA-NDP 50 % cellulose samples during second heating the changing areas are a clearly different. There is a big difference in melting peaks.

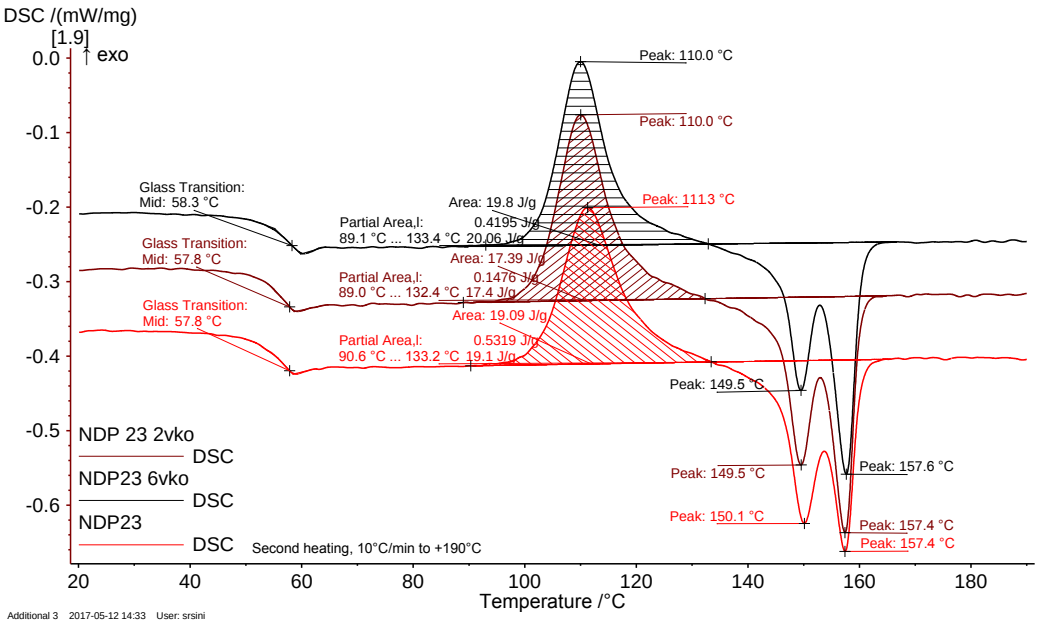
Pictures 28-31 contain results of PLA-NDP 50 % cellulose + epox- linseed oil 5 % heating and cooling curves for two and six weeks aged samples and original sample.



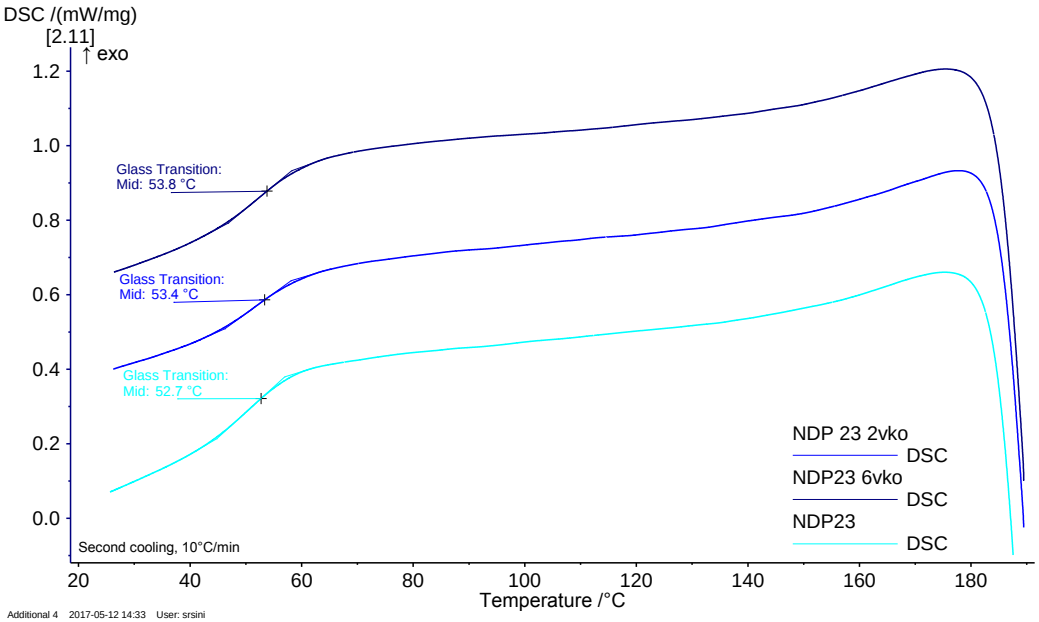
PICTURE 28. DSC results for non-aged PLA-NDP 50 % + epox 5 % and sample after two weeks and six week aging. Presented are the results of the first heating run.



PICTURE 29. DSC results for non-aged PLA-NDP 50 % + epox 5 % and sample after two weeks and six week aging. Presented are the results of the first cooling run.



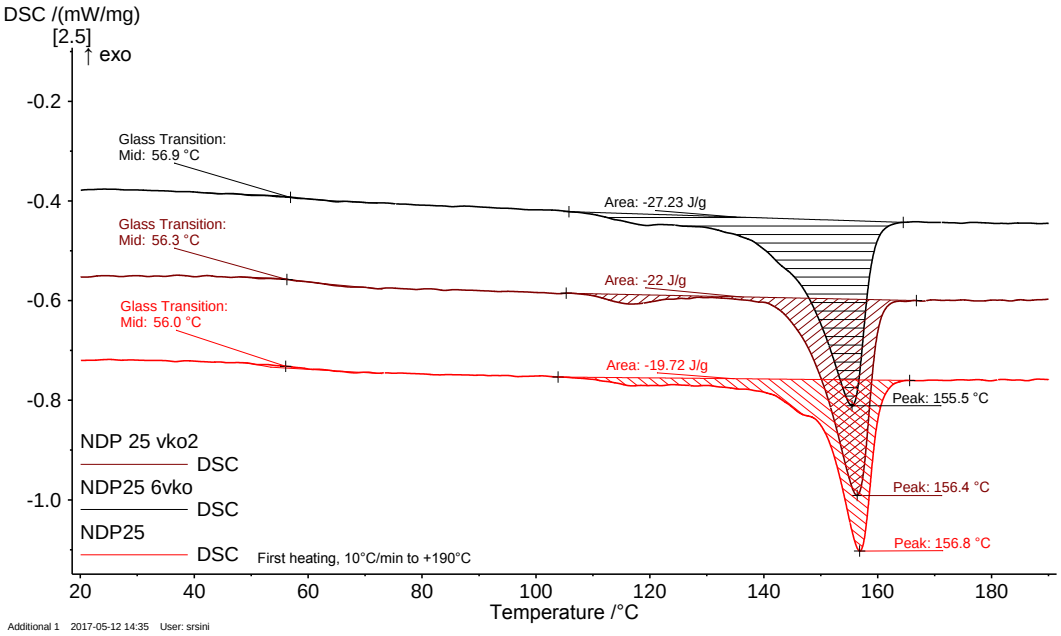
PICTURE 30. DSC results for non-aged PLA-NDP 50 % + epox 5 % and sample after two weeks and six week aging. Presented are the results of the second heating run.



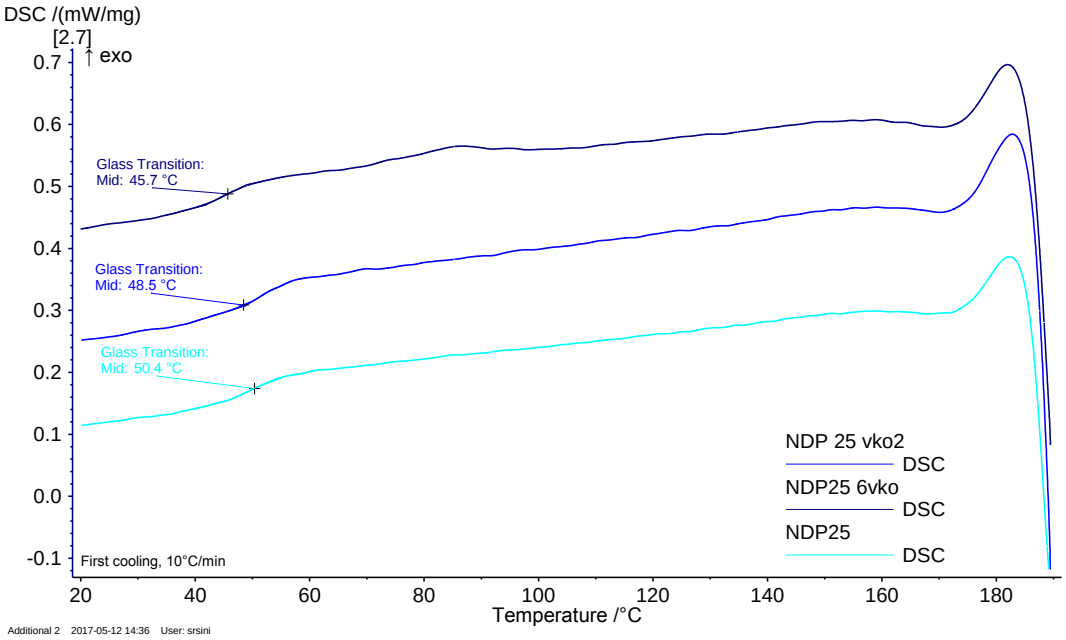
PICTURE 31. DSC results for non-aged PLA-NDP 50 % + epox 5 % and sample after two weeks and six week aging. Presented are the results of the second cooling run.

In pictures 28-31 heating and cooling stages have almost similar phenomena like sample PLA-NDP 50 % cellulose presented in pictures 24-27.

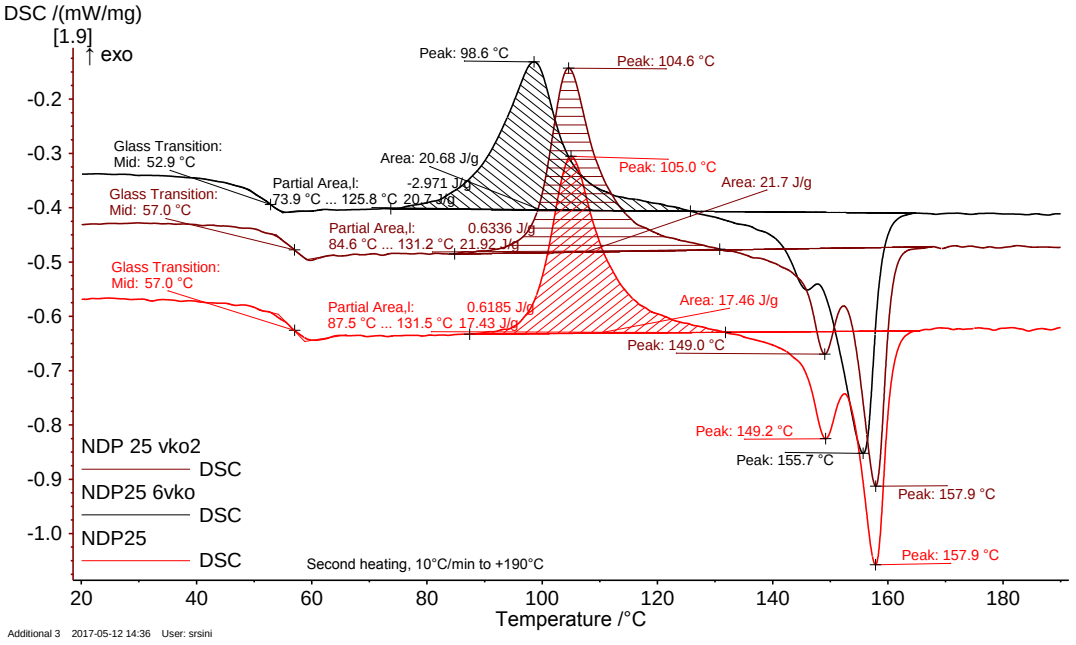
Pictures 32-35 contain DSC results for PLA-NDP 50 % cellulose + sorbitol derivative 5 %, heating and cooling curves for samples after two and six weeks aging and for non-aged sample.



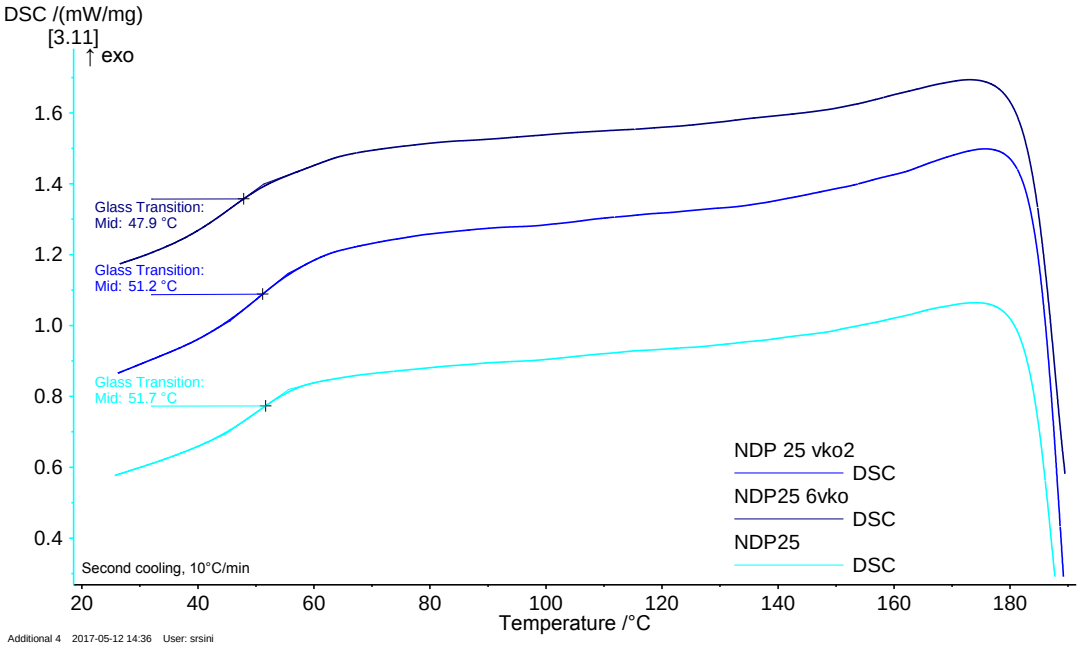
PICTURE 32. DSC results for non-aged PLA-NDP 50 % + sorbitol 5 % and sample after two weeks and six week aging. Presented are the results of the first heating run.



PICTURE 33. DSC results for non-aged PLA-NDP 50 % + sorbitol 5 % and sample after two weeks and six week aging. Presented are the results of the first cooling run.



PICTURE 34. DSC results for non-aged PLA-NDP 50 % + sorbitol 5 % and sample after two weeks and six week aging. Presented are the results of the second heating run.



PICTURE 35. DSC results for non-aged PLA-NDP 50 % + sorbitol 5 % and sample after two weeks and six week aging. Presented are the results of the second cooling run.

In picture 32-35 the results for heating runs have similar changes in areas and melting peaks compared to others samples. Areas are growing over second heating run.

In the table 5 below and in Appendix 10 (site 106) is present results of water absorption test during four months for all samples

TABLE 5. Results from water absorption test for PLA composite samples presented as averages weight change as m-% **(**mass percentage).

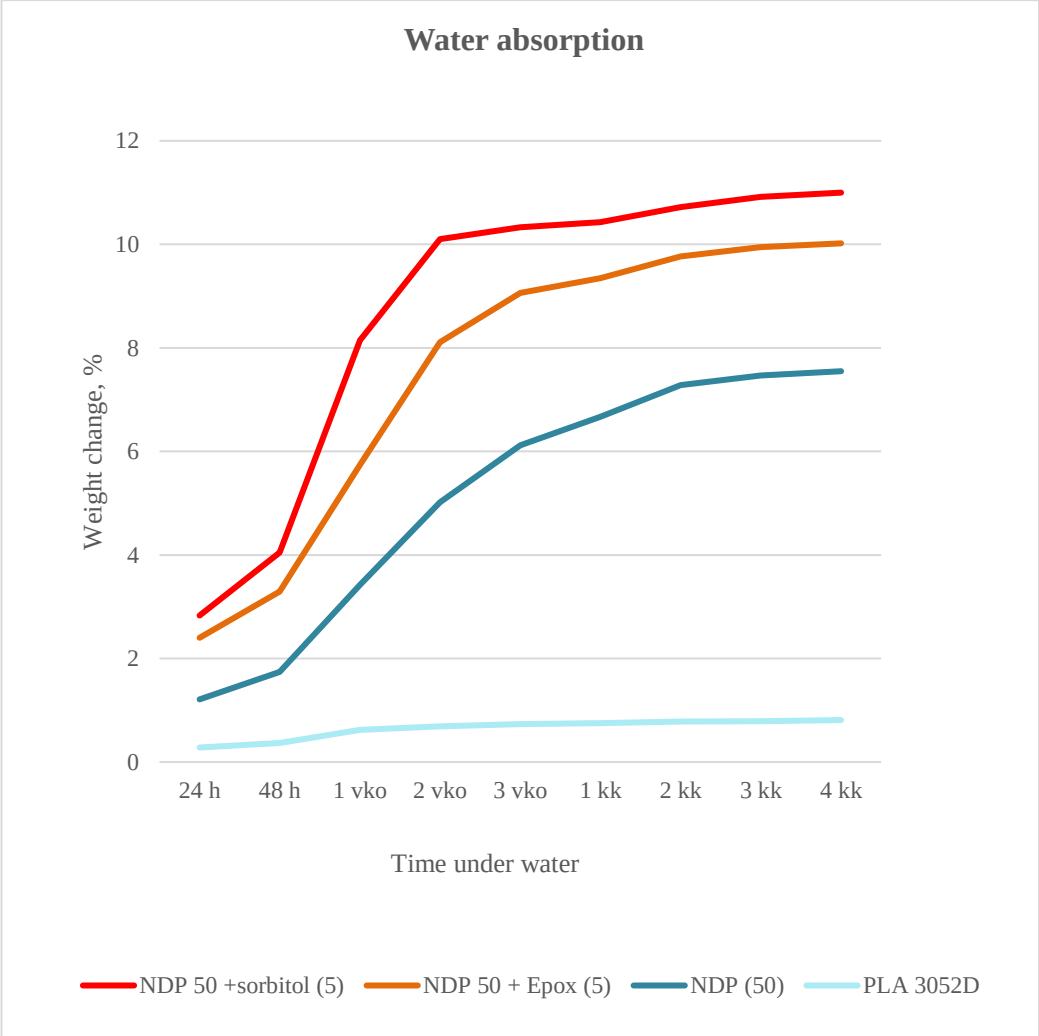
Time			**1 week**	**2 weeks**	**3 weeks**	**4 weeks**	**2 months**	**3 months**	**4 months**
Sample	**24 h**	**48 h**	**192 h**	**385 h**	**576 h**	**768 h**	**1536 h**	**2304 h**	**3072 h**
NDP (40)	0.94	1.36	2.65	3.82	4.63	5.10	5.79	6.01	6.09
NDP (50)	1.21	1.74	3.42	5.02	6.12	6.67	7.28	7.47	7.55
NDP (40) +epox 5	1.22	1.73	3.35	4.89	5.82	6.19	6.69	6.88	6.95
NDP (50) +epox 5	2.40	3.29	5.74	8.11	9.06	9.35	9.77	9.95	10.02
NDP (40) +sorbitol 5	1.76	2.59	5.33	7.47	7.83	7.98	8.28	8.42	8.49
NDP (50) +sorbitol 5	2.83	4.05	8.15	10.10	10.33	10.43	10.72	10.92	11.00
NDP (40) +epox 8	1.44	2.10	3.99	5.78	6.64	6.91	7.38	7.52	7.60
NDP (50) +epox 12	1.37	1.97	3.87	5.68	6.51	6.83	7.27	7.41	7.45
PLA 3052D	0.28	0.37	0.62	0.69	0.73	0.75	0.78	0.79	0.81

In the table 6 below and in Appendix 11 (site 107) is presented water absorption results for wooden reference samples for two months period.

TABLE 6. Results of water absorption test for wood comparison samples presented as average weight change as a mass percentage (m-%).

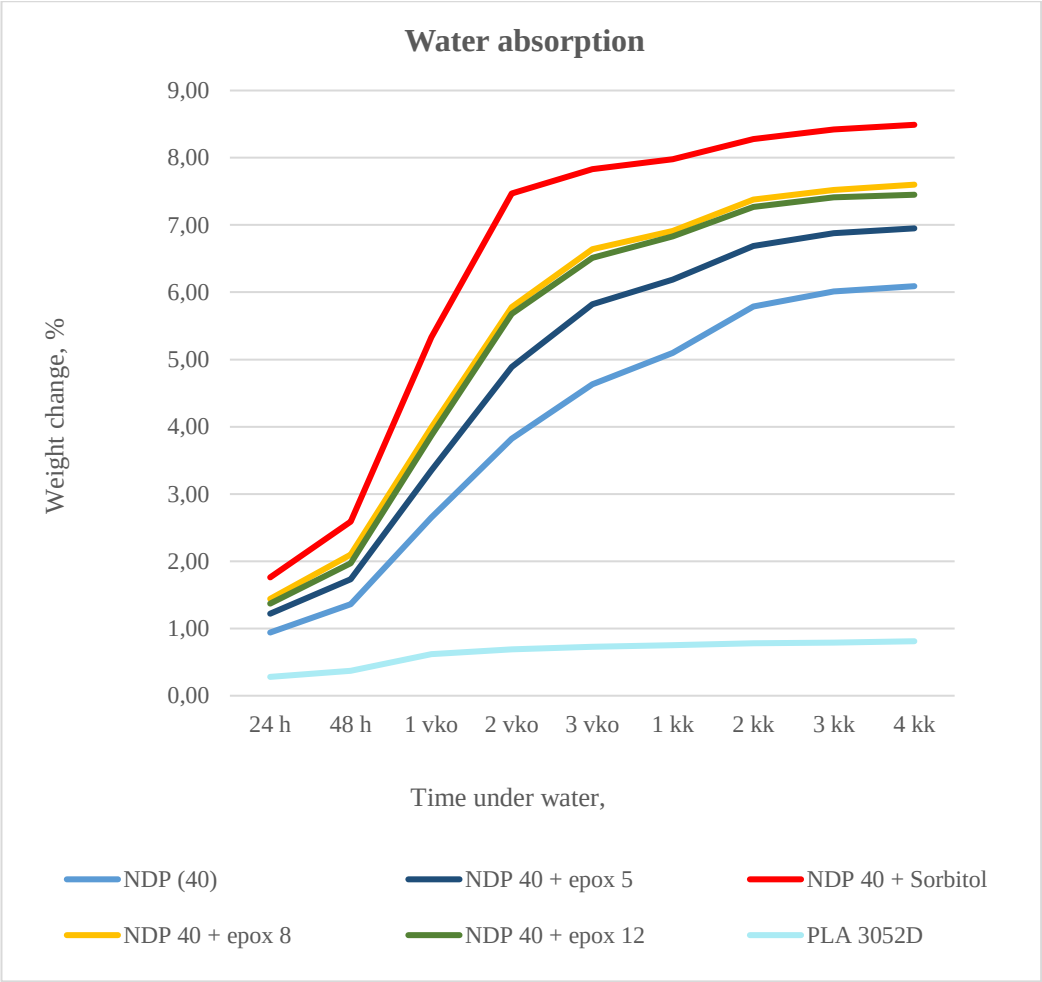
Time	**Pressure saturated pine m%**	**Spruce list m%**	**log of birch m%**
24 h	72.41	45.97	60.75
48 h	85.38	56.67	67.29
1 week	119.98	73.73	84.91
2 weeks	147.25	87.55	91.28
3 weeks	169.89	100.6	95.30
1 month	183.19	107.2	99.10
2 months	191.90	111.6	107.8

In the pictures 36, 37 and 38 below is presented the results of water absorption tests for reference and test series samples.



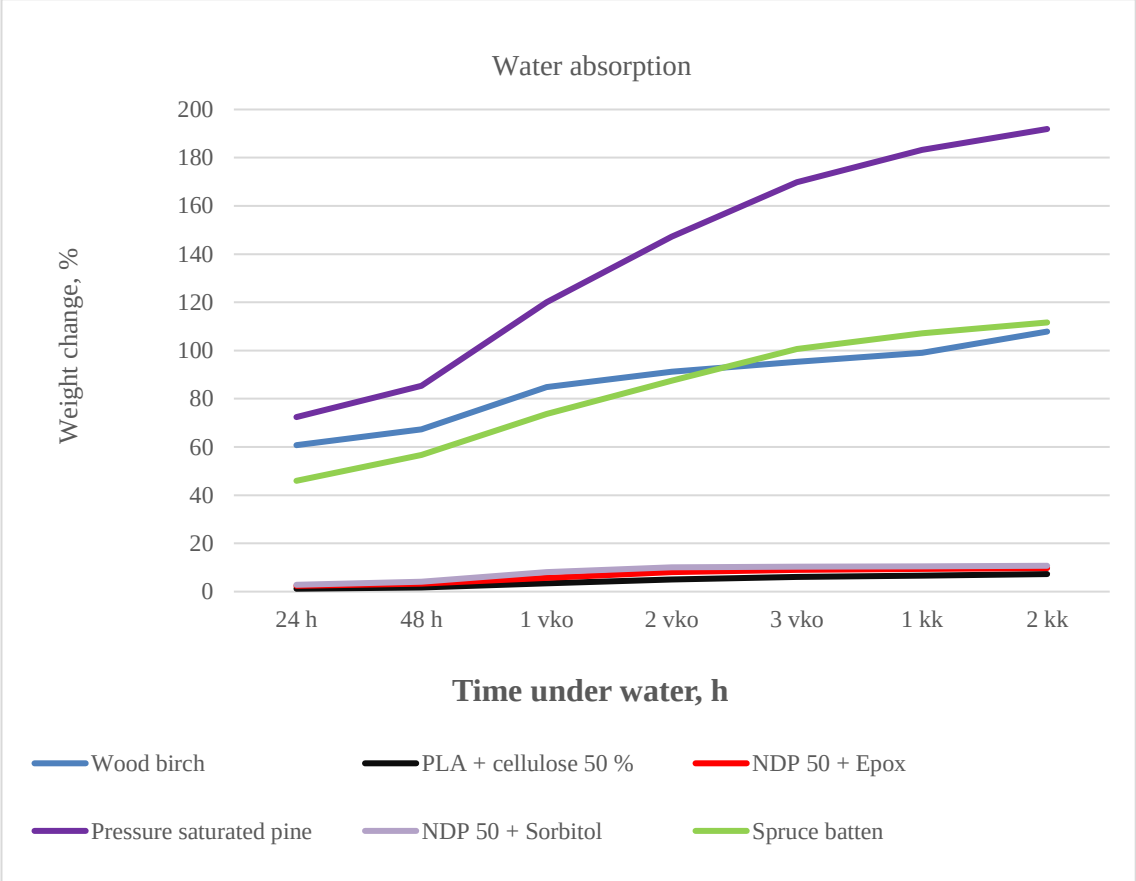
PICTURE 36. Water absorption results for PLA-NDP 50 % cellulose series and neat PLA 3052D samples.

Picture 36 contains results for neat PLA 3052 sample, PLA-NDP 50 without additives, PLA-NDP 50 + sorbitol 5% and PLA-NDP 50 + epox 5%. From picture 36 we can see that PLA-NDP 50 + sorbitol additive sample absorbs most water itself during four months. Lowest water absorbtion was in neat PLA 3052D sample and in between them there are PLA-NDP 50 and PLA-NDP 50 + Epox.



PICTURE 37. Water absorption results for PLA-NDP 40 % cellulose series and neat PLA 3052D samples.

In the picture 27 is presented neat PLA 3052 sample, PLA-NDP 40 without additives, PLA-NDP 40 + sorbitol 5 % and PLA-NDP 40 + epox 5 %, 8 % and 12 %. From picture 37 we can see that PLA-NDP 40 + sorbitol additive sample absorbs the most water itself during four months period. Lowest water absorption was in neat PLA 3052D sample and between them is PLA-NDP 40 that absorbed the second least water in itself, then PLA-NDP 40 + epox 5 %, 8 % and 12 % additive samples.



PICTURE 38. Water absorption results for PLA-NDP 50 % cellulose series and wood samples.

In the picture 38 is presented neat PLA 3052 sample, PLA-NDP 50 without additives, PLA-NDP 50 + sorbitol 5 % and PLA-NDP 50 + epox 5 % and wooden reference samples. From picture 38 we can see that PLA-NDP 50 series absorbs much less water compared to wooden reference samples during two months period. PLA composite samples and wooden reference samples has a big weight changes difference.

5 CONCLUSIONS

In this thesis experimental part is presenting sample processing before tests and materials those were used in the work. It also introduces devices and working methods used in this work. The methods used in material analysis were impact tests and tensile tests. Material temperature behaviour was studied using heat deflection temperature (HDT) test and differential scanning calorimetry (DSC). The purpose of DSC analysis was to determine glass transition temperature (Tg) of original samples and samples after aging and to find their differences. Determination of water absorption was also one of the tests methods.

Based on these experiments can be said that PLA based biocomposites with additive epoxy modified linseed oil, as reactive plasticizer, is more durable and longer lasting material. PLA based biocomposites with sorbitol derivative additive. In most tests the samples exposed for two weeks in 80% RH and 50°C the properties were weakened considerably and in samples exposed for six weeks the reduction in properties was even worse, but in samples with epoxy additive, the change was smaller than in other samples after exposure. Looking at the DSC curves, the effect of exposure is easy to be seen because the surface areas and peaks are change a bigger and in the second heating run, there can be seen significant cold crystallization. Determination of water absorption values after keeping samples for four months soaked in water proved that products those are made of this material are not recommended to be kept under water for long times. HDT value, referring thermal durability, was decreased due to epoxy modified linseed oil addition, which can be related to cellulose acting as plasticizer for PLA.

The size and length of cellulose fiber is a major factor in the attachment of additives and PLA. The improved connection of fibres and polymers can be found by the tests, PLA without the additive and the PLA with epoxy additive. Finally, the coupling of fibre and polymer can be seen tensile strength in results by simultaneous increase in tensile and impact strength properties when epoxy modified linseed oil is added as additive to the compound. The high amount of 12% epoxy linseed oil caused drop in strength properties, which is assumed to be linked in epoxy acting as plasticizer to PLA. The higher the epoxy amount is the greater the effect on the coupling ability is. Epoxidized linseed oil gives the compound better stretch properties, improve rigidity and tensile strength.

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APPENDICES

Appendix 1. Charpy impact tests, aging NDP series.

TABLE 7. Measurement protocol of original PLA 3052D and NDP series charpy impact tests.

Charpy impact test / unnotched sample									
					Temperature:		23 °C		%HR: 49
Measured by:	Sini Rauta				Date: 08.03.2016				
Break:	C = complete break, specimen separates to pieces								
	H = hinge, incomplete break, thin surface hinge which has no residual stiffnes								
	P = partial break, an incomplete break which is not hinge break								
	NB = no break, specimen only bent throught support block, possibly stress whitening								
Code number	Filler content [%]	Test piece no:	Thicknes of. test p. [mm]	Width of test piece [mm]	Hammer [J]	Impact energy [J]	Impact Strenght [kJ/m2]	Average	Obs. And break type /Standard deviation
NDP 20		1	4,16	10,08	2	0,570	13,59		C
		2	4,17	10,07	2	0,556	13,24		C
Original		3	4,17	10,12	2	0,535	12,68		C
		4	4,18	10,12	2	0,561	13,26		C
		5	4,18	10,10	2	0,560	13,26		C
		6	4,18	10,10	2	0,495	11,72		C
		7	4,16	10,10	2	0,573	13,64		C
		8	4,17	10,13	2	0,484	11,46		C
		9	4,15	10,12	2	0,587	13,98		C
		10	4,18	10,10	2	0,580	13,74	13,06	0,85
NDP 21		1	4,15	10,07	2	0,567	13,57		C
		2	4,18	10,08	2	0,530	12,58		C
Original		3	4,13	10,12	2	0,428	10,24		C
		4	4,14	10,08	2	0,385	9,23		C
		5	4,18	10,06	2	0,416	9,89		C
		6	4,15	10,05	2	0,504	12,08		C
		7	4,15	10,07	2	0,443	10,60		C
		8	4,17	10,07	2	0,448	10,67		C
		9	4,18	10,11	2	0,446	10,55		C
		10	4,16	10,14	2	0,549	13,01	11,05	1,46
NDP 22		1	4,17	10,05	2	0,553	13,20		C
		2	4,17	10,07	2	0,584	13,91		C
Original		3	4,17	10,07	2	0,647	15,41		C
		4	4,16	10,06	2	0,539	12,88		C
		5	4,17	10,07	2	0,772	18,38		C
		6	4,18	10,08	2	0,683	16,21		C
		7	4,17	10,05	2	0,757	18,06		C
		8	4,17	10,05	2	0,785	18,73		C
		9	4,18	10,05	2	0,865	20,59		C
		10	4,17	10,05	2	0,725	17,30	16,47	2,59
NDP 23		1	4,14	9,99	2	0,487	11,78		C
		2	4,15	10,02	2	0,546	13,13		C
Original		3	4,14	10	2	0,703	16,98		C
		4	4,14	10	2	0,580	14,01		C
		5	4,15	10	2	0,640	15,42		C
		6	4,15	10	2	0,414	9,98		C
		7	4,15	10	2	0,441	10,63		C
		8	4,14	10	2	0,580	14,01		C
		9	4,15	10	2	0,542	13,06		C
		10	4,15	10	2	0,542	13,06	13,21	2,10
NDP 24		1	4,15	10,03	2	0,498	11,96		C
		2	4,16	10,03	2	0,385	9,23		C
Original		3	4,14	10,03	2	0,647	15,58		C
		4	4,14	10,04	2	0,500	12,03		C
		5	4,14	10,03	2	0,549	13,22		C
		6	4,14	10,03	2	0,565	13,61		C
		7	4,15	10,03	2	0,470	11,29		C
		8	4,15	10,02	2	0,595	14,31		C
		9	4,15	10,03	2	0,582	13,98		C
		10	4,15	10,02	2	0,570	13,71	12,89	1,80
NDP 25		1	4,14	10,02	2	0,393	9,47		C
		2	4,15	10,02	2	0,408	9,81		C
Original		3	4,16	10,03	2	0,382	9,16		C
		4	4,15	10,00	2	0,349	8,41		C
		5	4,14	10,02	2	0,419	10,10		C
		6	4,15	10,04	2	0,273	6,55		C
		7	4,15	10,01	2	0,430	10,35		C
		8	4,15	10	2	0,430	10,36		C
		9	4,15	10,01	2	0,392	9,44		C
		10	4,14	10	2	0,507	12,25	9,59	1,47
NDP 28		1	4,15	10,02	2	0,800	19,24		C
		2	4,16	10,02	2	0,635	15,23		C
Original		3	4,16	10,02	2	0,665	15,95		C
		4	4,15	10,02	2	0,783	18,83		C
		5	4,16	10,02	2	0,817	19,60		C
		6	4,16	10,02	2	0,748	17,94		C
		7	4,15	10,01	2	0,794	19,11		C
		8	4,16	10,02	2	0,750	17,99		C
		9	4,16	10,02	2	0,750	17,99		C
		10	4,16	10,02	2	0,560	13,43	17,99	1,49
NDP 29		1	4,17	10,04	2	0,745	17,79		C
		2	4,17	10,07	2	0,694	16,53		C
Original		3	4,14	10,04	2	0,563	13,54		C
		4	4,17	10,05	2	0,720	17,18		C
		5	4,17	10,06	2	0,875	20,86		C
		6	4,16	10,06	2	0,805	19,24		C
		7	4,16	10,08	2	0,546	13,02		C
		8	4,17	10,06	2	0,904	21,55		C
		9	4,17	10,08	2	0,735	17,49		C
		10	4,16	10,05	2	0,898	21,48	17,87	3,02
PLA 3052D		1	4,11	10,09	2	0,637	15,36		
		2	4,11	10,09	2	0,753	18,16		
Original		3	4,10	10,06	2	0,670	16,24		
		4	4,10	10,05	2	0,729	17,69		
		5	4,10	10,05	2	0,610	14,80		
		6	4,11	10,06	2	0,614	14,85		
		7	4,09	10,07	2	0,642	15,59		
		8	4,09	10,03	2	0,673	16,41		
		9	4,10	10,06	2	0,699	16,95		
		10	4,10	10,07	2	0,752	18,21	16,43	1,29

Appendix 2. Charpy impact tests, two weeks aging NDP series.

TABLE 8. Measurement protocol of two weeks aging PLA 3052D and NDP series charpy impact tests.

Charpy impact test / unnotched sample									
					Temperature:		24,3 °C		%HR: 52
Measured by:		Sini Rauta			Date:	2.8.2016			2016
Break:	C = complete break, specimen separates to pieces								
	H = hinge, incomplete break, thin surface hinge which has no residual stiffnes								
	P = partial break, an incomplete break which is not hinge break								
	NB = no break, specimen only bent throught support block, possibly stress whitening								
				leveys					
Code number	Filler content [%]	Test piece no:	Thicknes of. test p. [mm]	Width of test piece [mm]	Hammer [J]	Impact energy [J]	Impact Strenght [kJ/m2]	Average	Obs. And break type /Standard deviation
PLA 3052D		1	10,10	4,26	2	1,089	25,31		C
		2	10,15	4,22	2	0,973	22,72		C
2 weeks		3	10,12	4,21	2	1,071	25,14		C
		4	10,12	4,23	2	0,843	19,69		C
		5	10,19	4,24	2	0,871	20,16		C
								22,60	2,66
NDP 20		1	10,16	4,21	2	0,453	10,59		C
		2	10,21	4,21	2	0,528	12,28		C
2 weeks		3	10,23	4,23	2	0,546	12,62		C
		4	10,18	4,23	2	0,510	11,84		C
		5	10,22	4,22	2	0,437	10,13		C
								11,49	1,08
NDP 21		1	10,26	4,21	2	0,389	9,01		C
		2	10,25	4,23	2	0,402	9,27		C
2 weeks		3	10,26	4,22	2	0,392	9,05		C
		4	10,20	4,20	2	0,373	8,71		C
		5	10,23	4,22	2	0,343	7,95		C
								8,80	0,52
NDP 22		1	10,16	4,20	2	0,684	16,03		C
		2	10,13	4,20	2	0,437	10,27		C
2 weeks		3	10,14	4,19	2	0,737	17,35		C
		4	10,16	4,18	2	0,716	16,86		C
		5	10,18	4,19	2	0,680	15,94		C
								15,29	2,87
NDP 23		1	10,10	4,18	2	0,435	10,30		C
		2	10,15	2,20	2	0,454	20,33		C
2 weeks		3	10,11	2,20	2	0,467	21,00		C
		4	10,12	2,18	2	0,448	20,31		C
		5	10,10	2,19	2	0,466	21,07		C
								18,60	4,65
NDP 24		1	10,19	4,19	2	0,510	11,94		C
		2	10,15	4,20	2	0,393	9,22		C
2 weeks		3	10,21	4,20	2	0,352	8,21		C
		4	10,16	4,20	2	0,368	8,62		C
		5	10,19	4,18	2	0,503	11,81		C
								9,96	1,79
NDP 25		1	10,13	4,19	2	0,187	4,41		C
		2	10,18	4,20	2	0,333	7,79		C
2 weeks		3	10,16	4,20	2	0,290	6,80		C
		4	10,16	4,20	2	0,368	8,62		C
		5	10,15	4,20	2	0,234	5,49		C
								6,62	1,70
NDP 28		1	10,15	4,18	2	0,865	20,39		C
		2	10,12	4,18	2	0,602	14,23		C
2 weeks		3	10,15	4,18	2	0,647	15,25		C
		4	10,14	4,18	2	0,867	20,46		C
		5	10,16	4,18	2	0,721	16,98		C
								17,46	2,88
NDP 29		1	10,17	4,18	2	0,901	21,19		C
		2	10,14	4,18	2	0,746	17,60		C
2 weeks		3	10,14	4,18	2	0,906	21,38		C
		4	10,13	4,18	2	0,993	23,45		C
		5	10,11	4,17	2	0,773	18,34		C
								20,39	2,40

Appendix 3. Charpy impact tests, six weeks aging NDP series.

TABLE 9. Measurement protocol of six weeks aging PLA 3052D and NDP series charpy impact tests.

Charpy impact test / unnotched sample									
					Temperature:		24,7 °C		%HR: 48
Measured by:		Sini Rauta			Date:	2.9.2016			
Break:	C = complete break, specimen separates to pieces								
	H = hinge, incomplete break, thin surface hinge which has no residual stiffnes								
	P = partial break, an incomplete break which is not hinge break								
	NB = no break, specimen only bent throught support block, possibly stress whitening								
CodeAC17:AL67 number	Filler content [%]	Test piece no:	Thicknes of. test p. [mm]	Width of test piece [mm]	Hammer [J]	Impact energy [J]	Impact Strenght [kJ/m2]	Average	Obs. And break type /Standard deviation
PLA 3052D		1	4,27	10,14	2	0,519	11,99		C
		2	4,27	10,13	2	0,571	13,20		C
6 weeks		3	4,26	10,14	2	0,459	10,63		C
		4	4,23	10,14	2	0,489	11,40		C
		5	4,24	10,13	2	0,472	10,99		C
								11,64	1,01
NDP 20		1	4,22	10,22	2	0,329	7,63		C
		2	4,22	10,21	2	0,269	6,24		C
6 weeks		3	4,21	10,23	2	0,360	8,36		C
		4	4,22	10,20	2	0,246	5,72		C
		5	4,22	10,22	2	0,307	7,12		C
								7,01	1,06
NDP 21		1	4,23	10,20	2	0,227	5,26		C
		2	4,22	10,24	2	0,179	4,14		C
6 weeks		3	4,22	10,22	2	0,187	4,34		C
		4	4,22	10,26	2	0,236	5,45		C
		5	4,21	10,21	2	0,141	3,28		C
								4,49	0,88
NDP 22		1	4,19	10,13	2	0,693	16,33		C
		2	4,20	10,16	2	0,487	11,41		C
6 weeks		3	4,20	10,19	2	0,701	16,38		C
		4	4,20	10,14	2	0,557	13,08		C
		5	4,19	10,17	2	0,693	16,26		C
								14,69	2,31
NDP 23		1	4,20	10,12	2	0,453	10,66		C
		2	4,20	10,12	2	0,448	10,54		C
6 weeks		3	4,19	10,15	2	0,574	13,50		C
		4	4,17	10,16	2	0,397	9,37		C
		5	4,20	10,12	2	0,420	9,88		C
								10,79	1,60
NDP 24		1	4,19	10,22	2	0,234	5,46		C
		2	4,19	10,18	2	0,204	4,78		C
6 weeks		3	4,20	10,16	2	0,268	6,28		C
		4	4,20	10,20	2	0,226	5,28		C
		5	4,19	10,19	2	0,168	3,93		C
								5,15	0,87
NDP 25		1	4,21	10,19	2	0,134	3,12		C
		2	4,21	10,19	2	0,129	3,01		C
6 weeks		3	4,21	10,17	2	0,086	2,01		C
		4	4,20	10,19	2	0,121	2,83		C
		5	4,20	10,20	2	0,140	3,27		C
								2,85	0,50
NDP 28		1	4,18	10,14	2	0,749	17,67		C
		2	4,20	10,14	2	0,665	15,61		C
6 weeks		3	4,18	10,13	2	0,687	16,22		C
		4	4,20	10,15	2	0,633	14,85		C
		5	4,18	10,11	2	0,813	19,24		C
								16,72	1,75
NDP 29		1	4,20	10,15	2	0,628	14,73		C
		2	4,19	10,16	2	0,942	22,13		C
6 weeks		3	4,20	10,15	2	0,549	12,88		C
		4	4,19	10,17	2	0,745	17,48		C
		5	4,19	10,21	2	0,901	21,06		C
								17,66	3,97

Appendix 4. The tensile test, original PLA and NDP samples (1-9).

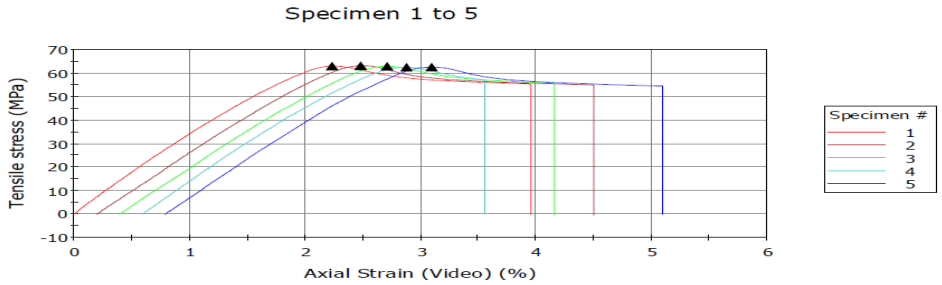
1.7.2015 13:55:53

PLA 3052D

Defaults Table

General: Last test date	1. heinäkuuta 2015
Text Inputs: Material	
Text Inputs: Specimen label	PLA 3052D
Text Inputs: Temperature / hymidity	24 °C / 47 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,13 mm
Dimension: Width	10,09 mm
Text Inputs: Note	Prepared 16.6.2015

Sample file name: PLA 3052D_1.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)	Strain at Yield (Zero Slope) (%)
1	62,8	2,23	2619	54,9	3,9	62,8	2,23
2	63,0	2,28	2612	54,7	4,3	63,0	2,28
3	62,8	2,31	2606	55,5	3,8	62,8	2,31
4	62,4	2,28	2604	56,8	3,0	62,4	2,28
5	62,5	2,30	2600	54,4	4,3	62,5	2,30
Mean	62,7	2,28	2608	55,3	3,9	62,7	2,28
Maximum	63,0	2,31	2619	56,8	4,3	63,0	2,31
Minimum	62,4	2,23	2600	54,4	3,0	62,4	2,23
Standard Deviation	0,3	0,0	7,2	0,9	0,6	0,3	0,0

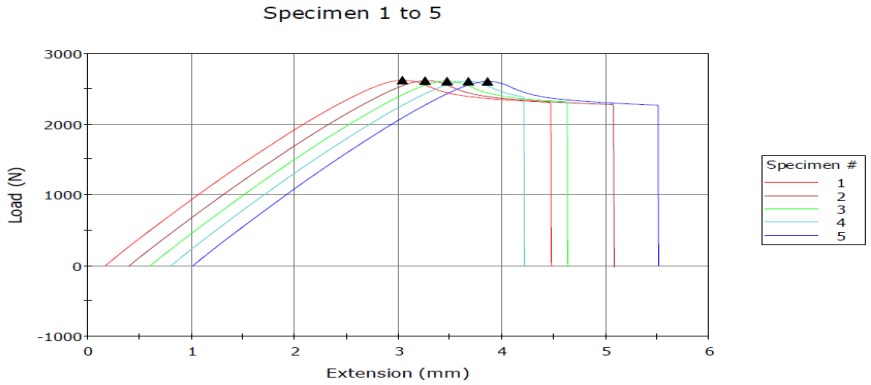
	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	54,0	1,72	3544	3576	3583
2	59,5	2,00	3331	3214	3315
3	60,0	2,04	3249	3348	3291
4	55,3	1,81	3443	3440	3444
5	58,4	1,96	3312	3291	3289
Mean	57,4	1,91	3376	3374	3384
Maximum	60,0	2,04	3544	3576	3583
Minimum	54,0	1,72	3249	3214	3289

1.7.2015 13:55:53

	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
Standard Deviation	2,6	0,1	117,2	139,7	128,1

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	62,8	2,2
2	63,0	2,3
3	62,8	2,3
4	62,4	2,3
5	62,5	2,3
Mean	62,7	2,3
Maximum	63,0	2,3
Minimum	62,4	2,2
Standard Deviation	0,3	0,0

Graph 2



PICTURE 39. Tensile test results for original PLA 3052D (1).

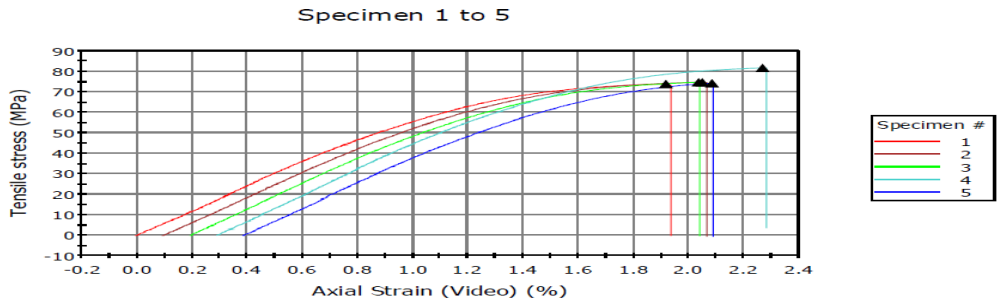
4.3.2016 10:37:42

ACEL-NDP20-19.2

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP20-19.2
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 19.2.2016

Sample file name: ACEL-NDP20-19.2.is_tens



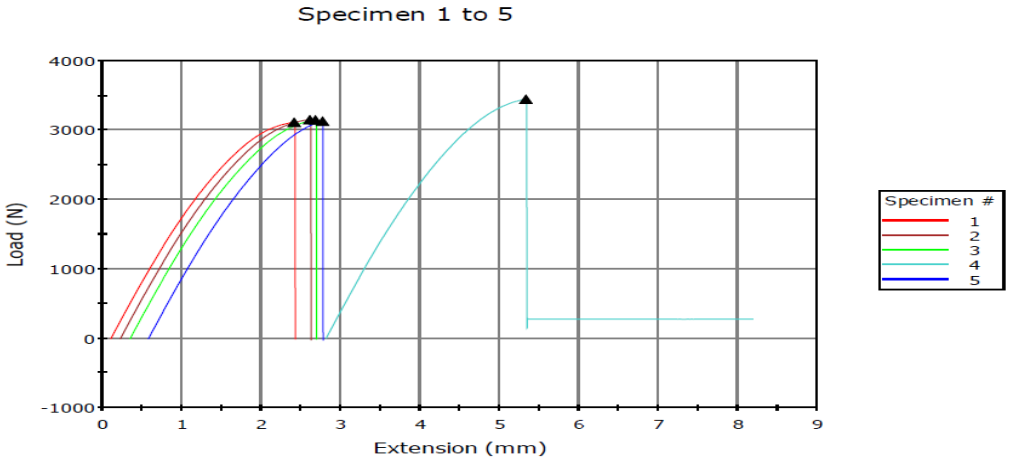
	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	73,8	1,92	3114	73,2	1,9	73,8
2	74,6	1,95	3151	74,4	2,0	74,6
3	74,6	1,84	3149	74,5	1,8	74,6
4	81,6	1,98	3445	6,7	4,5	81,6
5	74,2	1,70	3131	74,2	1,7	74,2
Mean	75,8	1,88	3198	60,6	2,4	75,8
Maximum	81,6	1,98	3445	74,5	4,5	81,6
Minimum	73,8	1,70	3114	6,7	1,7	73,8
Standard Deviation	3,3	0,1	138,7	30,1	1,2	3,3

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,92	66,3	1,32	5934	5812	6366
2	1,95	66,3	1,28	6131	6072	6207
3	1,84	66,1	1,25	6294	6269	6326
4	1,98	71,7	1,32	6406	6294	6482
5	1,70	67,0	1,28	6187	6084	6525
Mean	1,88	67,5	1,29	6191	6106	6381
Maximum	1,98	71,7	1,32	6406	6294	6525
Minimum	1,70	66,1	1,25	5934	5812	6207
Standard Deviation	0,1	2,4	0,0	177,8	193,7	126,9

4.3.2016 10:37:42

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	73,8	1,9
2	74,6	2,0
3	74,6	1,8
4	81,6	2,0
5	74,2	1,7
Mean	75,8	1,9
Maximum	81,6	2,0
Minimum	73,8	1,7
Standard Deviation	3,3	0,1

Graph 2



PICTURE 40. Tensile test results for original PLA -NDP composite with fibre content 40 % (2).

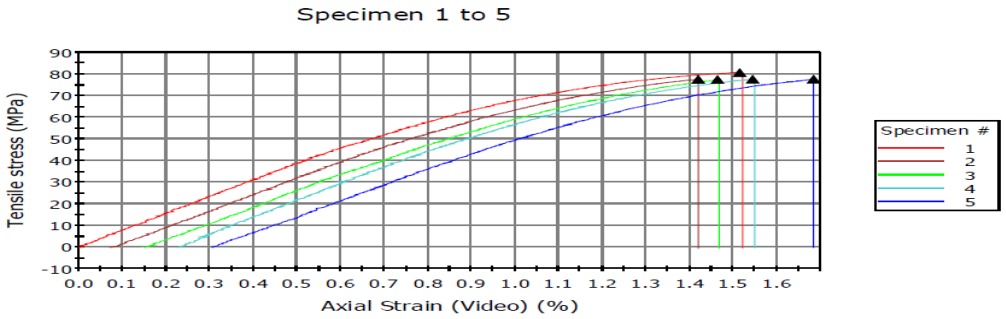
4.3.2016 10:19:07

ACEL-NDP21-50

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP21-50
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 19.2.2016

Sample file name: ACEL-NDP21-50.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	80,6	1,51	3403	79,9	1,5	80,6
2	77,5	1,34	3249	77,5	1,3	77,5
3	77,4	1,31	3266	77,4	1,3	77,4
4	77,6	1,32	3269	77,6	1,3	77,6
5	77,5	1,38	3267	77,5	1,4	77,5
Mean	78,1	1,37	3291	78,0	1,4	78,1
Maximum	80,6	1,51	3403	79,9	1,5	80,6
Minimum	77,4	1,31	3249	77,4	1,3	77,4
Standard Deviation	1,4	0,1	63,2	1,1	0,1	1,4

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,51	72,5	1,13	7782	7746	7754
2	1,34	72,9	1,16	7595	7518	7627
3	1,31	72,7	1,16	7657	7421	7795
4	1,32	71,0	1,08	8069	7883	8361
5	1,38	72,6	1,19	7376	7202	7397
Mean	1,37	72,3	1,14	7696	7554	7787
Maximum	1,51	72,9	1,19	8069	7883	8361
Minimum	1,31	71,0	1,08	7376	7202	7397
Standard Deviation	0,1	0,8	0,0	255,3	268,3	356,5

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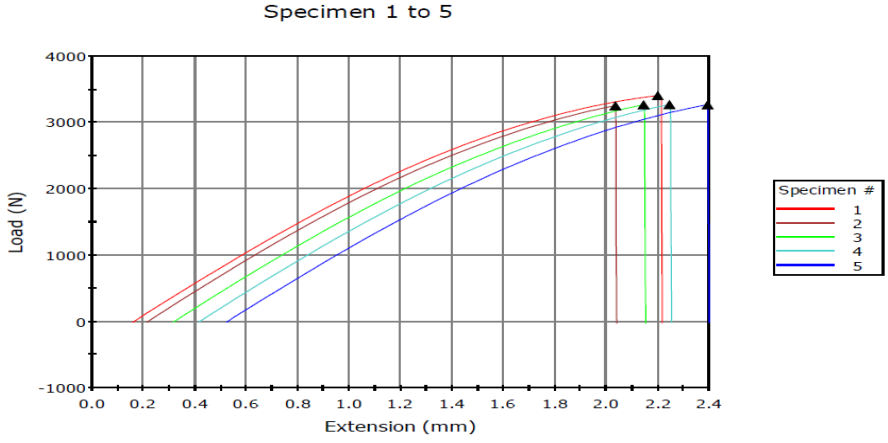
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	80,6	1,5
2	77,5	1,3
3	77,4	1,3
4	77,6	1,3
5	77,5	1,4
Mean	78,1	1,4
Maximum	80,6	1,5
Minimum	77,4	1,3
Standard Deviation	1,4	0,1

Graph 2



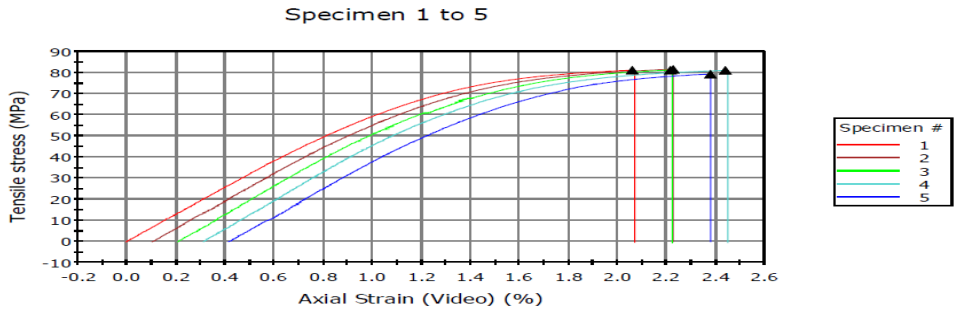
PICTURE 41. Tensile test results for original PLA -NDP composite with fibre content 50 % (3).

ACEL-NDP22-40

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP22-40
Text Inputs: Temperature / hymidity	23 °C / 50 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 18.2.2016

Sample file name: ACEL-NDP22-40.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	81,0	2,06	3330	80,8	2,1	81,0
2	81,4	2,12	3357	81,4	2,1	81,4
3	81,1	2,01	3326	80,7	2,0	81,1
4	81,0	2,13	3321	80,7	2,1	81,0
5	79,1	1,96	3260	79,1	2,0	79,1
Mean	80,7	2,05	3319	80,5	2,1	80,7
Maximum	81,4	2,13	3357	81,4	2,1	81,4
Minimum	79,1	1,96	3260	79,1	2,0	79,1
Standard Deviation	0,9	0,1	35,8	0,8	0,1	0,9

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,06	70,2	1,29	6406	6372	6419
2	2,12	70,1	1,28	6521	6507	6680
3	2,01	68,3	1,21	6772	6819	6757
4	2,13	69,5	1,24	6709	6669	6894
5	1,96	68,8	1,27	6454	6150	6764
Mean	2,05	69,4	1,26	6572	6504	6703
Maximum	2,13	70,2	1,29	6772	6819	6894
Minimum	1,96	68,3	1,21	6406	6150	6419
Standard Deviation	0,1	0,8	0,0	160,2	259,4	176,2

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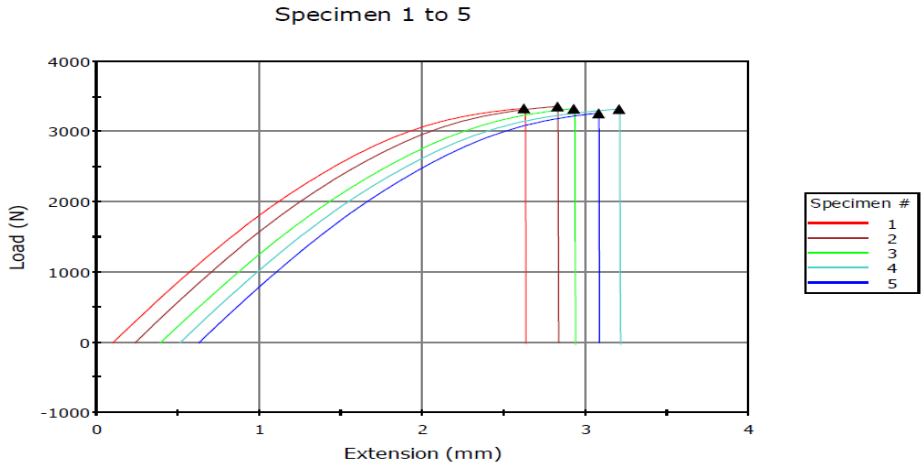
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	81,0	2,1
2	81,4	2,1
3	81,1	2,0
4	81,0	2,1
5	79,1	2,0
Mean	80,7	2,1
Maximum	81,4	2,1
Minimum	79,1	2,0
Standard Deviation	0,9	0,1

Graph 2



PICTURE 42. Tensile test results for original PLA -NDP composite with fibre content 40% and additive ELO 5 % (4).

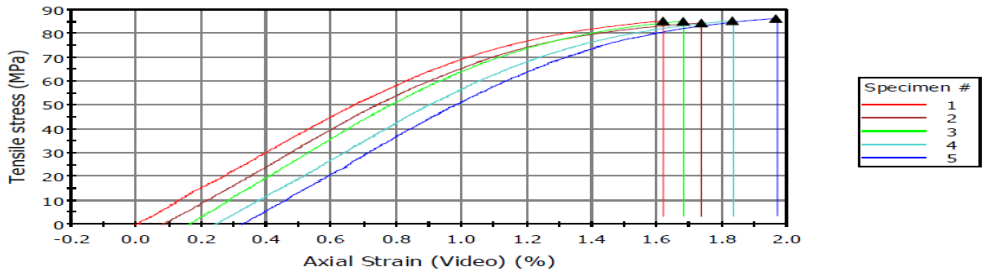
ACEL-NDP23-50

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP23-50
Text Inputs: Temperature / hymidity	24 °C / 47 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 24.2.2016

Sample file name: ACEL-NDP23-50.is_tens

Specimen 1 to 5



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	85,2	1,62	3535	6,6	3,2	85,2
2	84,4	1,65	3503	6,7	4,1	84,4
3	85,1	1,52	3523	6,5	4,7	85,1
4	85,4	1,59	3534	6,6	3,3	85,4
5	86,3	1,64	3563	6,8	3,0	86,3
Mean	85,3	1,60	3531	6,7	3,7	85,3
Maximum	86,3	1,65	3563	6,8	4,7	86,3
Minimum	84,4	1,52	3503	6,5	3,0	84,4
Standard Deviation	0,7	0,1	22,0	0,1	0,7	0,7

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,62	77,1	1,21	7647	7823	7972
2	1,65	76,3	1,18	7842	7675	7769
3	1,52	77,2	1,13	8271	8324	8406
4	1,59	78,2	1,21	7763	7529	7736
5	1,64	78,0	1,20	7838	7760	7801
Mean	1,60	77,4	1,19	7872	7822	7937
Maximum	1,65	78,2	1,21	8271	8324	8406
Minimum	1,52	76,3	1,13	7647	7529	7736
Standard Deviation	0,1	0,8	0,0	236,6	301,6	277,8

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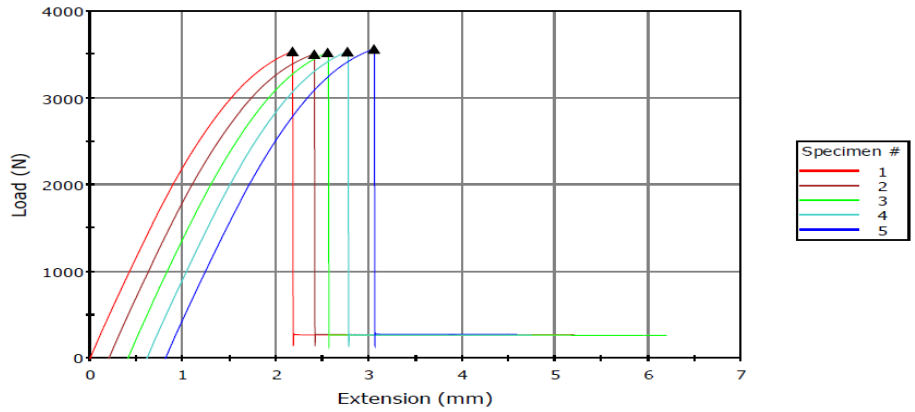
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	85,2	1,6
2	84,4	1,7
3	85,1	1,5
4	85,4	1,6
5	86,3	1,6
Mean	85,3	1,6
Maximum	86,3	1,7
Minimum	84,4	1,5
Standard Deviation	0,7	0,1

Graph 2

Specimen 1 to 5



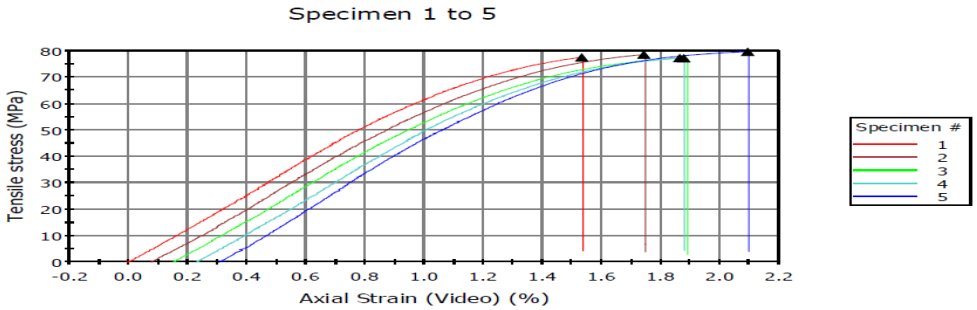
PICTURE 43. Tensile test results for original PLA -NDP composite with fibre content 50% and additive ELO 5 % (5).

ACEL-NDP24-40

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP24-40
Text Inputs: Temperature / hymidity	24 °C / 48 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 24.2.2016

Sample file name: ACEL-NDP24-40.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	77,4	1,53	3227	6,9	5,4	77,4
2	78,5	1,66	3265	6,8	7,9	78,5
3	77,2	1,72	3198	5,8	3,0	77,2
4	77,2	1,63	3200	7,1	2,8	77,2
5	79,6	1,78	3302	6,9	3,1	79,6
Mean	78,0	1,67	3238	6,7	4,4	78,0
Maximum	79,6	1,78	3302	7,1	7,9	79,6
Minimum	77,2	1,53	3198	5,8	2,8	77,2
Standard Deviation	1,1	0,1	44,8	0,5	2,2	1,1

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,53	73,4	1,33	6618	6276	6827
2	1,66	71,5	1,29	6712	6082	6584
3	1,72	69,9	1,26	6700	6353	6578
4	1,63	71,2	1,27	6763	6374	6674
5	1,78	71,8	1,24	6992	6694	7075
Mean	1,67	71,6	1,28	6757	6356	6748
Maximum	1,78	73,4	1,33	6992	6694	7075
Minimum	1,53	69,9	1,24	6618	6082	6578
Standard Deviation	0,1	1,2	0,0	141,5	221,6	209,0

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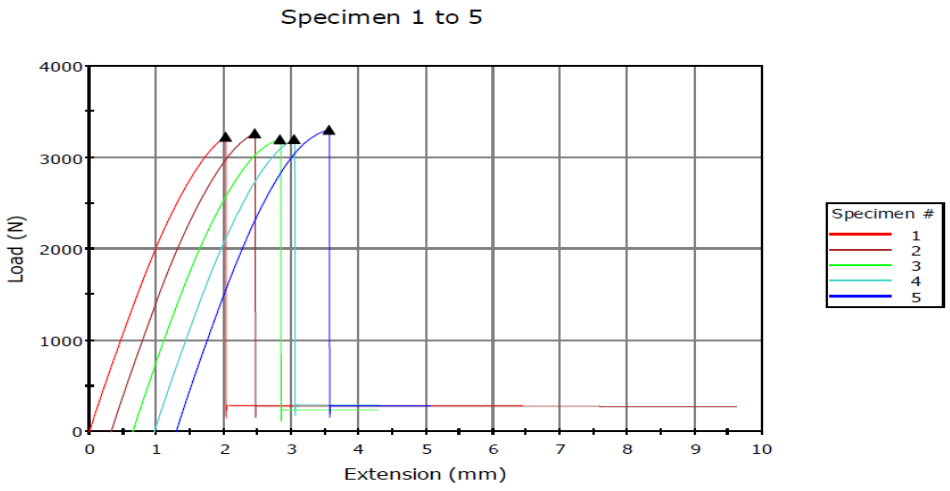
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	77,4	1,5
2	78,5	1,7
3	77,2	1,7
4	77,2	1,6
5	79,6	1,8
Mean	78,0	1,7
Maximum	79,6	1,8
Minimum	77,2	1,5
Standard Deviation	1,1	0,1

Graph 2



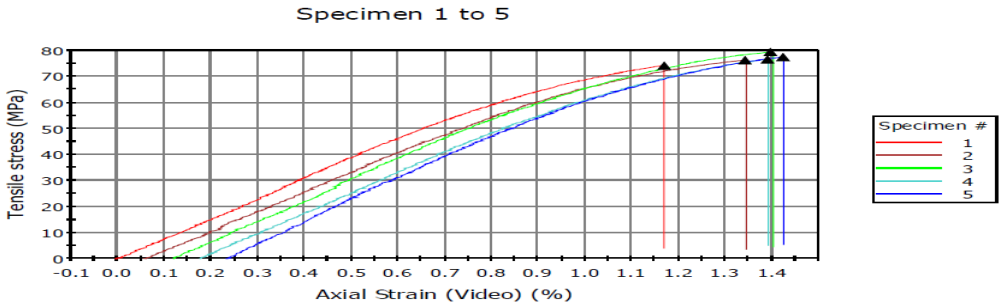
PICTURE 44. Tensile test results for original PLA -NDP composite with fibre content 40% and additive sorbitol derivative 5 % (6).

ACEL-NDP25-50

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP25-50
Text Inputs: Temperature / hymidity	24 °C / 46 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 24.2.2016

Sample file name: ACEL-NDP25-50.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	74,0	1,17	3087	6,8	2,3	74,0
2	76,2	1,28	3145	6,4	3,8	76,2
3	79,3	1,28	3284	7,3	3,3	79,3
4	76,4	1,21	3163	7,9	2,2	76,4
5	77,4	1,19	3204	8,0	2,3	77,4
Mean	76,7	1,23	3176	7,3	2,8	76,7
Maximum	79,3	1,28	3284	8,0	3,8	79,3
Minimum	74,0	1,17	3087	6,4	2,2	74,0
Standard Deviation	1,9	0,1	73,4	0,7	0,7	1,9

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,17	72,6	1,11	8080	7554	8086
2	1,28	73,6	1,17	7644	7753	7529
3	1,28	74,9	1,10	8535	7783	8001
4	1,21	75,0	1,15	7903	7686	7933
5	1,19	74,1	1,07	8550	8713	8790
Mean	1,23	74,0	1,12	8142	7898	8068
Maximum	1,28	75,0	1,17	8550	8713	8790
Minimum	1,17	72,6	1,07	7644	7554	7529
Standard Deviation	0,1	1,0	0,0	396,8	464,1	457,1

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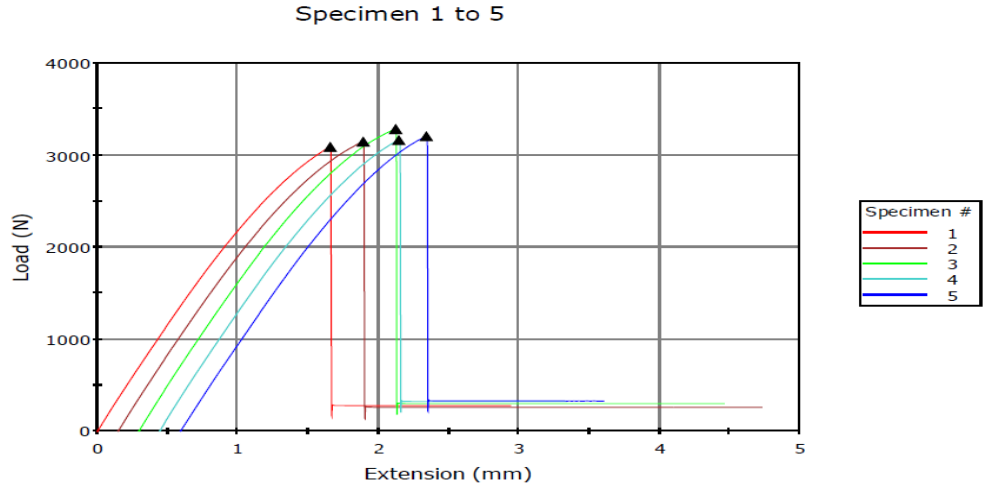
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	74,0	1,2
2	76,2	1,3
3	79,3	1,3
4	76,4	1,2
5	77,4	1,2
Mean	76,7	1,2
Maximum	79,3	1,3
Minimum	74,0	1,2
Standard Deviation	1,9	0,1

Graph 2



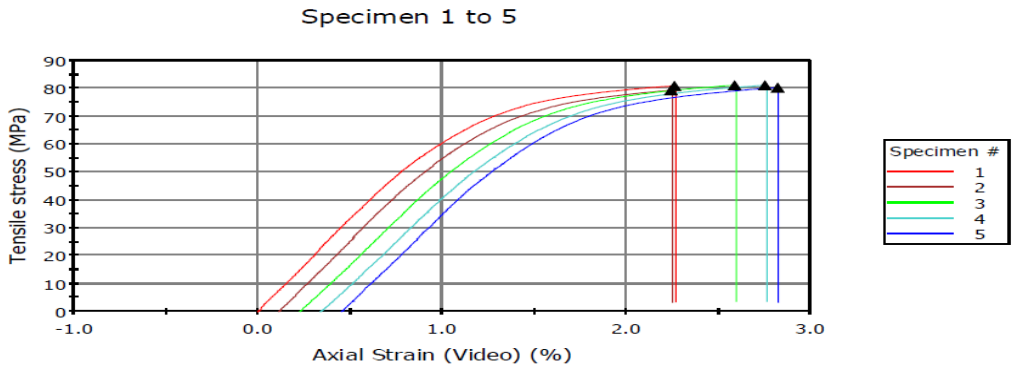
PICTURE 45. Tensile test results for original PLA -NDP composite with fibre content 50% and additive sorbitol derivative 5 % (7).

ACEL-NDP28-40

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP28-40
Text Inputs: Temperature / hymidity	24 °C / 48 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 24.2.2016

Sample file name: ACEL-NDP28-40.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	80,9	2,26	3355	6,4	3,6	80,9
2	79,3	2,13	3298	6,3	3,2	-----
3	81,1	2,36	3356	6,6	4,4	81,1
4	81,0	2,41	3362	6,5	3,8	81,0
5	80,2	2,36	3336	6,2	3,2	80,2
Mean	80,5	2,30	3341	6,4	3,7	80,8
Maximum	81,1	2,41	3362	6,6	4,4	81,1
Minimum	79,3	2,13	3298	6,2	3,2	80,2
Standard Deviation	0,8	0,1	26,3	0,2	0,5	0,4

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,26	68,8	1,24	6634	6399	6977
2	-----	68,5	1,25	6515	6516	6653
3	2,36	70,0	1,33	6223	6089	6382
4	2,41	69,5	1,34	6150	6074	6270
5	2,36	68,9	1,29	6298	6259	6449
Mean	2,35	69,1	1,29	6364	6267	6546
Maximum	2,41	70,0	1,34	6634	6516	6977
Minimum	2,26	68,5	1,24	6150	6074	6270
Standard Deviation	0,1	0,6	0,0	203,4	192,8	278,3

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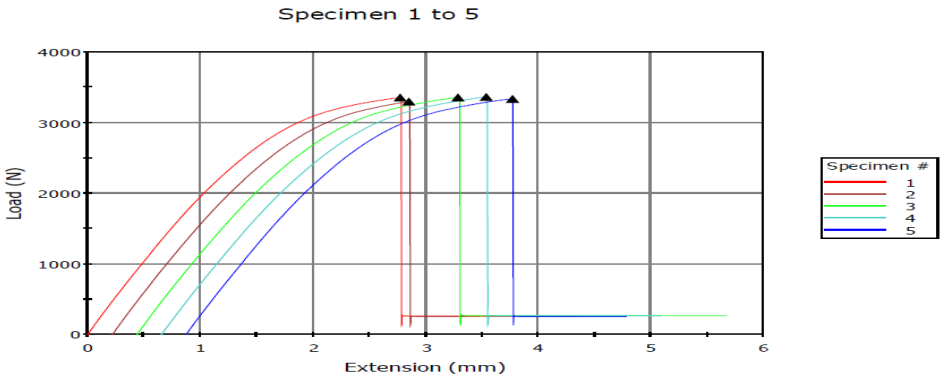
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	80,9	2,3
2	79,3	2,1
3	81,1	2,4
4	81,0	2,4
5	80,2	2,4
Mean	80,5	2,3
Maximum	81,1	2,4
Minimum	79,3	2,1
Standard Deviation	0,8	0,1

Graph 2



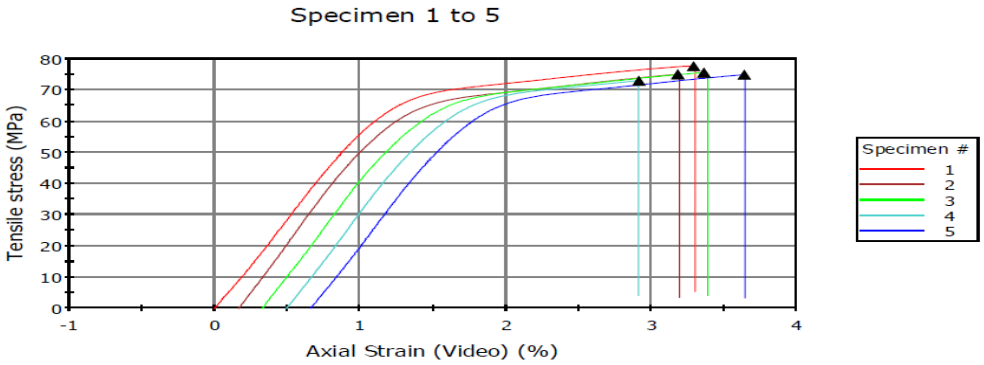
PICTURE 46. Tensile test results for original PLA -NDP composite with fibre content 40% and additive ELO 8 % (8).

ACEL-NDP29-40

Defaults Table

General: Last test date	4. maaliskuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	ACEL-NDP29-40
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\Minano 5mm_min Modifioitu ISO 527.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,12 mm
Dimension: Width	10,07 mm
Text Inputs: Note	Prepared 24.2.2016

Sample file name: ACEL-NDP29-40.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	77,6	3,29	3243	8,1	7,1	77,6
2	75,0	3,01	3141	6,1	6,6	75,0
3	75,5	3,03	3164	6,7	4,8	75,5
4	72,9	2,42	3056	6,7	4,0	72,9
5	74,8	2,98	3137	6,2	5,4	74,8
Mean	75,1	2,95	3148	6,7	5,6	75,1
Maximum	77,6	3,29	3243	8,1	7,1	77,6
Minimum	72,9	2,42	3056	6,1	4,0	72,9
Standard Deviation	1,7	0,3	67,0	0,8	1,3	1,7

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	3,29	67,3	1,38	5764	5360	6041
2	3,01	63,2	1,21	6314	6075	6425
3	3,03	64,4	1,25	6103	5919	6242
4	2,42	65,1	1,28	6051	5937	6188
5	2,98	64,7	1,29	5938	5756	6086
Mean	2,95	64,9	1,28	6034	5810	6196
Maximum	3,29	67,3	1,38	6314	6075	6425
Minimum	2,42	63,2	1,21	5764	5360	6041
Standard Deviation	0,3	1,5	0,1	203,5	275,8	150,4

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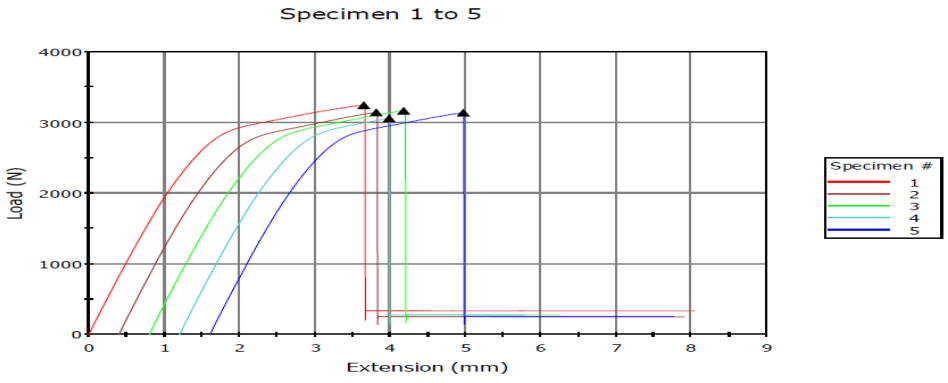
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	77,6	3,3
2	75,0	3,0
3	75,5	3,0
4	72,9	2,4
5	74,8	3,0
Mean	75,1	2,9
Maximum	77,6	3,3
Minimum	72,9	2,4
Standard Deviation	1,7	0,3

Graph 2



PICTURE 47. Tensile test results for original PLA -NDP composite with fibre content 40% and additive ELO 12 % (9).

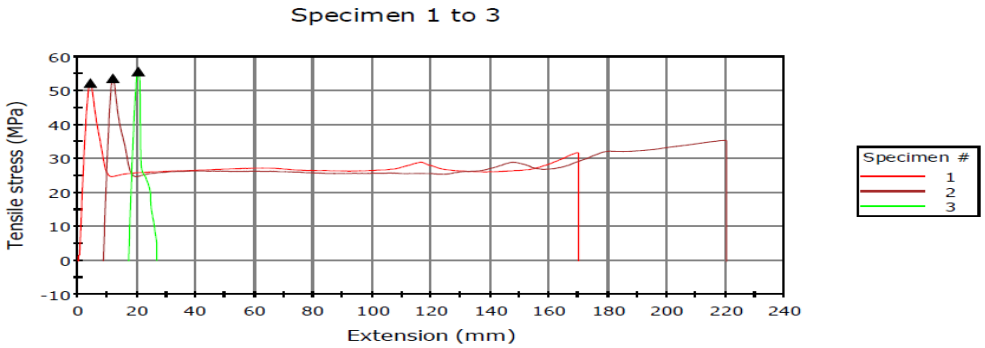
Appendix 5. The tensile test, 2 weeks aging PLA and NDP (1-9).

Acell PLA ref. olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell PLA ref. olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	23 °C / 55 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,21 mm
Dimension: Width	10,16 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell PLA ref. olosuhdekaappi 2vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	52,2	2,88	2232	30,6	175,8	-----
2	53,6	3,06	2311	35,0	215,9	53,6
3	55,6	2,77	2401	3,1	17,8	55,6
Mean	53,8	2,91	2315	22,9	136,5	54,6
Maximum	55,6	3,06	2401	35,0	215,9	55,6
Minimum	52,2	2,77	2232	3,1	17,8	53,6
Standard Deviation	1,7	0,1	84,8	17,3	104,8	1,4

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	-----	39,8	1,48	2912	2894	2882
2	3,06	47,1	2,11	2497	2456	2499
3	2,77	47,5	1,82	2939	2883	2977
Mean	2,92	44,8	1,80	2783	2744	2786
Maximum	3,06	47,5	2,11	2939	2894	2977
Minimum	2,77	39,8	1,48	2497	2456	2499
Standard Deviation	0,2	4,3	0,3	247,8	249,5	252,9

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	52,2	2,9

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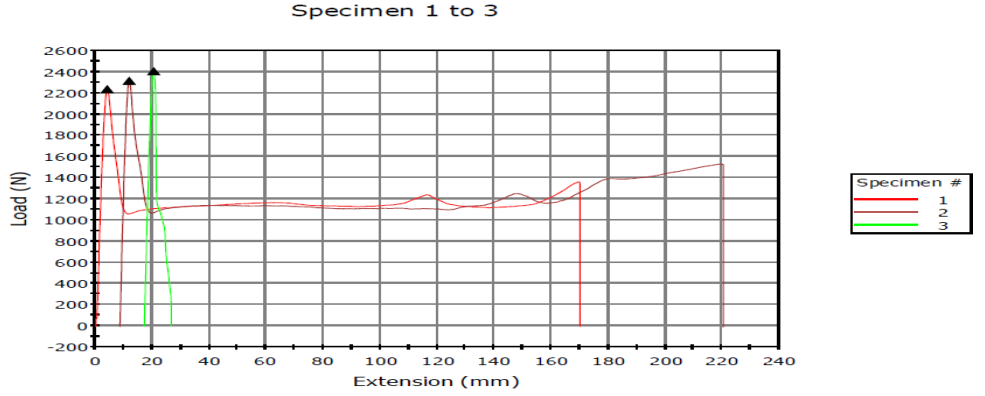
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	53,6	3,1
3	55,6	2,8
Mean	53,8	2,9
Maximum	55,6	3,1
Minimum	52,2	2,8
Standard Deviation	1,7	0,1

Graph 2



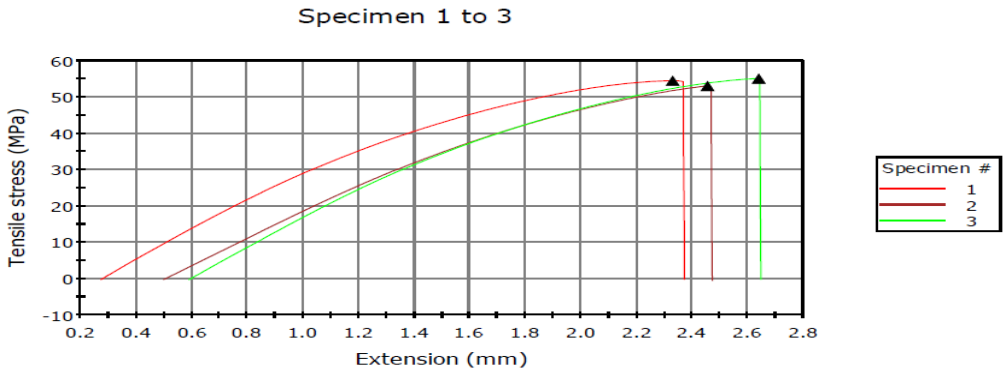
PICTURE 48. Tensile test results for two weeks aging PLA 3052D (1).

Acell 20 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 20 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	24 °C / 52 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,21 mm
Dimension: Width	10,16 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 20 olosuhdekaappi 2vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	54,4	1,65	2344	54,2	1,7	54,4
2	53,0	1,02	2288	52,8	1,0	53,0
3	55,0	1,84	2383	55,0	1,8	55,0
Mean	54,1	1,50	2338	54,0	1,5	54,1
Maximum	55,0	1,84	2383	55,0	1,8	55,0
Minimum	53,0	1,02	2288	52,8	1,0	53,0
Standard Deviation	1,0	0,4	47,5	1,1	0,4	1,0

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,65	42,7	0,89	6158	6178	6408
2	1,02	40,4	0,45	13400	7990	37794
3	1,84	47,3	1,24	4582	4523	4826
Mean	1,50	43,5	0,86	8046	6230	16343
Maximum	1,84	47,3	1,24	13400	7990	37794
Minimum	1,02	40,4	0,45	4582	4523	4826
Standard Deviation	0,4	3,5	0,4	4702,6	1733,6	18594,0

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	54,4	1,7

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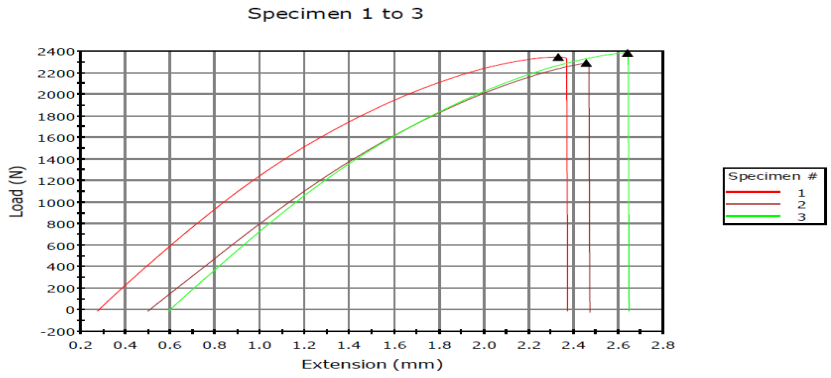
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	53,0	1,0
3	55,0	1,8
Mean	54,1	1,5
Maximum	55,0	1,8
Minimum	53,0	1,0
Standard Deviation	1,0	0,4

Graph 2



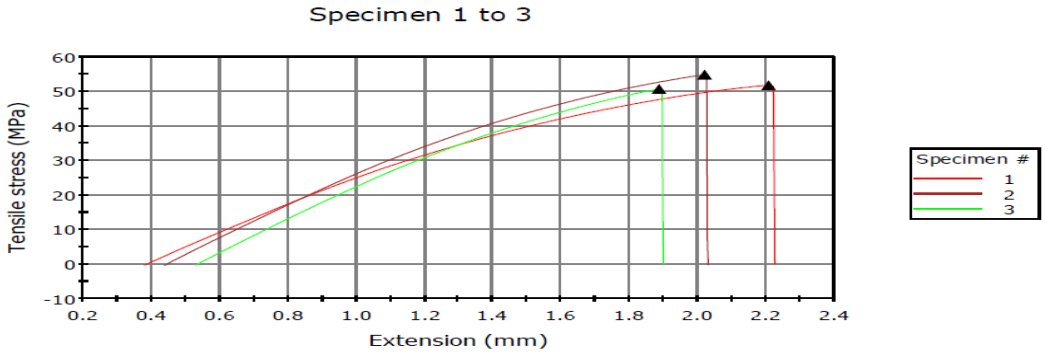
PICTURE 49. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% (2).

Acell 21 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 21 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 51 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,20 mm
Dimension: Width	10,16 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 21 olosuhdekaappi 2vko_1.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	51,7	1,65	2207	51,4	1,7	-----
2	54,8	1,38	2350	54,4	1,4	-----
3	50,7	1,09	2194	50,5	1,1	50,7
Mean	52,4	1,37	2250	52,1	1,4	50,7
Maximum	54,8	1,65	2350	54,4	1,7	50,7
Minimum	50,7	1,09	2194	50,5	1,1	50,7
Standard Deviation	2,1	0,3	86,5	2,0	0,3	-----

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	-----	44,6	1,18	4581	4575	4634
2	-----	48,0	1,04	5746	5753	6165
3	1,09	48,7	1,01	6049	6061	6137
Mean	1,09	47,1	1,08	5459	5463	5645
Maximum	1,09	48,7	1,18	6049	6061	6165
Minimum	1,09	44,6	1,01	4581	4575	4634
Standard Deviation	-----	2,2	0,1	775,2	784,8	876,1

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	51,7	1,7

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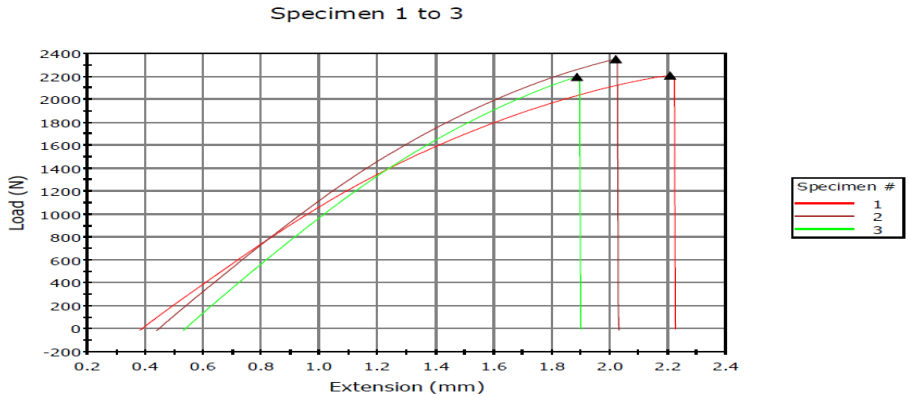
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	54,8	1,4
3	50,7	1,1
Mean	52,4	1,4
Maximum	54,8	1,7
Minimum	50,7	1,1
Standard Deviation	2,1	0,3

Graph 2



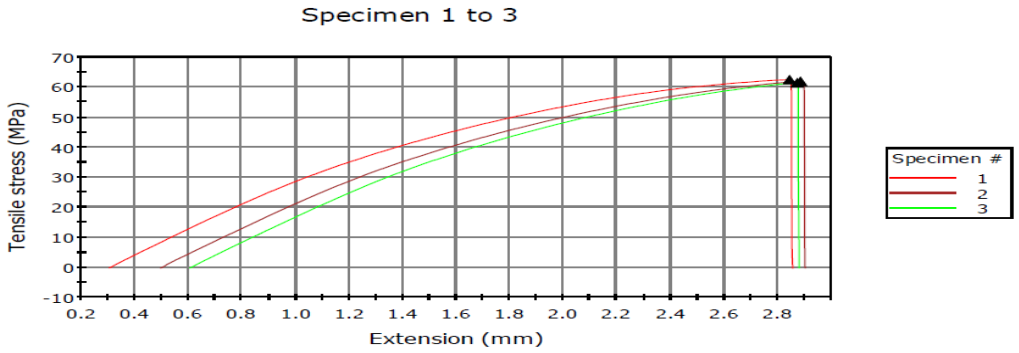
PICTURE 50. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50 % (3).

Acell 22 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 22 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 50 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,20 mm
Dimension: Width	10,17 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 22 olosuhdekaappi 2vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	62,4	2,23	2666	62,3	2,2	62,4
2	61,9	2,06	2641	61,4	2,1	61,9
3	61,4	1,99	2616	61,4	2,0	61,4
Mean	61,9	2,09	2641	61,7	2,1	61,9
Maximum	62,4	2,23	2666	62,3	2,2	62,4
Minimum	61,4	1,99	2616	61,4	2,0	61,4
Standard Deviation	0,5	0,1	24,7	0,5	0,1	0,5

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,23	47,3	1,16	4966	4916	5069
2	2,06	48,3	1,20	4854	4729	5038
3	1,99	51,3	1,30	4671	4150	4719
Mean	2,09	48,9	1,22	4830	4598	4942
Maximum	2,23	51,3	1,30	4966	4916	5069
Minimum	1,99	47,3	1,16	4671	4150	4719
Standard Deviation	0,1	2,1	0,1	149,2	399,3	193,6

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	62,4	2,2

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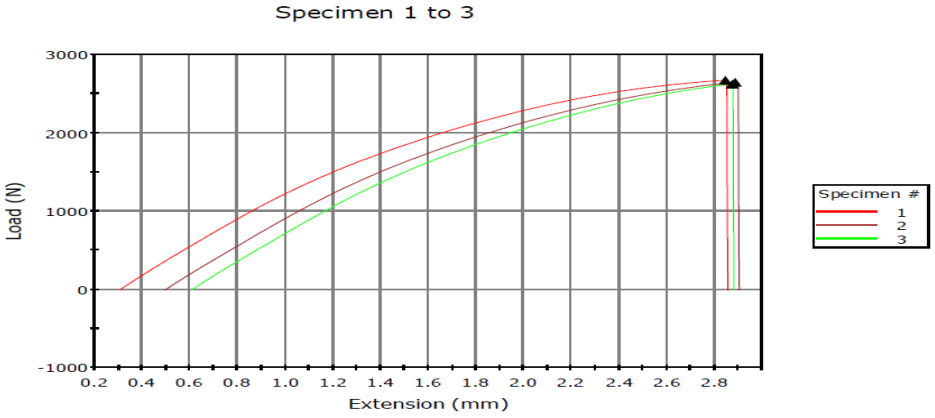
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	61,9	2,1
3	61,4	2,0
Mean	61,9	2,1
Maximum	62,4	2,2
Minimum	61,4	2,0
Standard Deviation	0,5	0,1

Graph 2



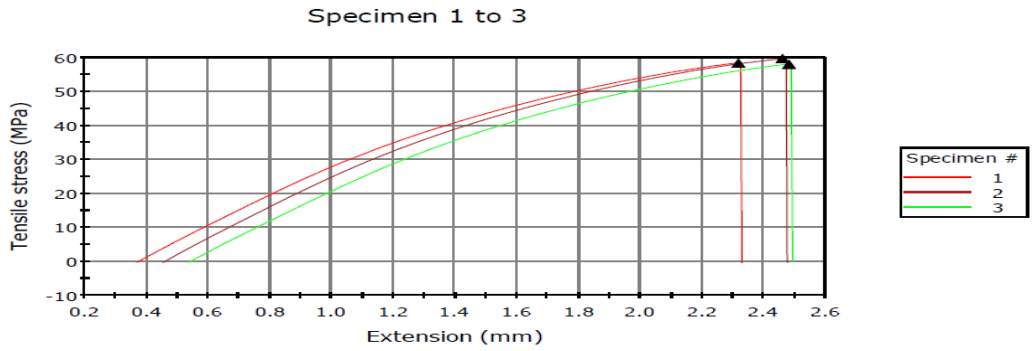
PICTURE 51. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 5 % (4).

Acell 23 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 23 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 50 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL. im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,19 mm
Dimension: Width	10,18 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 23 olosuhdekaappi 2vko_1.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	58,4	1,61	2490	58,3	1,6	58,4
2	59,7	1,67	2537	59,1	1,7	59,7
3	58,0	1,66	2465	57,6	1,6	-----
Mean	58,7	1,65	2497	58,3	1,6	59,0
Maximum	59,7	1,67	2537	59,1	1,7	59,7
Minimum	58,0	1,61	2465	57,6	1,6	58,4
Standard Deviation	0,9	0,0	36,5	0,8	0,0	0,9

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,61	47,0	1,01	5855	5880	5741
2	1,67	48,6	1,08	5560	5496	5619
3	-----	48,4	1,12	5277	5264	5306
Mean	1,64	48,0	1,07	5564	5546	5555
Maximum	1,67	48,6	1,12	5855	5880	5741
Minimum	1,61	47,0	1,01	5277	5264	5306
Standard Deviation	0,0	0,9	0,1	289,0	311,3	224,7

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	58,4	1,6

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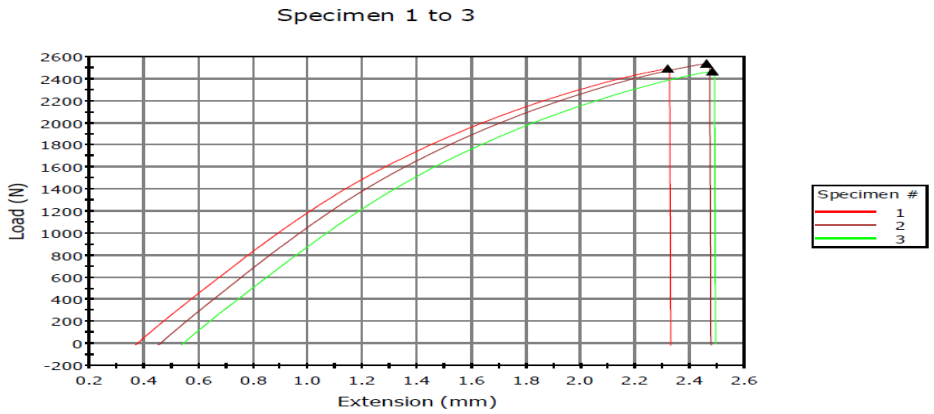
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	59,7	1,7
3	58,0	1,7
Mean	58,7	1,6
Maximum	59,7	1,7
Minimum	58,0	1,6
Standard Deviation	0,9	0,0

Graph 2



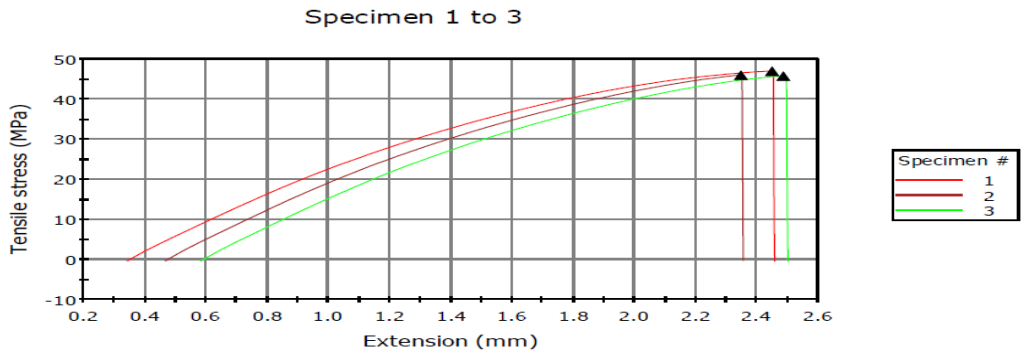
PICTURE 52. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50% and additive ELO 5 % (5).

Acell 24 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 24 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 50 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,20 mm
Dimension: Width	10,20 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 24 olosuhdekaappi 2vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	46,9	1,97	2010	46,9	2,0	46,9
2	45,9	1,74	1967	45,9	1,7	45,9
3	45,7	1,71	1953	45,5	1,7	45,7
Mean	46,2	1,81	1977	46,1	1,8	46,2
Maximum	46,9	1,97	2010	46,9	2,0	46,9
Minimum	45,7	1,71	1953	45,5	1,7	45,7
Standard Deviation	0,7	0,1	29,5	0,7	0,1	0,7

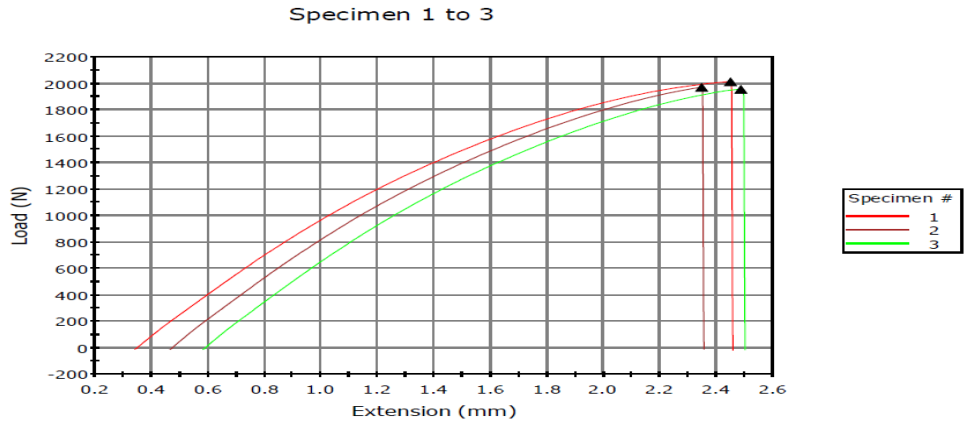
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,97	40,2	1,33	3565	3459	3737
2	1,74	35,5	1,10	3958	3991	4125
3	1,71	38,5	1,17	3960	3879	4020
Mean	1,81	38,1	1,20	3828	3776	3961
Maximum	1,97	40,2	1,33	3960	3991	4125
Minimum	1,71	35,5	1,10	3565	3459	3737
Standard Deviation	0,1	2,4	0,1	227,7	280,6	200,7

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	46,9	2,0

2.8.2016 13:56:53

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	45,9	1,7
3	45,7	1,7
Mean	46,2	1,8
Maximum	46,9	2,0
Minimum	45,7	1,7
Standard Deviation	0,7	0,1

Graph 2



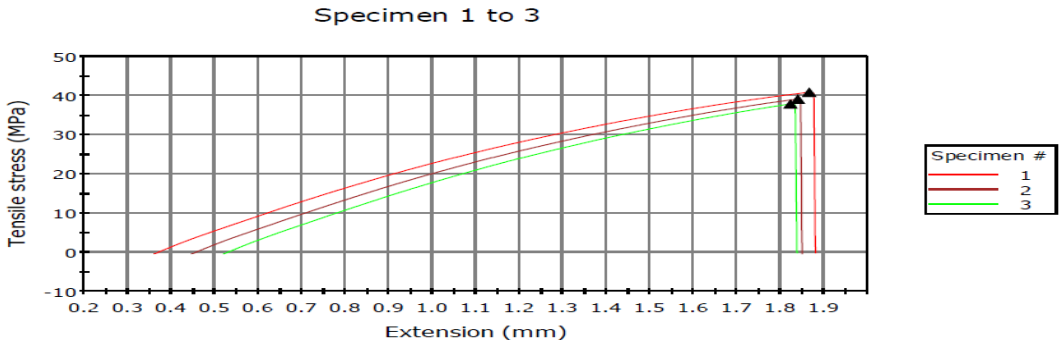
PICTURE 53. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive sorbitol derivative 5 % (6).

Acell 25 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 25 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,20 mm
Dimension: Width	10,19 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 25 olosuhdekaappi 2vko_1.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	40,8	1,30	1747	40,6	1,3	40,8
2	39,1	1,22	1674	38,9	1,2	39,1
3	37,8	1,14	1618	37,6	1,2	37,8
Mean	39,2	1,22	1680	39,0	1,2	39,2
Maximum	40,8	1,30	1747	40,6	1,3	40,8
Minimum	37,8	1,14	1618	37,6	1,2	37,8
Standard Deviation	1,5	0,1	64,6	1,5	0,1	1,5

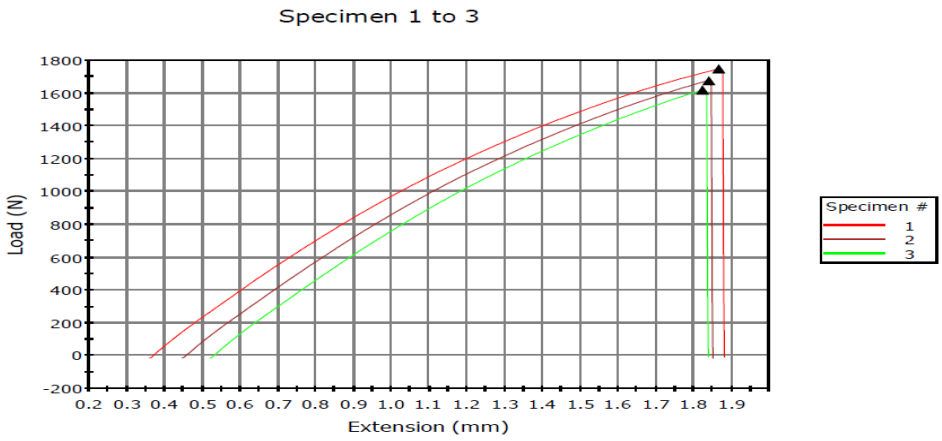
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,30	36,7	1,08	4291	4167	3982
2	1,22	38,3	1,18	3925	3705	4305
3	1,14	37,7	1,15	4007	3851	4025
Mean	1,22	37,6	1,14	4075	3908	4104
Maximum	1,30	38,3	1,18	4291	4167	4305
Minimum	1,14	36,7	1,08	3925	3705	3982
Standard Deviation	0,1	0,8	0,1	192,0	236,0	175,6

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	40,8	1,3

2.8.2016 14:04:58

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	39,1	1,2
3	37,8	1,1
Mean	39,2	1,2
Maximum	40,8	1,3
Minimum	37,8	1,1
Standard Deviation	1,5	0,1

Graph 2



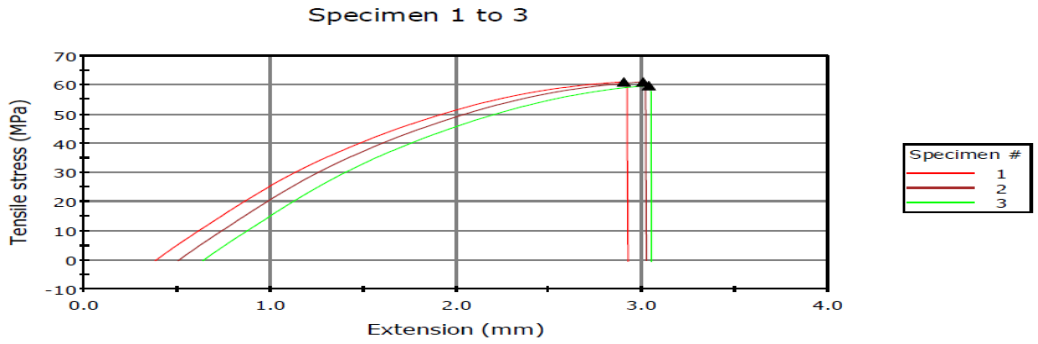
PICTURE 54. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50% and additive sorbitol derivative 5 % (7).

Acell 28 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 28 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,16 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 28 olosuhdekaappi 2vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	61,0	2,12	2564	61,0	2,1	61,0
2	61,0	2,17	2566	60,5	2,2	61,0
3	59,8	2,02	2528	59,5	2,0	59,8
Mean	60,6	2,11	2552	60,3	2,1	60,6
Maximum	61,0	2,17	2566	61,0	2,2	61,0
Minimum	59,8	2,02	2528	59,5	2,0	59,8
Standard Deviation	0,7	0,1	21,3	0,8	0,1	0,7

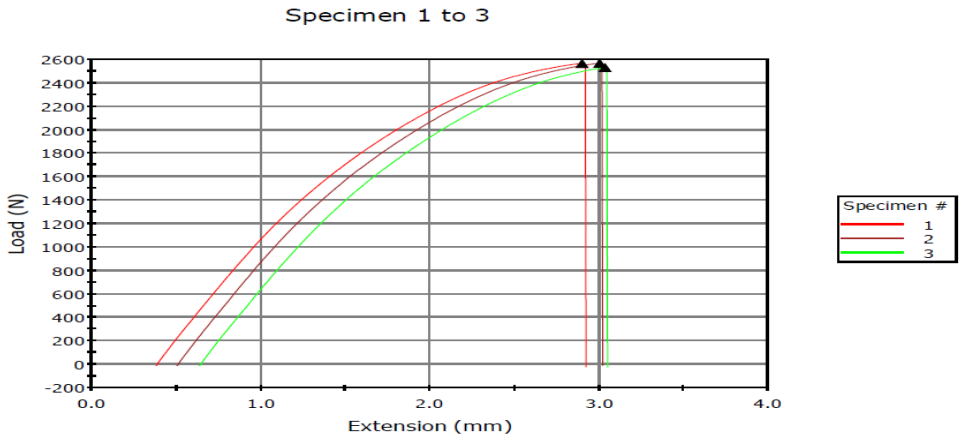
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,12	45,1	1,02	5465	5634	5771
2	2,17	45,8	1,10	5131	5009	5243
3	2,02	46,3	1,13	5000	4917	5112
Mean	2,11	45,7	1,08	5199	5187	5375
Maximum	2,17	46,3	1,13	5465	5634	5771
Minimum	2,02	45,1	1,02	5000	4917	5112
Standard Deviation	0,1	0,6	0,1	239,7	390,0	348,9

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	61,0	2,1

2.8.2016 14:40:28

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	61,0	2,2
3	59,8	2,0
Mean	60,6	2,1
Maximum	61,0	2,2
Minimum	59,8	2,0
Standard Deviation	0,7	0,1

Graph 2



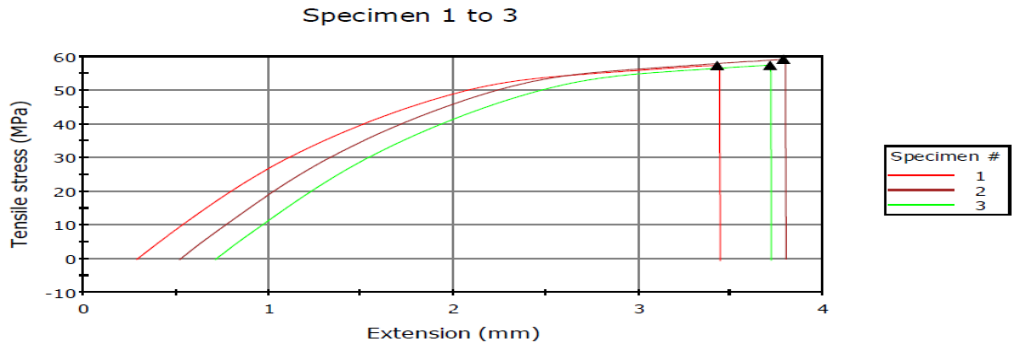
PICTURE 55. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 8 % (8).

Acell 29 olosuhdekaappi 2vko

Defaults Table

General: Last test date	2. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell 29 olosuhdekaappi 2vko
Text Inputs: Temperature / hymidity	25 °C / 48 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,19 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 2.8.2016

Sample file name: Acell 29 olosuhdekaappi 2vko_1.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	57,3	2,96	2425	57,0	3,0	57,3
2	59,1	3,03	2497	58,7	3,0	59,1
3	57,3	2,70	2426	57,3	2,7	57,3
Mean	57,9	2,89	2449	57,7	2,9	57,9
Maximum	59,1	3,03	2497	58,7	3,0	59,1
Minimum	57,3	2,70	2425	57,0	2,7	57,3
Standard Deviation	1,1	0,2	41,0	0,9	0,2	1,1

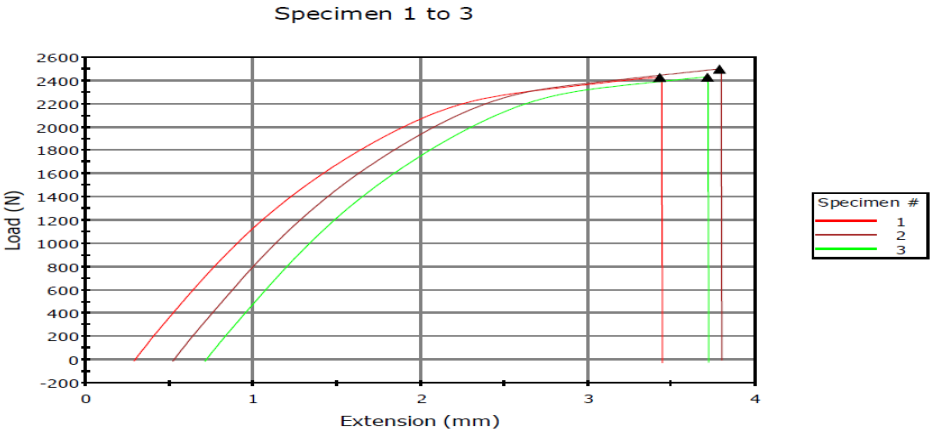
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,96	42,2	1,15	4441	4380	4478
2	3,03	44,1	1,17	4528	4461	4601
3	2,70	44,5	1,22	4365	4126	4437
Mean	2,89	43,6	1,18	4444	4322	4505
Maximum	3,03	44,5	1,22	4528	4461	4601
Minimum	2,70	42,2	1,15	4365	4126	4437
Standard Deviation	0,2	1,2	0,0	81,6	174,3	85,2

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	57,3	3,0

2.8.2016 14:49:46

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	59,1	3,0
3	57,3	2,7
Mean	57,9	2,9
Maximum	59,1	3,0
Minimum	57,3	2,7
Standard Deviation	1,1	0,2

Graph 2



PICTURE 56. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 12 % (9).

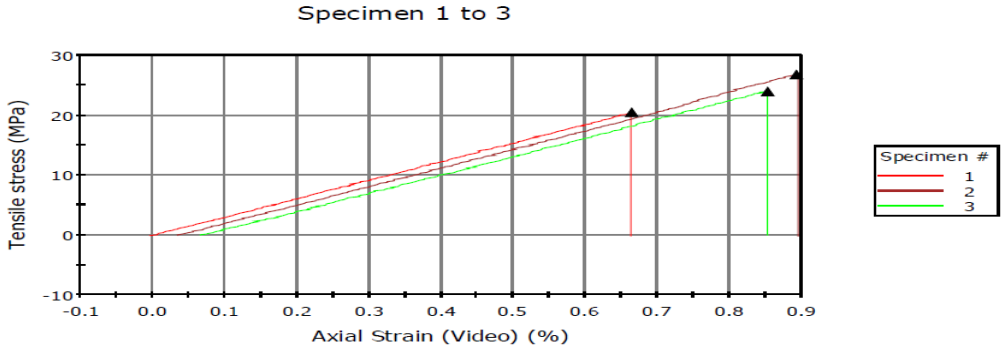
Appendix 6. The tensile test, 6 weeks aging sample PLA and NDP (1-9).

Acell PLA ref. olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell PLA ref. olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 50 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell PLA ref. olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
X 1	20,5	0,66	875	20,5	0,7	20,5
2	26,8	0,86	1145	26,8	0,9	26,8
3	23,9	0,78	1024	23,9	0,8	23,9
Mean	25,3	0,82	1084	25,3	0,8	25,3
Maximum	26,8	0,86	1145	26,8	0,9	26,8
Minimum	23,9	0,78	1024	23,9	0,8	23,9
Standard Deviation	2,0	0,1	85,4	2,0	0,1	2,0

	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
X 1	0,66	14,3	0,67	3121	3081	3104
2	0,86	20,4	0,86	3200	3043	3212
3	0,78	17,9	0,79	3192	3044	3199
Mean	0,82	19,1	0,82	3196	3044	3206
Maximum	0,86	20,4	0,86	3200	3044	3212
Minimum	0,78	17,9	0,79	3192	3043	3199
Standard Deviation	0,1	1,7	0,1	5,7	0,3	9,0

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
X 1	20,5	0,7

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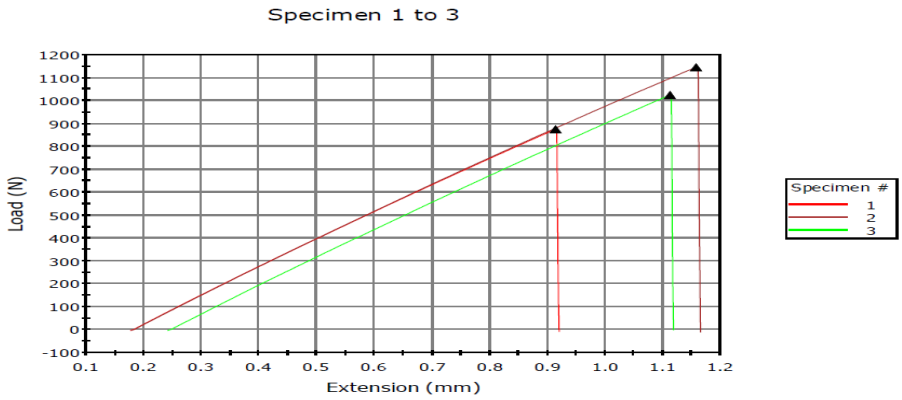
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	26,8	0,9
3	23,9	0,8
Mean	25,3	0,8
Maximum	26,8	0,9
Minimum	23,9	0,8
Standard Deviation	2,0	0,1

Graph 2



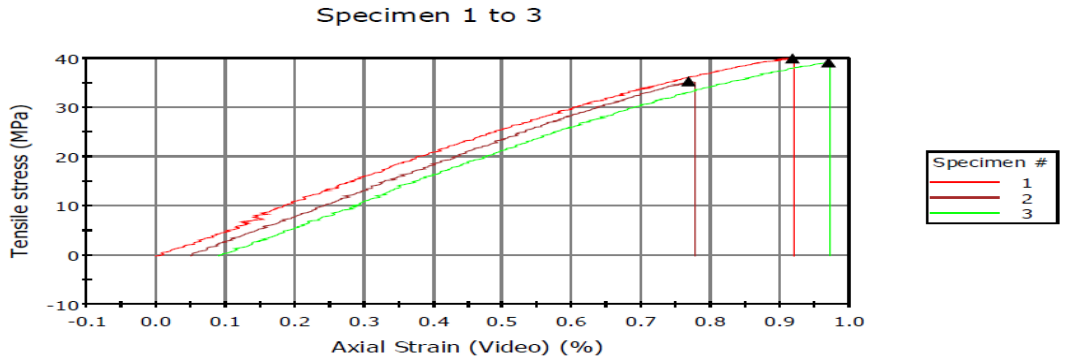
PICTURE 57. Tensile test results for six weeks aging PLA 3052D (1).

Acell NDP 20 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 20 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 20 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	40,0	0,92	1728	39,7	0,9	40,0
X 2	35,3	0,72	1527	35,1	0,7	35,3
3	39,1	0,88	1690	38,9	0,9	39,1
Mean	39,6	0,90	1709	39,3	0,9	39,6
Maximum	40,0	0,92	1728	39,7	0,9	40,0
Minimum	39,1	0,88	1690	38,9	0,9	39,1
Standard Deviation	0,6	0,0	26,3	0,6	0,0	0,6

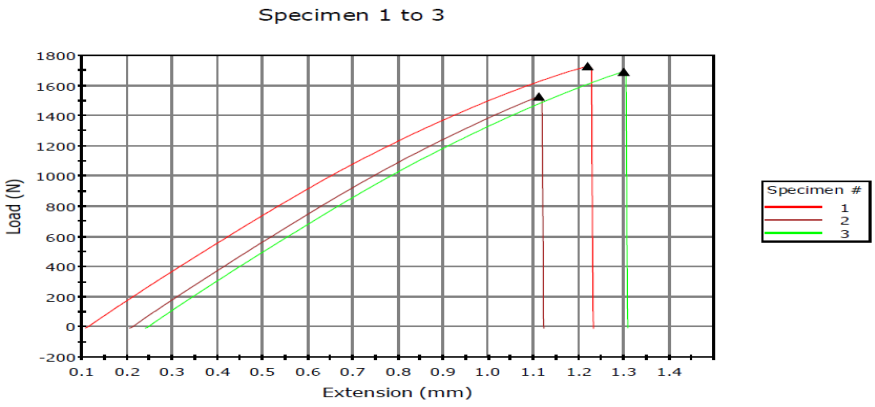
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	0,92	39,5	0,92	5516	5798	5230
X 2	0,72	27,6	0,73	5282	5153	5283
3	0,88	37,7	0,88	5680	5281	5517
Mean	0,90	38,6	0,90	5598	5539	5373
Maximum	0,92	39,5	0,92	5680	5798	5517
Minimum	0,88	37,7	0,88	5516	5281	5230
Standard Deviation	0,0	1,2	0,0	115,9	366,0	203,0

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	40,0	0,9

30.8.2016 11:38:45

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
X 2	35,3	0,7
3	39,1	0,9
Mean	39,6	0,9
Maximum	40,0	0,9
Minimum	39,1	0,9
Standard Deviation	0,6	0,0

Graph 2



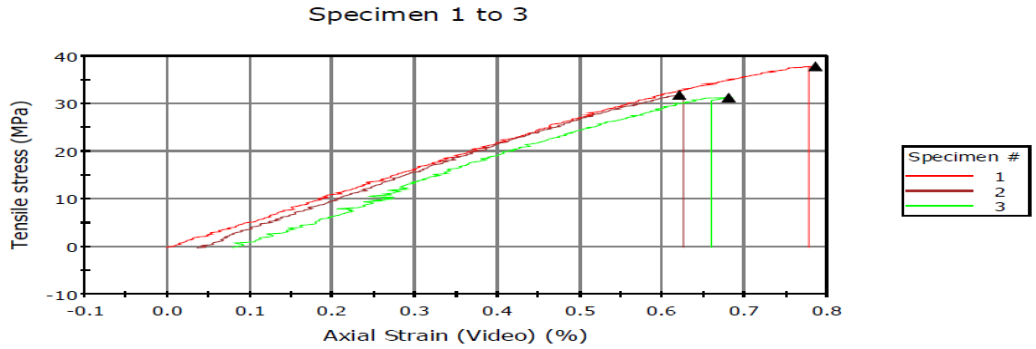
PICTURE 58. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40 % (2).

Acell NDP 21 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 21 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 21 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	37,8	0,78	1637	37,6	0,8	37,8
2	31,8	0,58	1384	31,7	0,6	31,8
3	31,3	0,60	1360	30,7	0,6	31,3
Mean	33,6	0,66	1460	33,3	0,7	33,6
Maximum	37,8	0,78	1637	37,6	0,8	37,8
Minimum	31,3	0,58	1360	30,7	0,6	31,3
Standard Deviation	3,6	0,1	153,2	3,8	0,1	3,6

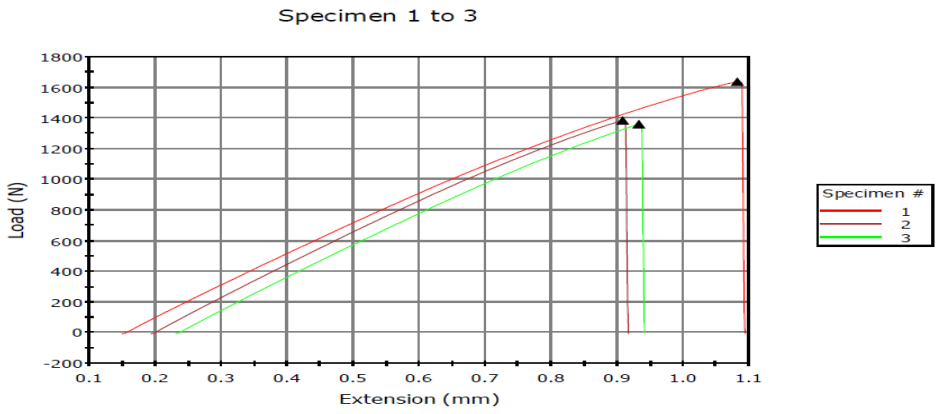
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	0,78	32,3	0,79	5486	5563	5577
2	0,58	23,8	0,59	6174	5911	6309
3	0,60	24,7	0,61	6437	6442	6411
Mean	0,66	27,0	0,66	6032	5972	6099
Maximum	0,78	32,3	0,79	6437	6442	6411
Minimum	0,58	23,8	0,59	5486	5563	5577
Standard Deviation	0,1	4,7	0,1	491,0	442,8	455,0

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	37,8	0,8

30.8.2016 11:48:37

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	31,8	0,6
3	31,3	0,6
Mean	33,6	0,7
Maximum	37,8	0,8
Minimum	31,3	0,6
Standard Deviation	3,6	0,1

Graph 2



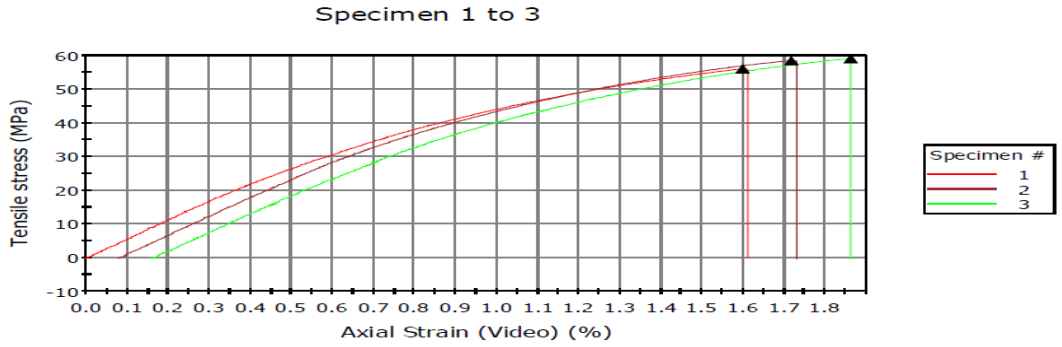
PICTURE 59. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50 % (3).

Acell NDP 22 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 22 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL. im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 22 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
X 1	56,0	1,60	2384	55,8	1,6	56,0
2	58,4	1,64	2484	58,3	1,6	58,4
3	59,0	1,70	2507	59,0	1,7	59,0
Mean	58,7	1,67	2496	58,6	1,7	58,7
Maximum	59,0	1,70	2507	59,0	1,7	59,0
Minimum	58,4	1,64	2484	58,3	1,6	58,4
Standard Deviation	0,4	0,0	16,6	0,5	0,0	0,4

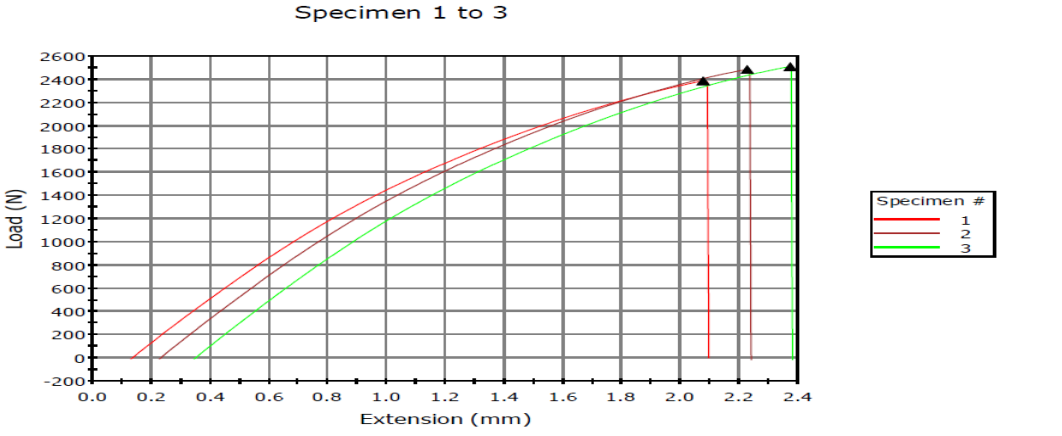
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
X 1	1,60	42,9	0,96	5671	5699	5695
2	1,64	46,8	1,03	5596	5617	5612
3	1,70	46,4	1,05	5496	5559	5516
Mean	1,67	46,6	1,04	5546	5588	5564
Maximum	1,70	46,8	1,05	5596	5617	5612
Minimum	1,64	46,4	1,03	5496	5559	5516
Standard Deviation	0,0	0,3	0,0	70,7	41,4	67,5

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
X 1	56,0	1,6

30.8.2016 12:17:30

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	58,4	1,6
3	59,0	1,7
Mean	58,7	1,7
Maximum	59,0	1,7
Minimum	58,4	1,6
Standard Deviation	0,4	0,0

Graph 2



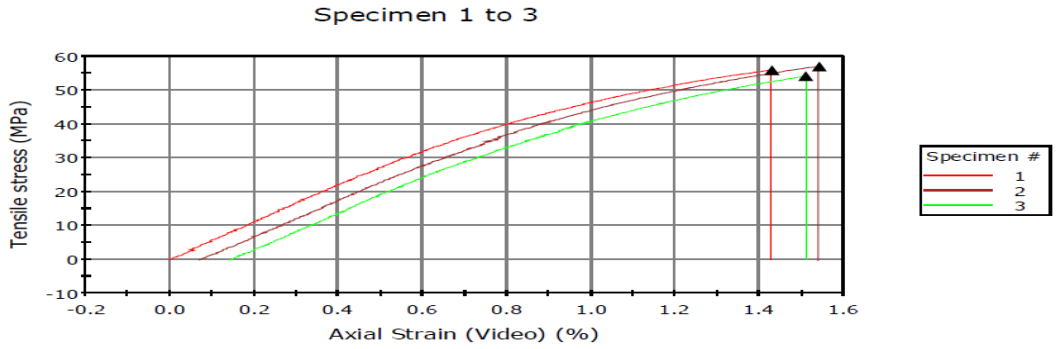
PICTURE 60. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 5 % (4).

Acell NDP 23 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 23 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 23 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	55,8	1,43	2364	55,5	1,4	55,8
2	56,9	1,47	2402	56,3	1,5	56,9
X 3	54,1	1,37	2307	53,9	1,4	54,1
Mean	56,3	1,45	2383	55,9	1,5	56,3
Maximum	56,9	1,47	2402	56,3	1,5	56,9
Minimum	55,8	1,43	2364	55,5	1,4	55,8
Standard Deviation	0,8	0,0	26,5	0,5	0,0	0,8

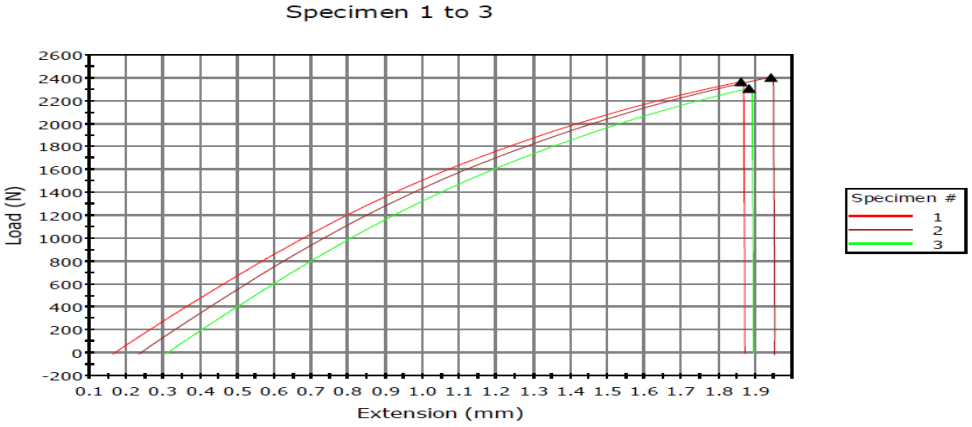
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,43	48,1	1,06	5573	5519	5620
2	1,47	50,1	1,15	5302	5326	5435
X 3	1,37	48,5	1,11	5331	5350	5552
Mean	1,45	49,1	1,11	5437	5422	5528
Maximum	1,47	50,1	1,15	5573	5519	5620
Minimum	1,43	48,1	1,06	5302	5326	5435
Standard Deviation	0,0	1,5	0,1	191,6	136,3	131,3

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	55,8	1,4

30.8.2016 12:29:54

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	56,9	1,5
X 3	54,1	1,4
Mean	56,3	1,4
Maximum	56,9	1,5
Minimum	55,8	1,4
Standard Deviation	0,8	0,0

Graph 2



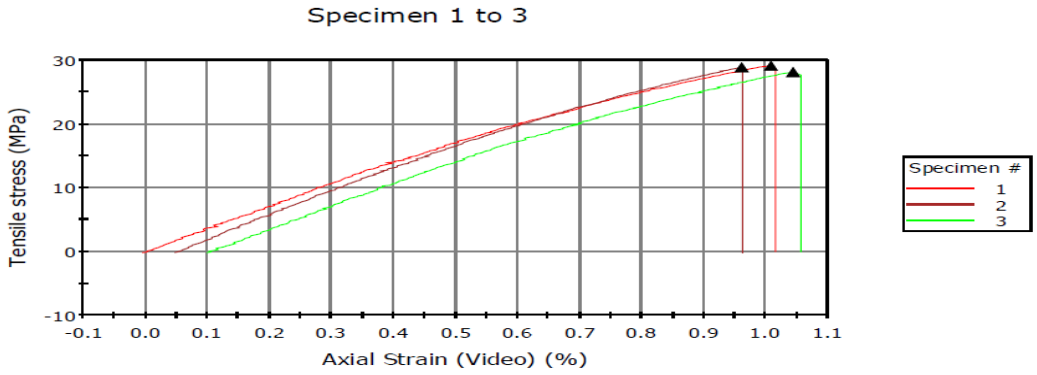
PICTURE 61. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50% and additive ELO 5 % (5).

Acell NDP 24 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 24 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 24 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	29,1	1,01	1251	28,6	1,0	29,1
2	28,8	0,91	1234	28,5	0,9	28,8
3	28,1	0,94	1205	27,6	0,9	28,1
Mean	28,7	0,95	1230	28,2	1,0	28,7
Maximum	29,1	1,01	1251	28,6	1,0	29,1
Minimum	28,1	0,91	1205	27,6	0,9	28,1
Standard Deviation	0,5	0,0	23,0	0,5	0,1	0,5

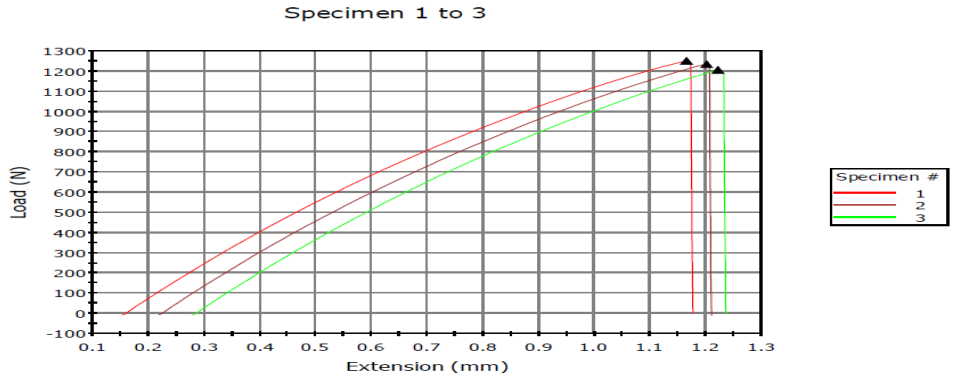
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	1,01	29,0	1,01	3613	3504	3621
2	0,91	28,0	0,91	3936	3829	4013
3	0,94	27,1	0,95	3633	3670	3625
Mean	0,95	28,1	0,96	3727	3667	3753
Maximum	1,01	29,0	1,01	3936	3829	4013
Minimum	0,91	27,1	0,91	3613	3504	3621
Standard Deviation	0,0	0,9	0,0	181,1	162,4	225,4

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	29,1	1,0

30.8.2016 12:37:09

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	28,8	0,9
3	28,1	0,9
Mean	28,7	1,0
Maximum	29,1	1,0
Minimum	28,1	0,9
Standard Deviation	0,5	0,0

Graph 2



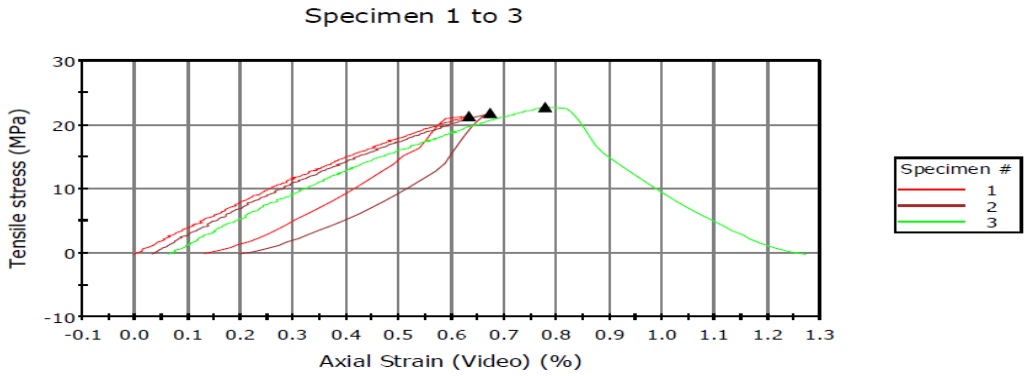
PICTURE 62. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive sorbitol derivative 5 % (6).

Acell NDP 25 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 25 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	24 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 25 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	21,4	0,63	913	20,9	0,6	-----
2	21,8	0,64	932	21,7	0,6	-----
3	22,7	0,71	967	22,5	0,8	22,7
Mean	22,0	0,66	937	21,7	0,7	22,7
Maximum	22,7	0,71	967	22,5	0,8	22,7
Minimum	21,4	0,63	913	20,9	0,6	22,7
Standard Deviation	0,7	0,0	27,0	0,8	0,1	-----

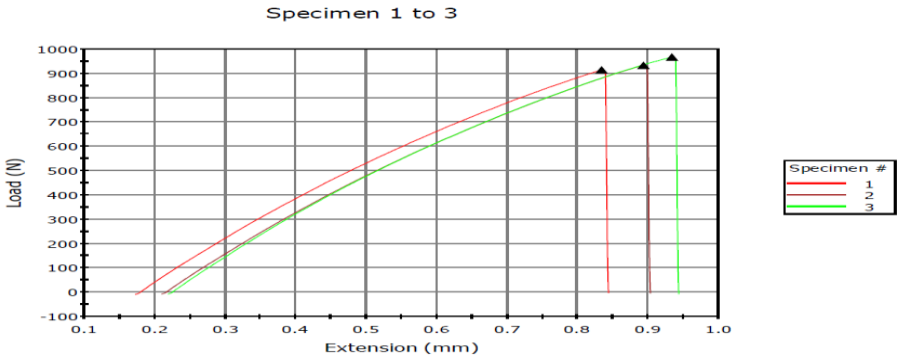
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	-----	-----	-----	3964	3923	3997
2	-----	15,7	0,57	4265	4047	4313
3	0,71	22,6	0,73	4282	3917	4337
Mean	0,71	19,2	0,65	4170	3962	4216
Maximum	0,71	22,6	0,73	4282	4047	4337
Minimum	0,71	15,7	0,57	3964	3917	3997
Standard Deviation	-----	4,9	0,1	178,7	73,6	189,9

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	21,4	0,6

30.8.2016 12:44:20

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	21,8	0,6
3	22,7	0,7
Mean	22,0	0,7
Maximum	22,7	0,7
Minimum	21,4	0,6
Standard Deviation	0,7	0,0

Graph 2



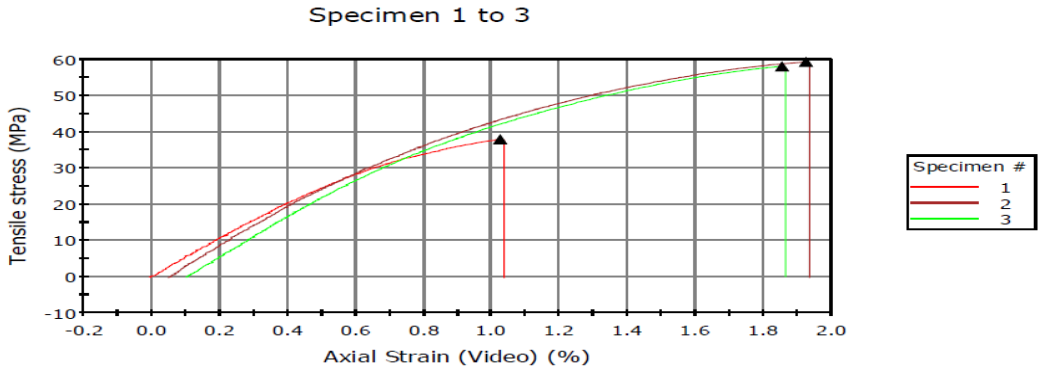
PICTURE 63. Tensile test results for two weeks aging PLA -NDP composite with fibre content 50% and additive sorbitol derivative 5 % (7).

Acell NDP 28 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 28 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	25 °C / 49 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 28 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
X 1	37,9	1,02	1610	37,8	1,0	37,9
2	59,2	1,87	2501	59,1	1,9	59,2
3	58,0	1,75	2463	57,7	1,8	58,0
Mean	58,6	1,81	2482	58,4	1,8	58,6
Maximum	59,2	1,87	2501	59,1	1,9	59,2
Minimum	58,0	1,75	2463	57,7	1,8	58,0
Standard Deviation	0,9	0,1	27,0	1,0	0,1	0,9

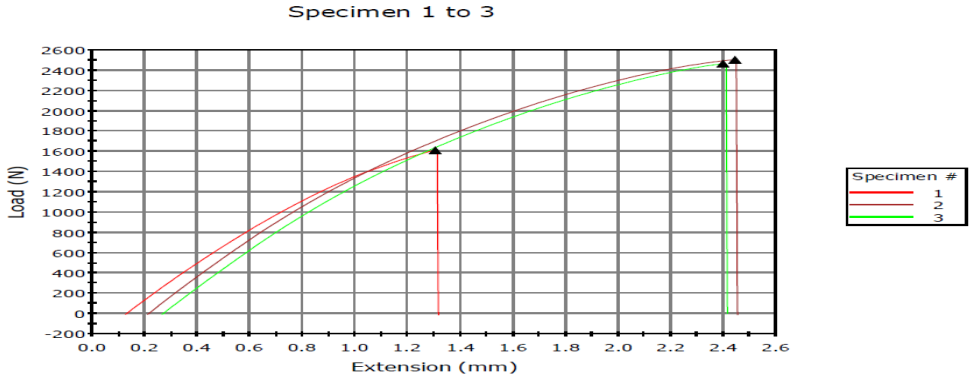
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
X 1	1,02	35,2	0,86	5322	5224	5386
2	1,87	43,4	0,97	5564	5666	5751
3	1,75	43,8	0,98	5624	5642	5633
Mean	1,81	43,6	0,98	5594	5654	5692
Maximum	1,87	43,8	0,98	5624	5666	5751
Minimum	1,75	43,4	0,97	5564	5642	5633
Standard Deviation	0,1	0,3	0,0	42,0	17,2	83,7

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
X 1	37,9	1,0

30.8.2016 13:13:27

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	59,2	1,9
3	58,0	1,7
Mean	58,6	1,8
Maximum	59,2	1,9
Minimum	58,0	1,7
Standard Deviation	0,9	0,1

Graph 2



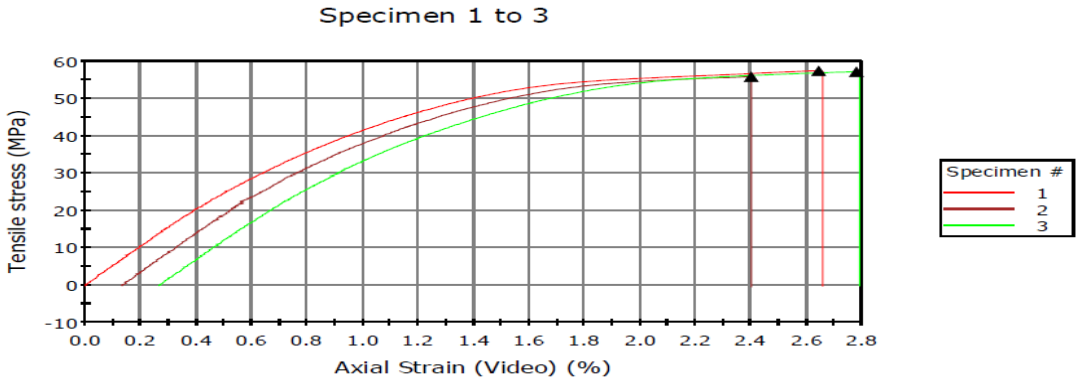
PICTURE 64. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 8 % (8).

Acell NDP 29 olosuhdekaappi 6vko

Defaults Table

General: Last test date	30. elokuuta 2016
Text Inputs: Material	
Text Inputs: Specimen label	Acell NDP 29 olosuhdekaappi 6vko
Text Inputs: Temperature / hymidity	25 °C / 48 % RH
General: Method Name	C:\Documents and Settings\All Users\Documents\Instron\Bluehill\Templates\Veto\ACEL.im_tens
General: Method description	Modifioitu ISO 527 5mm/min
Test: Rate 1	5,0 mm/min
Dimension: Thickness	4,23 mm
Dimension: Width	10,10 mm
Text Inputs: Note	Prepared 30.8.2016

Sample file name: Acell NDP 29 olosuhdekaappi 6vko.is_tens



	Tensile stress at Max Load (MPa)	Tensile strain at Max Load (%)	Maximum Load (N)	Stress at Break (MPa)	Strain at Break (%)	Stress at Yield (Zero Slope) (MPa)
1	57,4	2,64	2436	57,2	2,7	57,4
2	55,7	2,27	2373	55,5	2,3	55,7
3	57,1	2,51	2427	56,9	2,5	57,1
Mean	56,7	2,47	2412	56,5	2,5	56,7
Maximum	57,4	2,64	2436	57,2	2,7	57,4
Minimum	55,7	2,27	2373	55,5	2,3	55,7
Standard Deviation	0,9	0,2	34,1	0,9	0,2	0,9

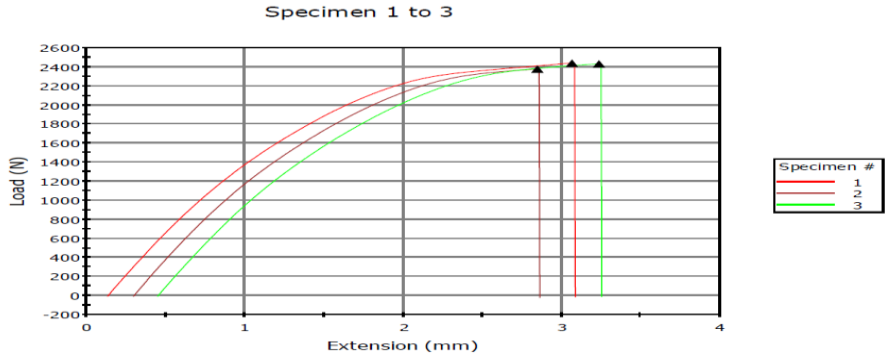
	Strain at Yield (Zero Slope) (%)	Stress at Offset Yield (0,2 %) (MPa)	Strain at Offset Yield (0,2 %) (%)	Modulus (Automatic) (MPa)	Modulus (0,05-0,25 %) (MPa)	Modulus (Auto Young's) (MPa)
1	2,64	42,5	1,04	5019	5133	5206
2	2,27	42,2	1,02	5126	5158	5223
3	2,51	42,1	1,04	4977	5148	5097
Mean	2,47	42,3	1,03	5041	5146	5175
Maximum	2,64	42,5	1,04	5126	5158	5223
Minimum	2,27	42,1	1,02	4977	5133	5097
Standard Deviation	0,2	0,2	0,0	76,8	12,6	68,2

	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
1	57,4	2,6

30.8.2016 13:22:36

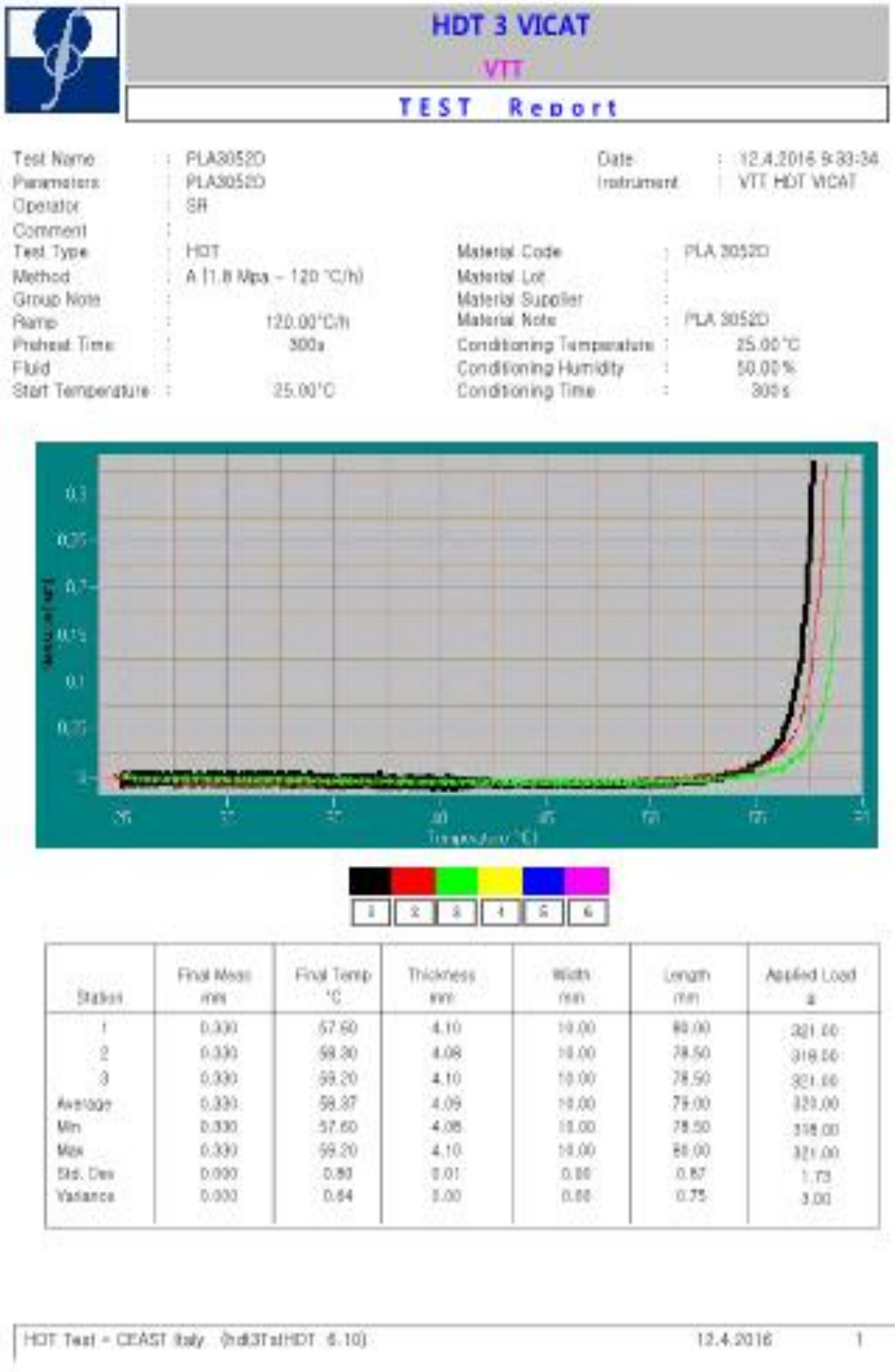
	Tensile stress at First Peak (MPa)	Tensile strain at First Peak (%)
2	55,7	2,3
3	57,1	2,5
Mean	56,7	2,5
Maximum	57,4	2,6
Minimum	55,7	2,3
Standard Deviation	0,9	0,2

Graph 2



PICTURE 65. Tensile test results for two weeks aging PLA -NDP composite with fibre content 40% and additive ELO 12 % (9).

Appendix 7. HDT by method A (1,80 MPa), PLA and NDP (1-9).



HDT 3 VICAT

VTT

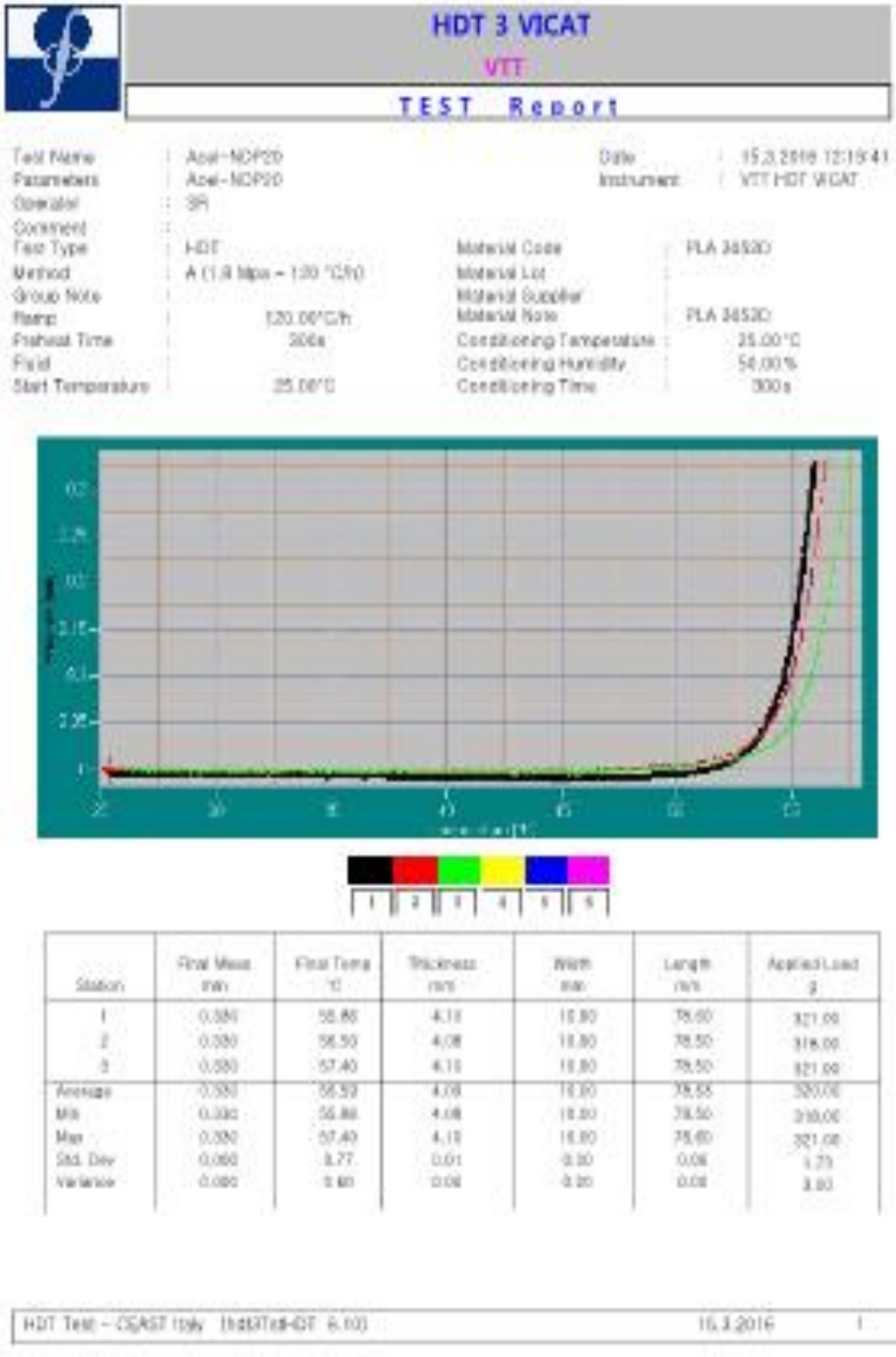
TEST Report

Test Name	: PLA3052D		Date	: 12.4.2016 9:33:34	
Parameters	: PLA3052D		Instrument	: VTT HDT VICAT	
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	: PLA 3052D	
Method	: A (1.8 Mpa - 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120.00°C/h		Material Note	: PLA 3052D	
Preheat Time	: 300s		Conditioning Temperature	: 25.00 °C	
Fluid	:		Conditioning Humidity	: 50.00 %	
Start Temperature	: 25.00°C		Conditioning Time	: 300 s	

Station	Final Mean mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.330	57.60	4.10	10.00	80.00	321.00
2	0.330	58.30	4.08	10.00	78.50	318.00
3	0.330	59.20	4.10	10.00	78.50	321.00
Average	0.330	58.37	4.09	10.00	79.00	320.00
Min	0.330	57.60	4.08	10.00	78.50	318.00
Max	0.330	59.20	4.10	10.00	80.00	321.00
Std. Dev	0.000	0.80	0.01	0.00	0.87	1.73
Variance	0.000	0.64	0.00	0.00	0.75	3.00

HDT Test - CEAST Italy (hdt3TstHDT 6.10) 12.4.2016 1

PICTURE 66. HDT by method A (1,80 MPa), PLA 3052D (1).



HDT 3 VICAT

VTT

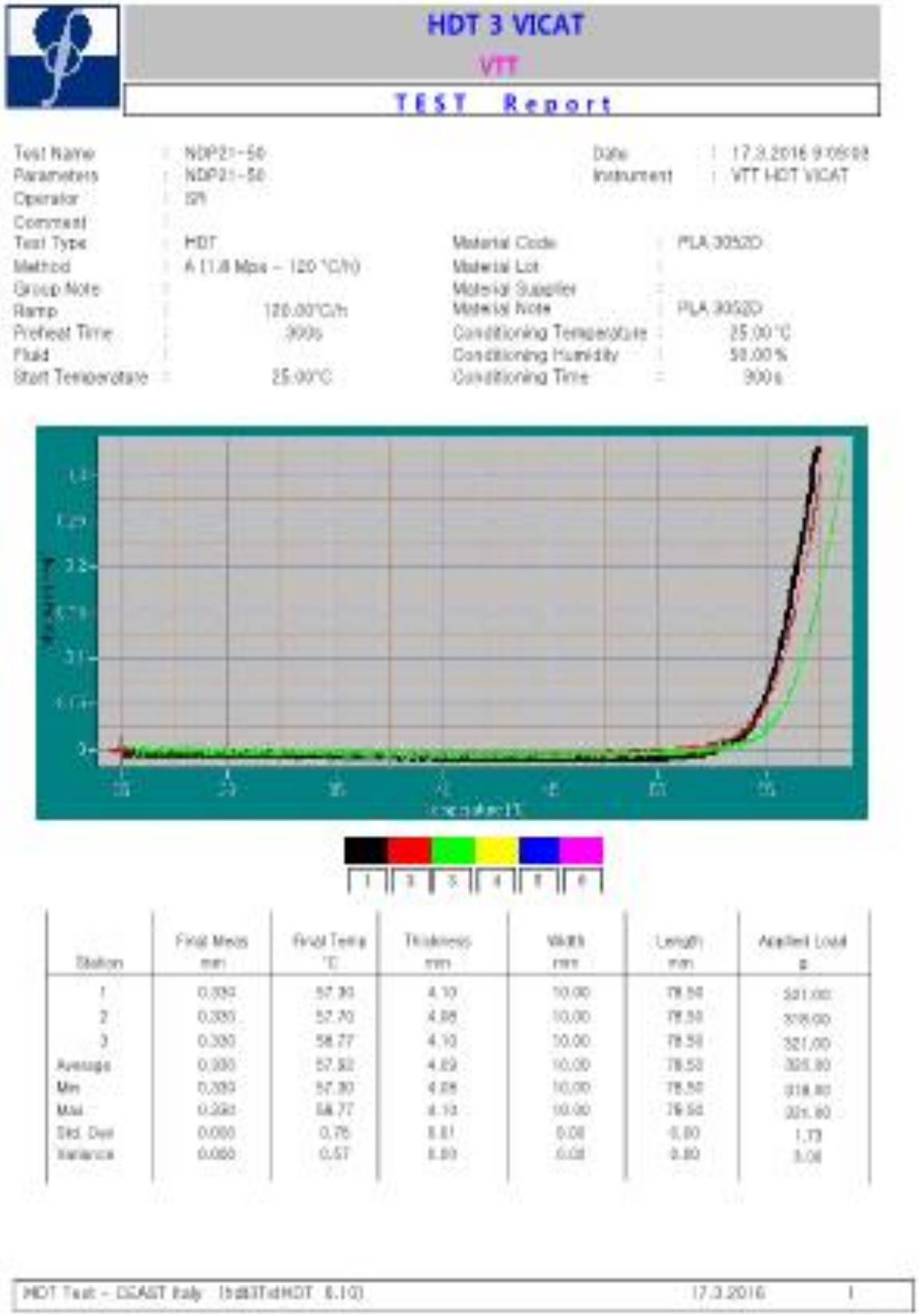
TEST Report

Test Name	Acel-NDP20	Date	15.3.2016 12:19:41
Parameters	Acel-NDP20	Instrument	VTT HDT VICAT
Operator	SR		
Comment			
Test Type	HDT	Material Code	PLA 3052D
Method	A (1,8 Mpa – 120 °C/h)	Material Lot	
Group Note		Material Supplier	
Ramp	120,00°C/h	Material Note	PLA 3052D
Preheat Time	300s	Conditioning Temperature	25,00°C
Fluid		Conditioning Humidity	50,00%
Start Temperature	25,00°C	Conditioning Time	300s

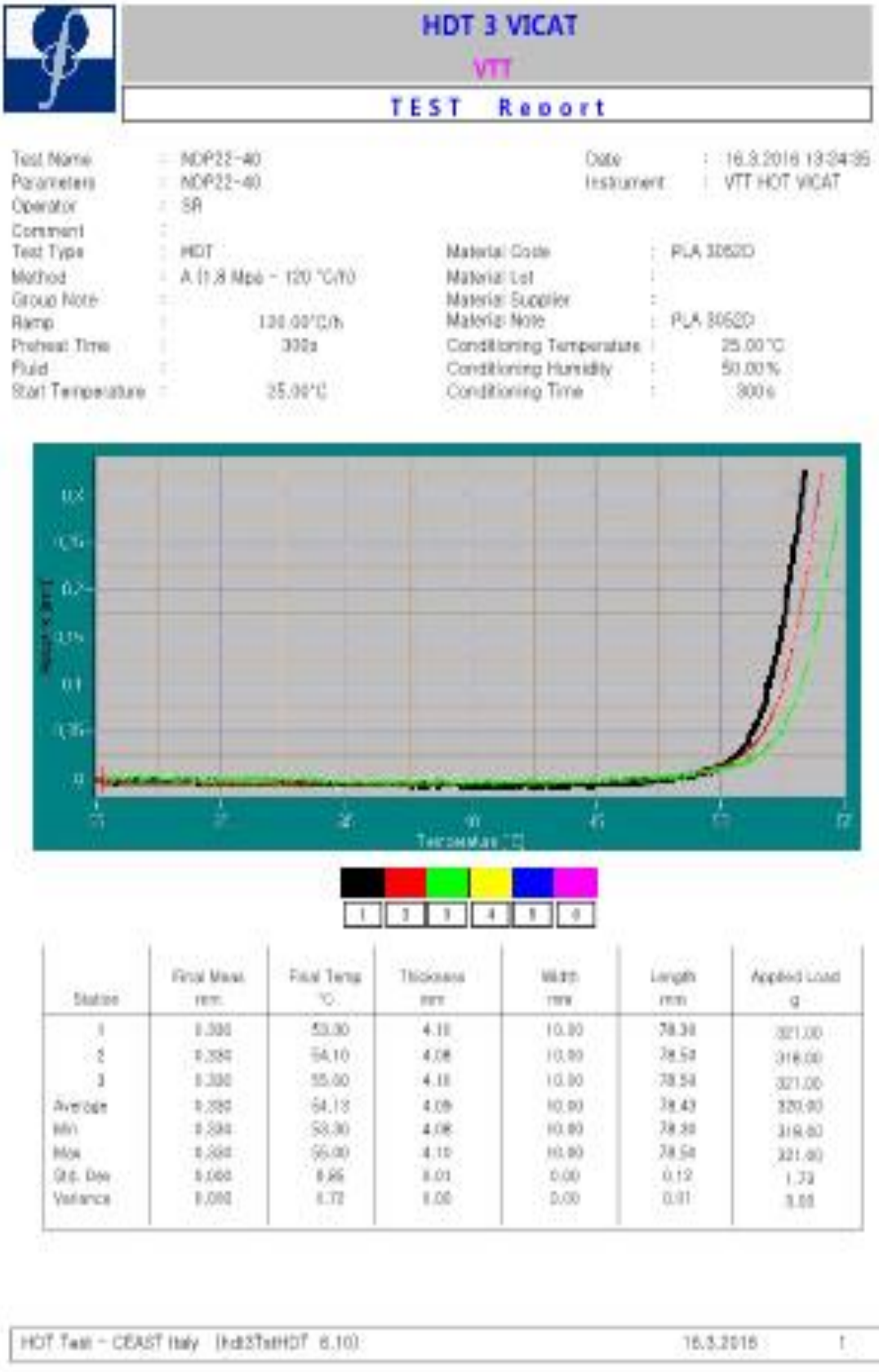
Station	Final Mass mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0,000	58,80	4,11	15,80	79,60	321,00
2	0,000	58,50	4,08	15,80	79,50	316,00
3	0,000	57,40	4,11	15,80	79,50	321,00
Average	0,000	58,23	4,09	15,80	79,55	320,00
Min	0,000	57,40	4,08	15,80	79,50	316,00
Max	0,000	58,80	4,11	15,80	79,60	321,00
Std. Dev	0,000	0,77	0,01	0,00	0,06	2,89
Variance	0,000	0,60	0,00	0,00	0,00	8,33

HDT Test – CEAST Italy IntelliTest-IDT 6.03 15.3.2016 1

PICTURE 67. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 40 % (2).



PICTURE 68. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 50 % (3).



HDT 3 VICAT

VTT

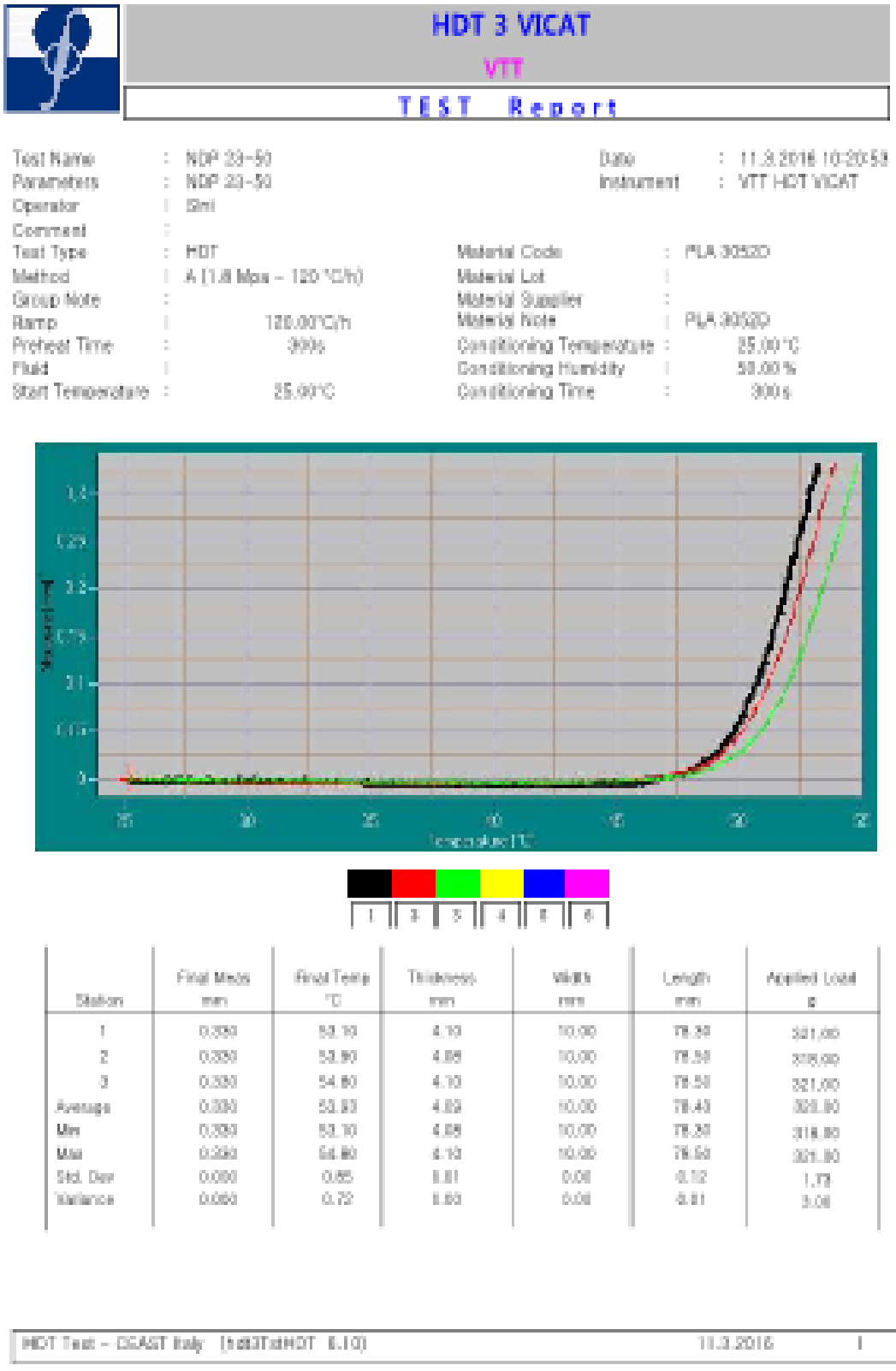
TEST Report

Test Name	NDP22-40	Date	16.3.2016 13:24:35
Parameters	NDP22-40	Instrument	VTT HDT VICAT
Operator	SR		
Comment			
Test Type	HDT	Material Code	PLA 3052D
Method	A (1,8 Mpa - 120 °C/h)	Material Lot	
Group Note		Material Supplier	
Ramp	120,00°C/h	Material Note	PLA 3052D
Preheat Time	300s	Conditioning Temperature	25,00°C
Fluid		Conditioning Humidity	50,00%
Start Temperature	25,00°C	Conditioning Time	900s

Station	Final Mean mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0,330	53,30	4,10	10,00	78,38	321,00
2	0,330	54,10	4,08	10,00	78,54	319,00
3	0,330	55,00	4,10	10,00	78,54	321,00
Average	0,330	54,13	4,09	10,00	78,49	320,00
Min	0,330	53,30	4,08	10,00	78,38	319,00
Max	0,330	55,00	4,10	10,00	78,54	321,00
Std. Dev	0,000	0,85	0,01	0,00	0,12	1,73
Variance	0,000	0,72	0,00	0,00	0,01	3,00

HDT Test - CEAST Italy [hdt3TestHDT 6.10] 16.3.2016 1

PICTURE 69. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 40% and additive ELO 5 % (4).



HDT 3 VICAT

VTT

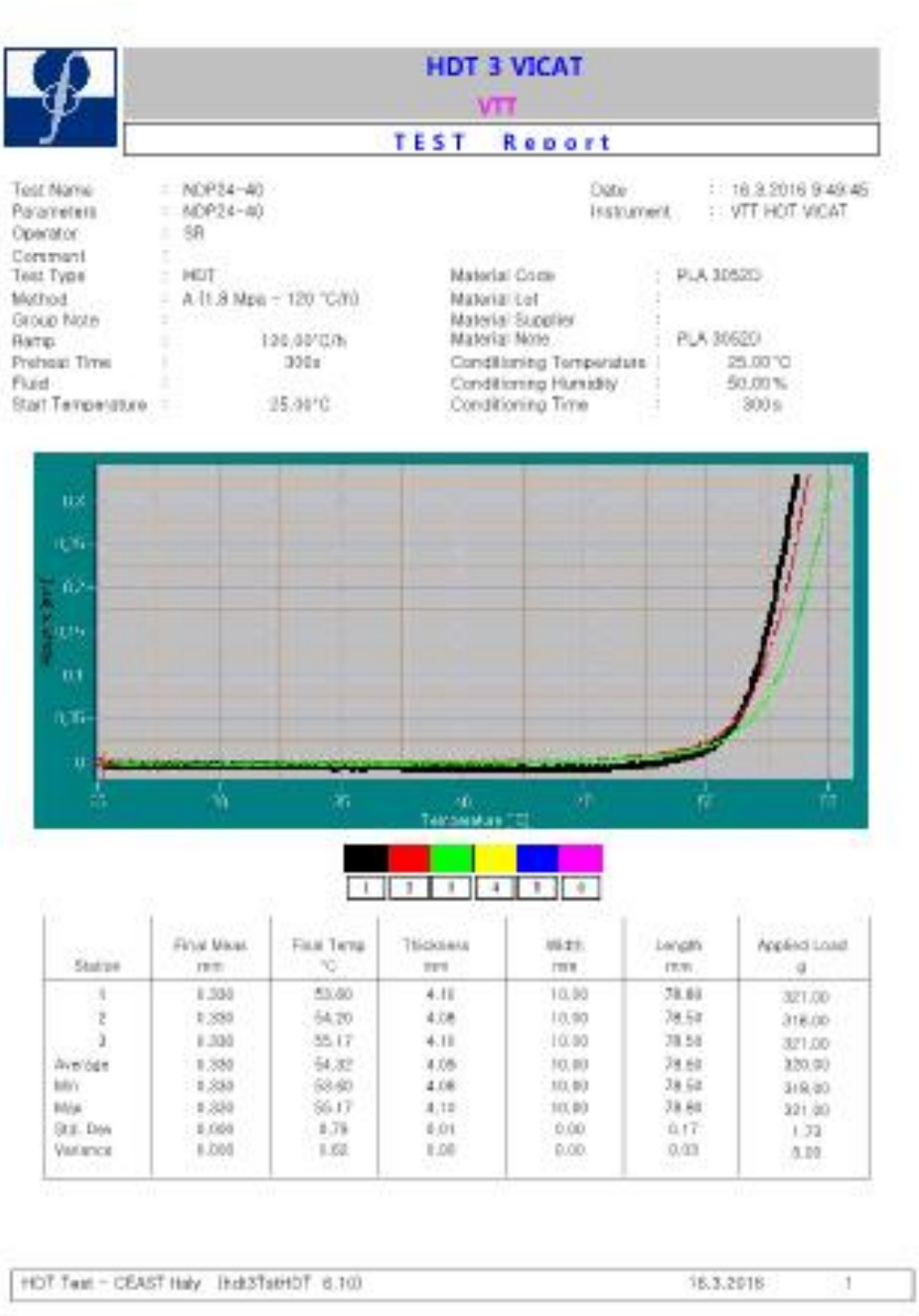
TEST Report

Test Name	: NDP 23-50		Date	: 11.3.2016 10:20:53	
Parameters	: NDP 23-50		Instrument	: VTT HDT VICAT	
Operator	: Sini				
Comment	:				
Test Type	: HDT		Material Code	: PLA 3052D	
Method	: A (1,8 Mpa – 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120,00°C/h		Material Note	: PLA 3052D	
Preheat Time	: 300s		Conditioning Temperature	: 25,00 °C	
Fluid	:		Conditioning Humidity	: 50,00 %	
Start Temperature	: 25,00°C		Conditioning Time	: 300 s	

Station	Final Meas. mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0,350	53,10	4,10	10,00	78,59	321,00
2	0,320	53,90	4,05	10,00	78,59	318,00
3	0,330	54,80	4,10	10,00	78,59	321,00
Average	0,330	53,93	4,08	10,00	78,43	320,00
Min	0,320	53,10	4,05	10,00	78,39	318,00
Max	0,350	54,80	4,10	10,00	78,59	321,00
Std. Dev	0,050	0,85	0,03	0,00	0,12	1,73
Variance	0,003	0,72	0,00	0,00	0,01	3,00

HDT Test – CEAST Italy [HDT Std HDT 6.10] 11.3.2016 1

PICTURE 70. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 50% and additive ELO 5 % (5).



HDT 3 VICAT

VTT

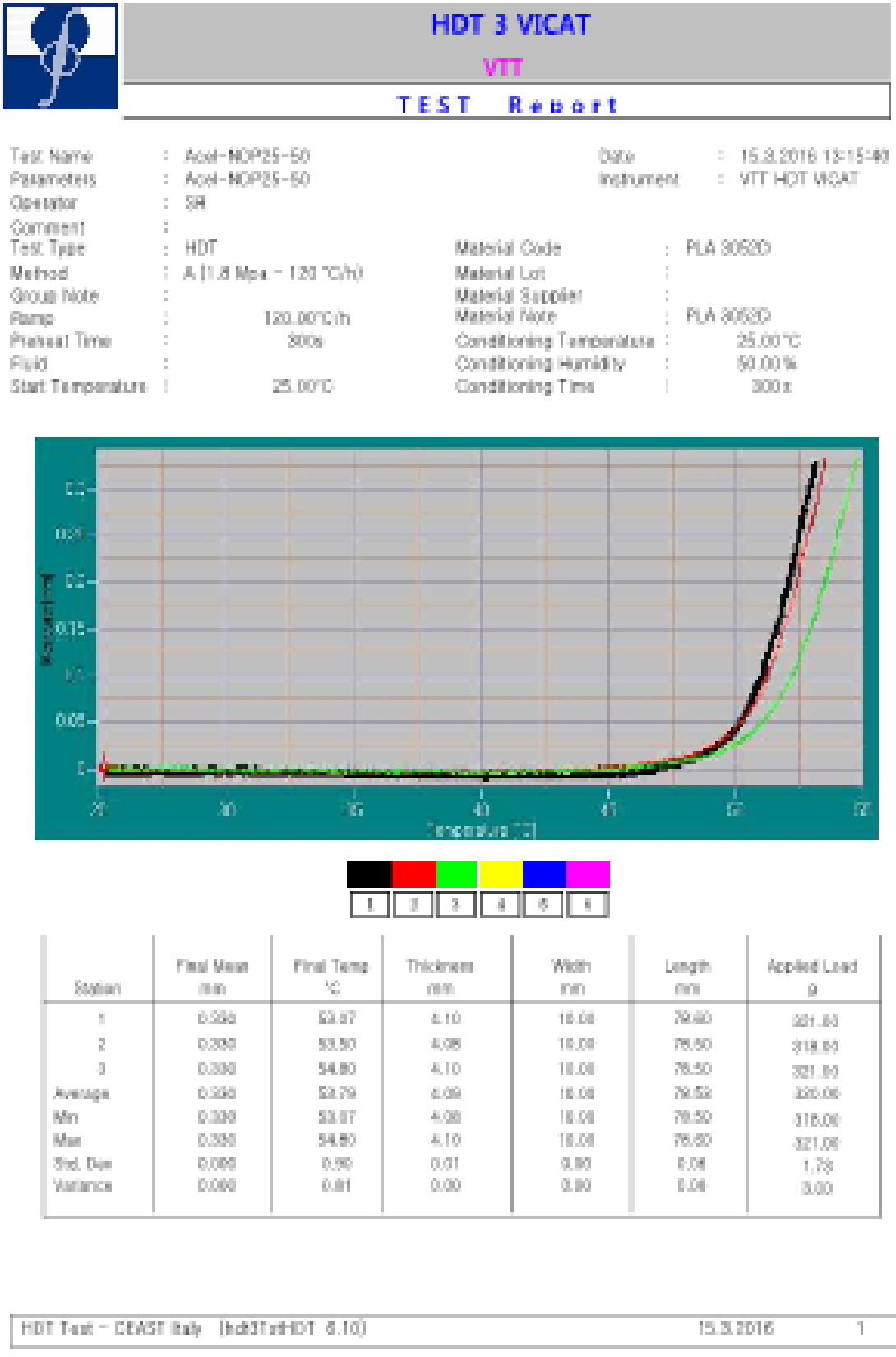
TEST Report

Test Name	: NDP34-40	Date	: 16.3.2016 9:49:45
Parameters	: NDP24-40	Instrument	: VTT HDT VICAT
Operator	: SR		
Comment	:		
Test Type	: HDT	Material Code	: PLA 3052D
Method	: A (1.8 Mpa - 120 °C/h)	Material Lot	:
Group Note	:	Material Supplier	:
Ramp	: 120.00°C/h	Material Note	: PLA 3052D
Preheat Time	: 300s	Conditioning Temperature	: 25.00°C
Fluid	:	Conditioning Humidity	: 50.00%
Start Temperature	: 25.00°C	Conditioning Time	: 300s

Station	Final Meas. mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.330	53.60	4.10	10.90	78.69	321.00
2	0.350	54.20	4.08	10.90	78.54	316.00
3	0.330	55.17	4.10	10.90	78.58	321.00
Average	0.337	54.32	4.09	10.90	78.60	319.00
Min	0.330	53.60	4.08	10.90	78.54	316.00
Max	0.350	55.17	4.10	10.90	78.69	321.00
Std. Dev	0.009	0.79	0.01	0.00	0.17	1.73
Variance	0.000	0.62	0.00	0.00	0.03	3.00

HDT Test - CEAST Italy (hdt3TstHDT 6.10) 16.3.2016 1

PICTURE 71. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 40% and additive sorbitol derivative 5 % (6).



HDT 3 VICAT

VTT

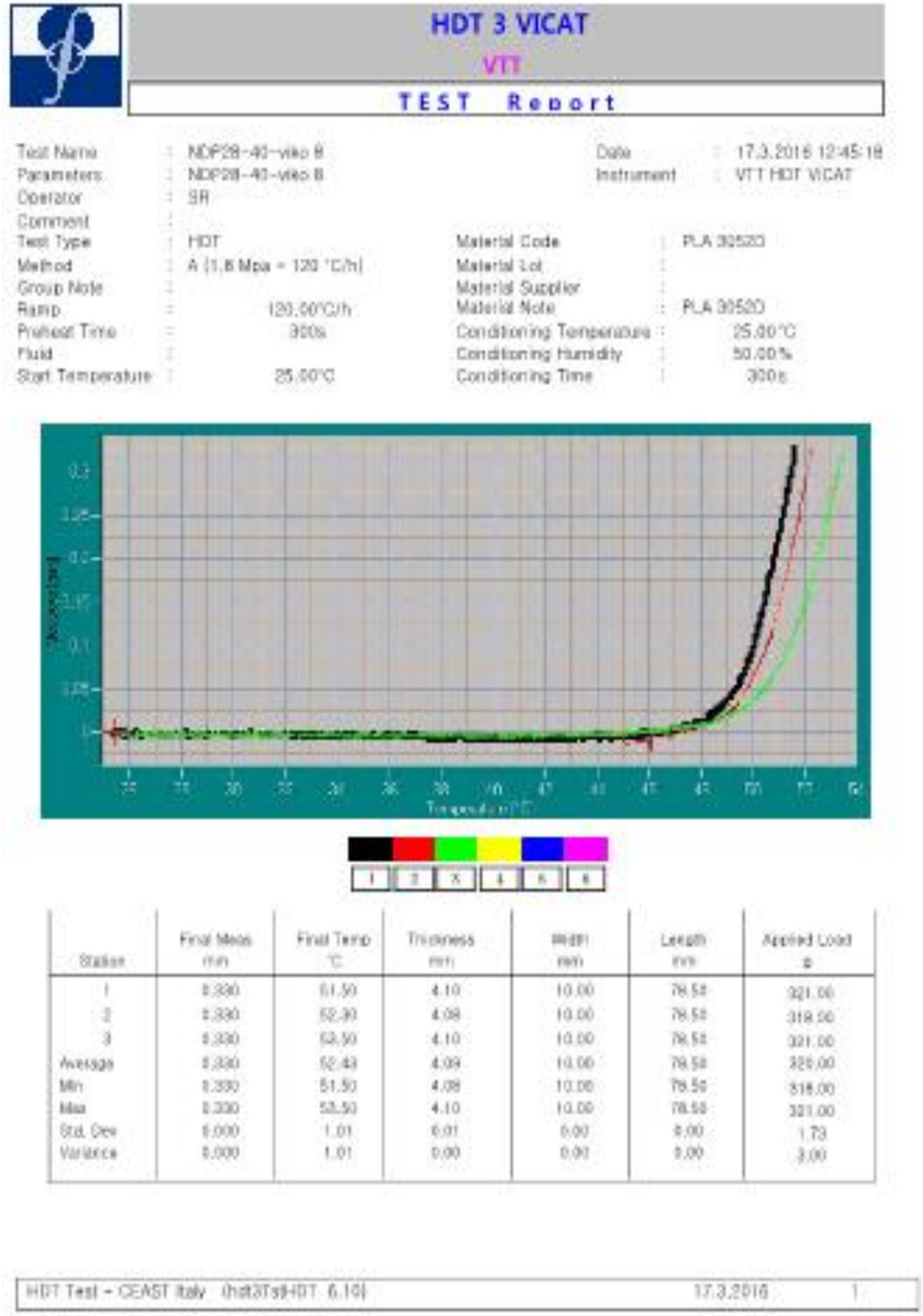
TEST Report

Test Name	: Acet-NDP25-50		Date	: 15.3.2016 12:15:40	
Parameters	: Acet-NDP25-50		Instrument	: VTT HDT VICAT	
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	: PLA 3052D	
Method	: A (1,8 Mpa - 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120,00°C/h		Material Note	: PLA 3052D	
Preheat Time	: 300s		Conditioning Temperature	: 25,00 °C	
Fluid	:		Conditioning Humidity	: 50,00 %	
Start Temperature	: 25,00°C		Conditioning Time	: 300 s	

Station	Final Mean mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0,350	53,87	4,10	10,00	79,60	321,00
2	0,350	53,50	4,09	10,00	79,50	318,00
3	0,350	54,80	4,10	10,00	79,50	321,00
Average	0,350	52,79	4,09	10,00	79,52	320,00
Min	0,350	53,87	4,08	10,00	79,50	318,00
Max	0,350	54,80	4,10	10,00	79,60	321,00
Std. Dev	0,000	0,70	0,01	0,00	0,06	1,73
Variance	0,000	0,81	0,00	0,00	0,00	3,00

HDT Test - CEAST Italy (hdt3TestHDT 6.10) 15.3.2016 1

PICTURE 72. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 50% and additive sorbitol derivative 5 % (7).



HDT 3 VICAT

VTT

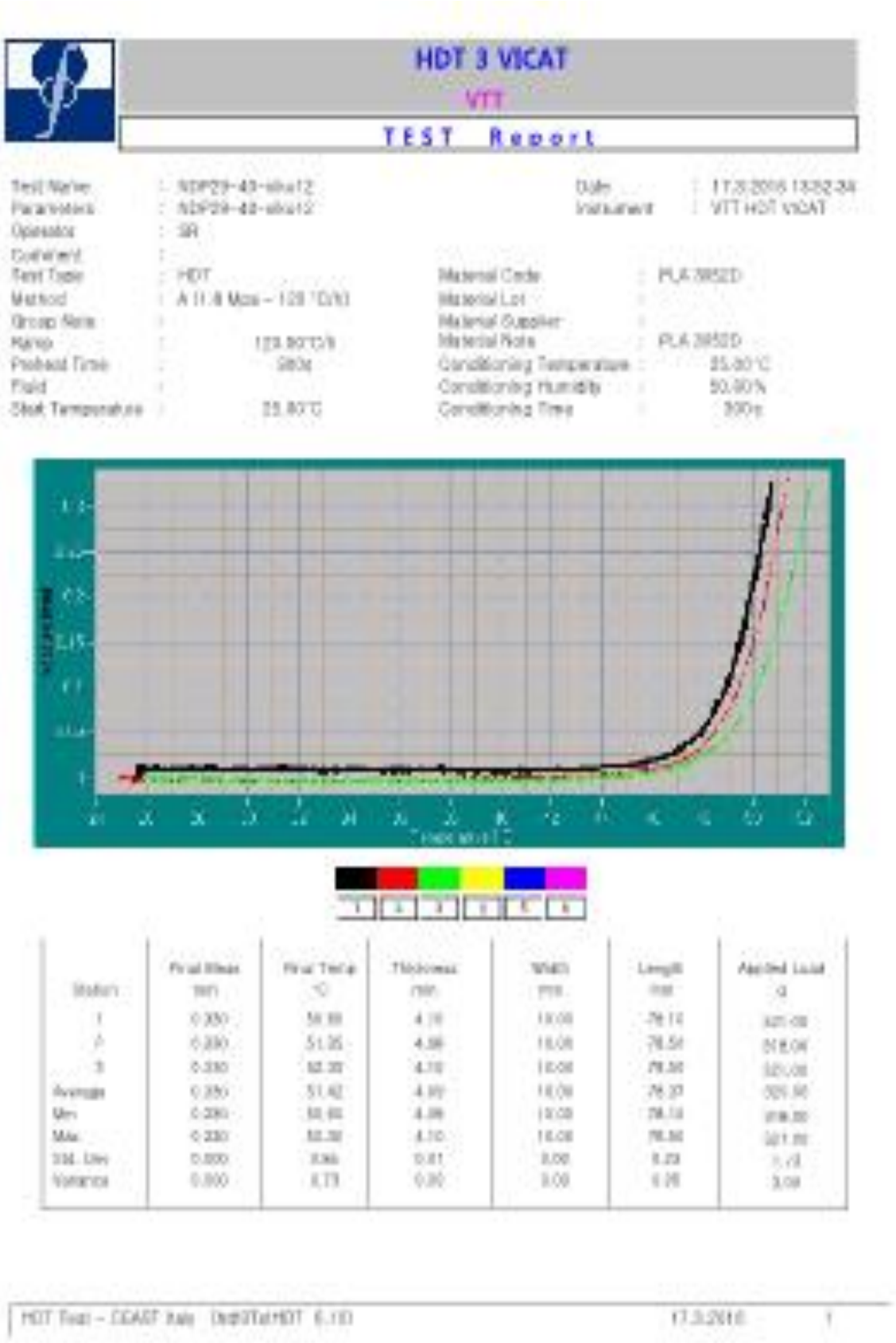
TEST Report

Test Name	: NDP28-40-viko 8		Date	:	17.3.2016 12:45:18
Parameters	: NDP28-40-viko 8		Instrument	:	VTT HDT VICAT
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	:	PLA 3052D
Method	: A (1,8 Mpa = 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120,00°C/h		Material Note	:	PLA 3052D
Preheat Time	: 300s		Conditioning Temperature	:	25,00 °C
Fluid	:		Conditioning Humidity	:	50,00 %
Start Temperature	: 25,00°C		Conditioning Time	:	300s

Station	Final Meas mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0,330	51,50	4,10	10,00	78,50	321,00
2	0,330	52,30	4,09	10,00	78,50	319,00
3	0,330	53,50	4,10	10,00	78,50	321,00
Average	0,330	52,43	4,09	10,00	78,50	320,00
Min	0,330	51,50	4,09	10,00	78,50	319,00
Max	0,330	53,50	4,10	10,00	78,50	321,00
Std. Dev	0,000	1,01	0,01	0,00	0,00	1,73
Variance	0,000	1,01	0,00	0,00	0,00	3,00

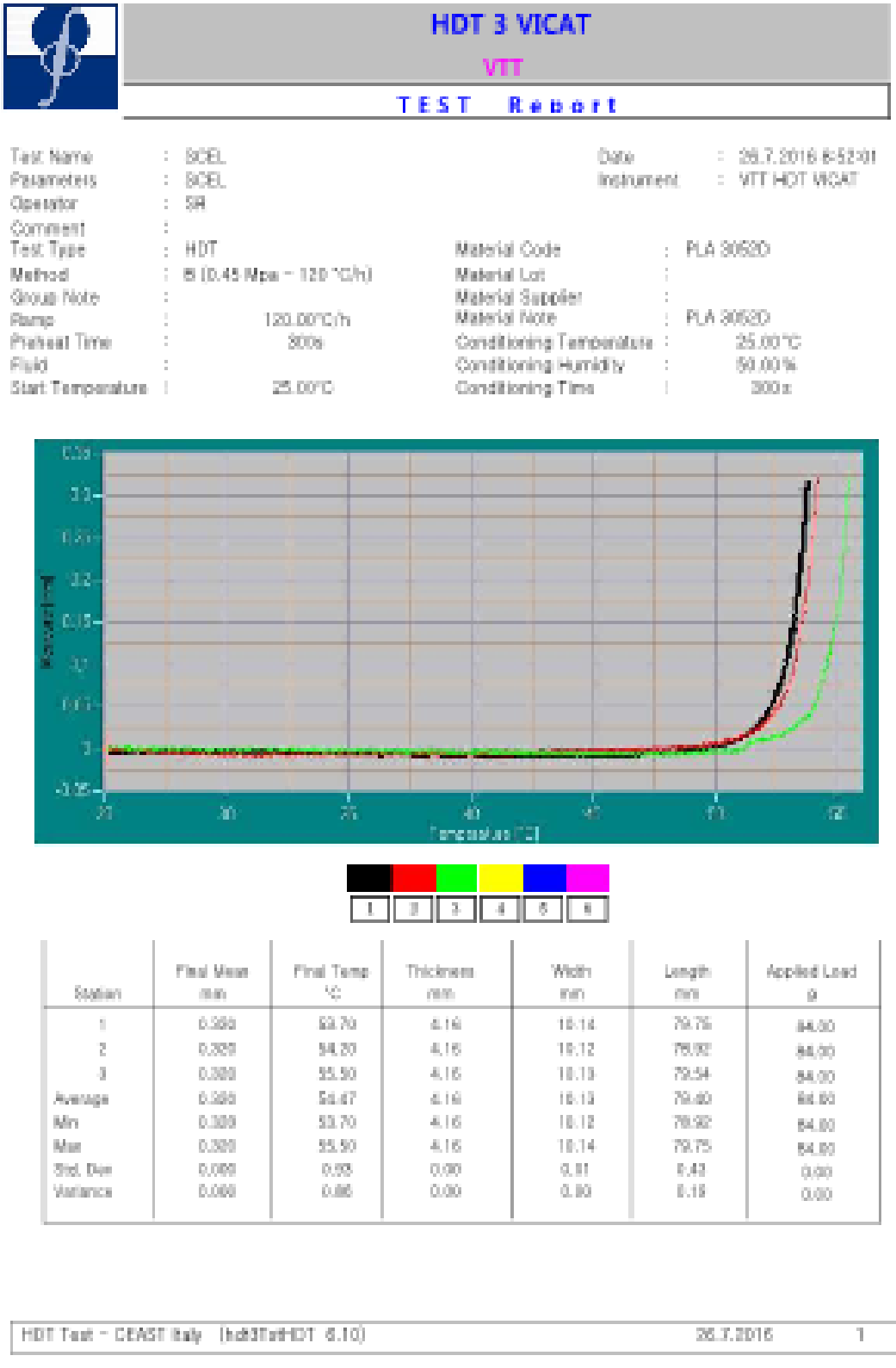
HDT Test - CEAST Italy (hdt3Ts9-HDT 6.10) 17.3.2016 1

PICTURE 73. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 40% and additive ELO 8 % (8).



PICTURE 74. HDT test results by method A (1,80 MPa), PLA -NDP composite with fibre content 40% and additive ELO 12 % (9).

Appendix 8. HDT by method B (0,45 MPa), PLA and NDP (1-9)



HDT 3 VICAT

VTT

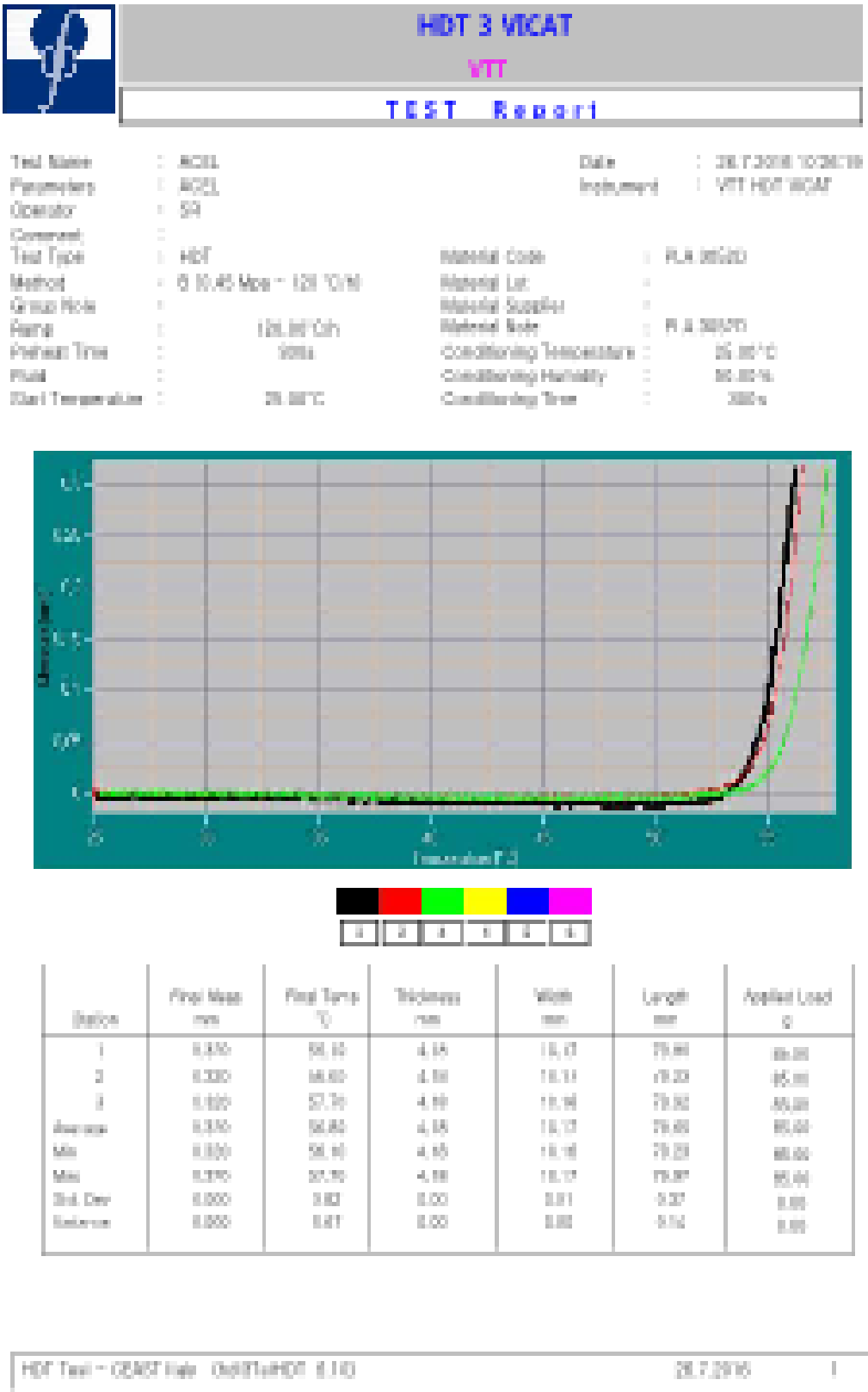
TEST Report

Test Name	: SIDEL		Date	: 26.7.2016 8:52:01	
Parameters	: SIDEL		Instrument	: VTT HDT VICAT	
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	: PLA 3052D	
Method	: B (0.45 Mpa - 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120.00°C/h		Material Note	: PLA 3052D	
Preheat Time	: 300s		Conditioning Temperature	: 25.00°C	
Fluid	:		Conditioning Humidity	: 50.00%	
Start Temperature	: 25.00°C		Conditioning Time	: 300s	

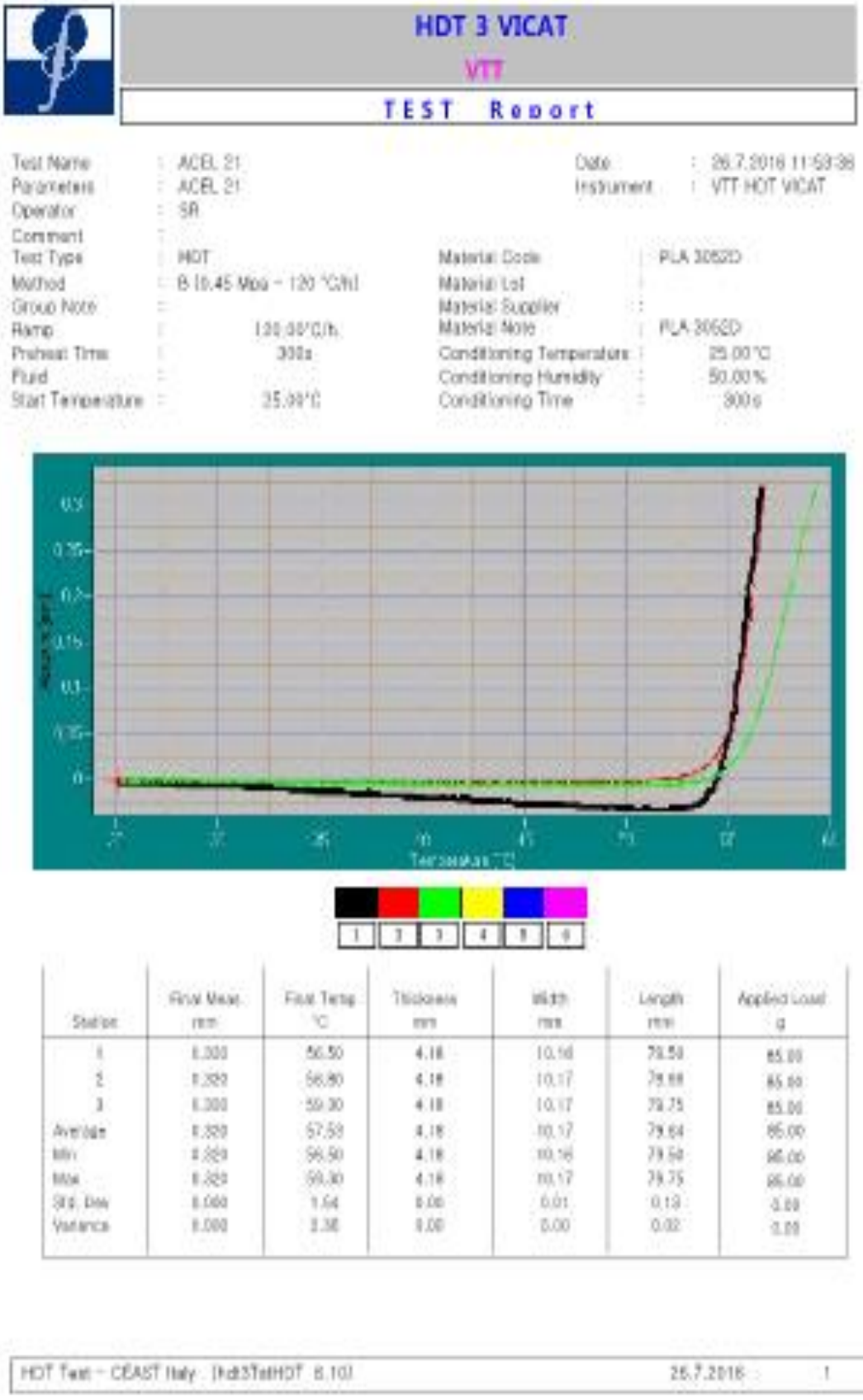
Station	Final Mean mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.320	53.70	4.16	10.14	79.76	84.00
2	0.320	54.20	4.16	10.12	79.80	84.00
3	0.320	55.50	4.16	10.13	79.84	84.00
Average	0.320	54.47	4.16	10.13	79.80	84.00
Min	0.320	53.70	4.16	10.12	79.80	84.00
Max	0.320	55.50	4.16	10.14	79.75	84.00
Std. Dev	0.000	0.05	0.00	0.01	0.42	0.00
Variance	0.000	0.00	0.00	0.00	0.18	0.00

HDT Test - CEAST Italy (hdt3TestHDT 6.10) 26.7.2016 1

PICTURE 75. HDT test results by method B (0,45 MPa), PLA 3052D (1).



PICTURE 76. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 40 % (2).



HDT 3 VICAT

VTT

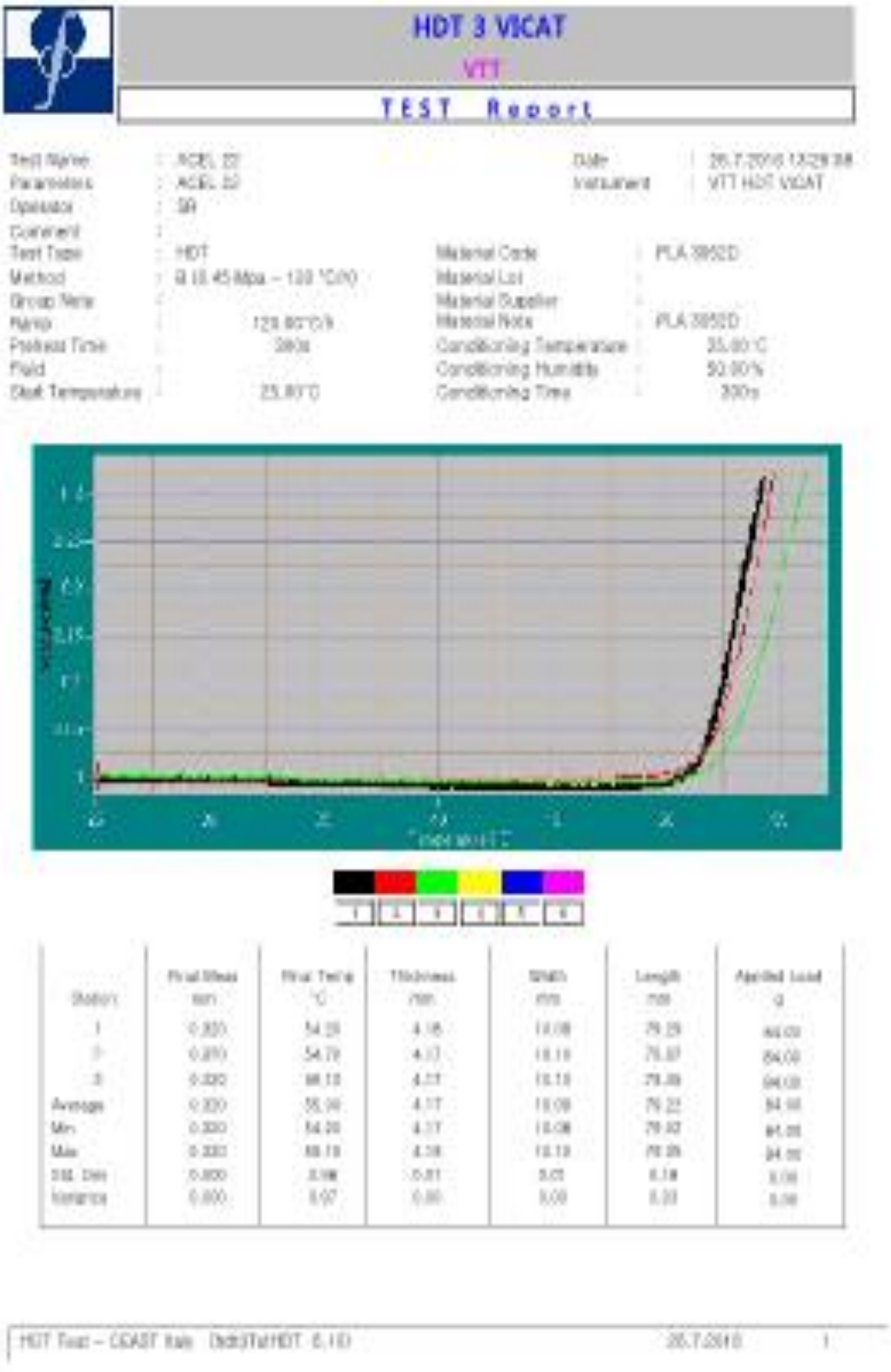
TEST Report

Test Name	: ACEL 21	Date	: 26.7.2016 11:53:38
Parameters	: ACEL 21	Instrument	: VTT HDT VICAT
Operator	: SR		
Comment	:		
Test Type	: HDT	Material Code	: PLA 3052D
Method	: B (0.45 Mpa - 120 °C/h)	Material Lot	:
Group Note	:	Material Supplier	:
Ramp	: 120.00°C/h	Material Note	: PLA 3052D
Preheat Time	: 300s	Conditioning Temperature	: 25.00°C
Fluid	:	Conditioning Humidity	: 50.00%
Start Temperature	: 35.00°C	Conditioning Time	: 900s

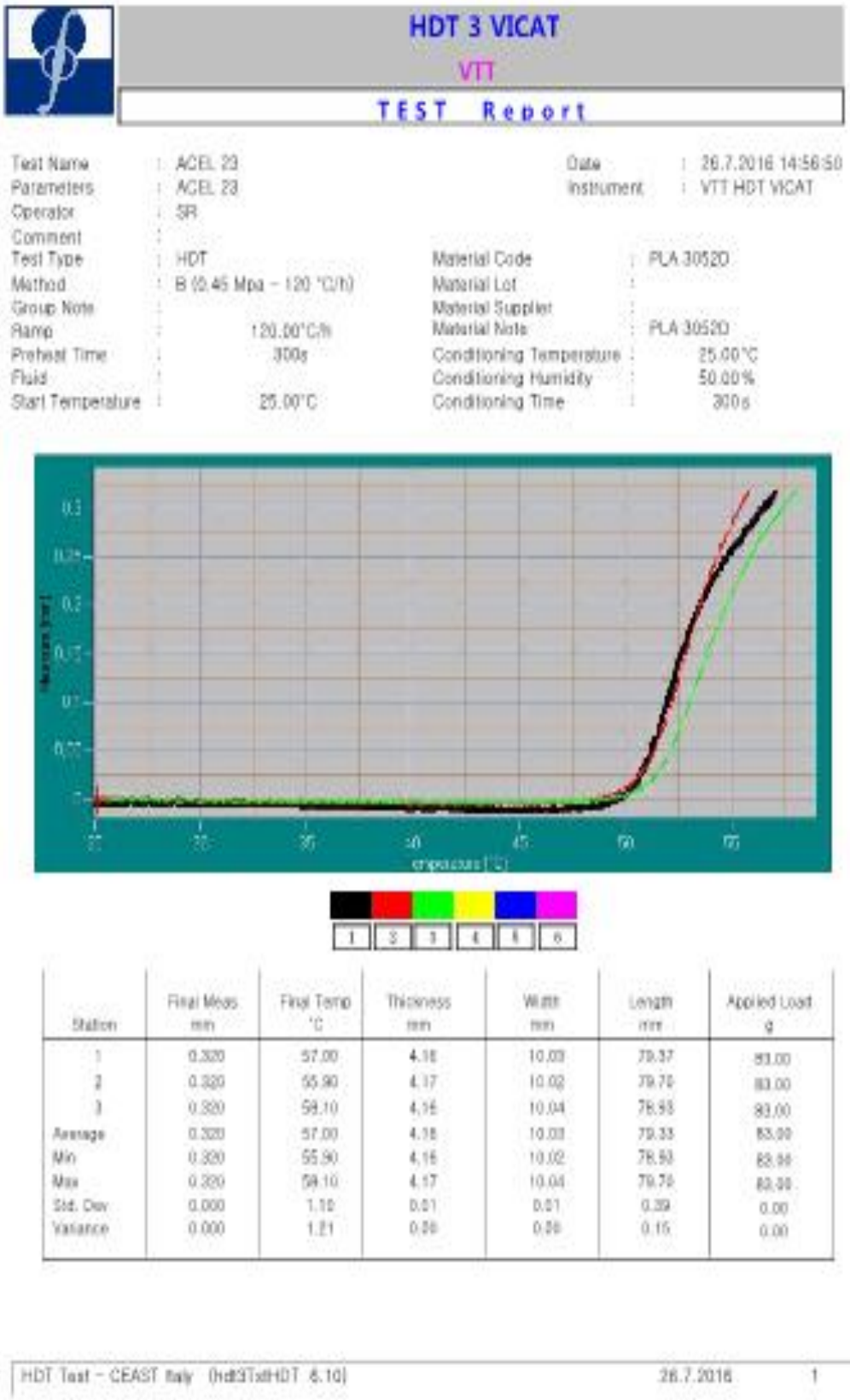
Station	Final Meas. mm	Final Temp. °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.000	56.50	4.18	10.16	79.58	65.00
2	0.000	56.80	4.18	10.17	79.68	65.00
3	0.000	59.30	4.18	10.17	79.75	65.00
Average	0.000	57.53	4.18	10.17	79.64	65.00
Min	0.000	56.50	4.18	10.16	79.58	65.00
Max	0.000	59.30	4.18	10.17	79.75	65.00
Std. Dev.	0.000	1.64	0.00	0.01	0.13	0.00
Variance	0.000	2.68	0.00	0.00	0.02	0.00

HDT Test - CEAST Italy [hdt3TestHDT 6.10] 26.7.2016 1

PICTURE 77. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 50 % (3).



PICTURE 78. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 40% and additive ELO 5 % (4).



HDT 3 VICAT

VTT

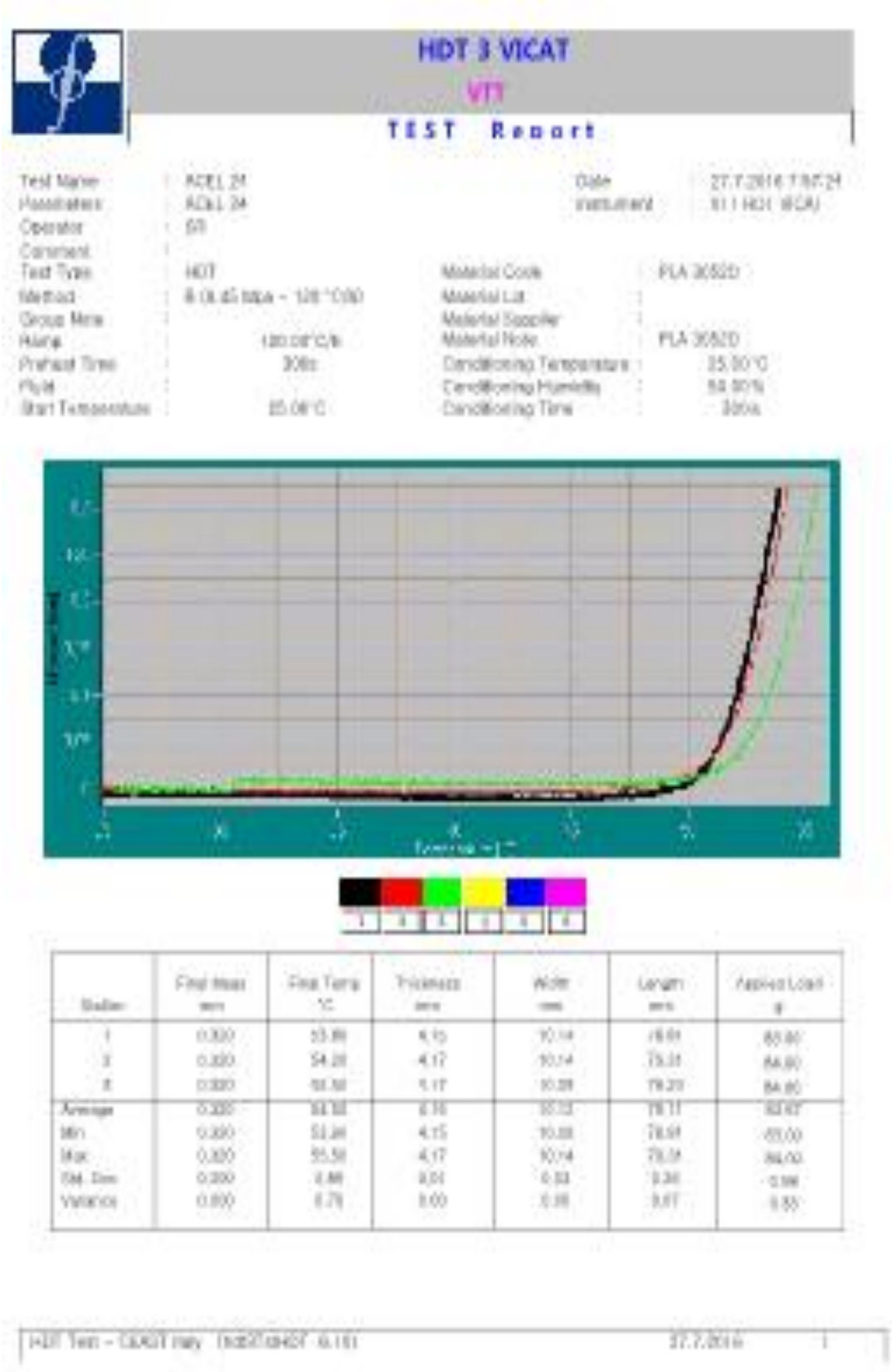
TEST Report

Test Name	: ACEL 23		Date	:	26.7.2016 14:56:50
Parameters	: ACEL 23		Instrument	:	VTT HDT VICAT
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	:	PLA 3052D
Method	: B (0.45 Mpa – 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120.00°C/h		Material Note	:	PLA 3052D
Preheat Time	: 300s		Conditioning Temperature	:	25.00°C
Fluid	:		Conditioning Humidity	:	50.00%
Start Temperature	: 25.00°C		Conditioning Time	:	300s

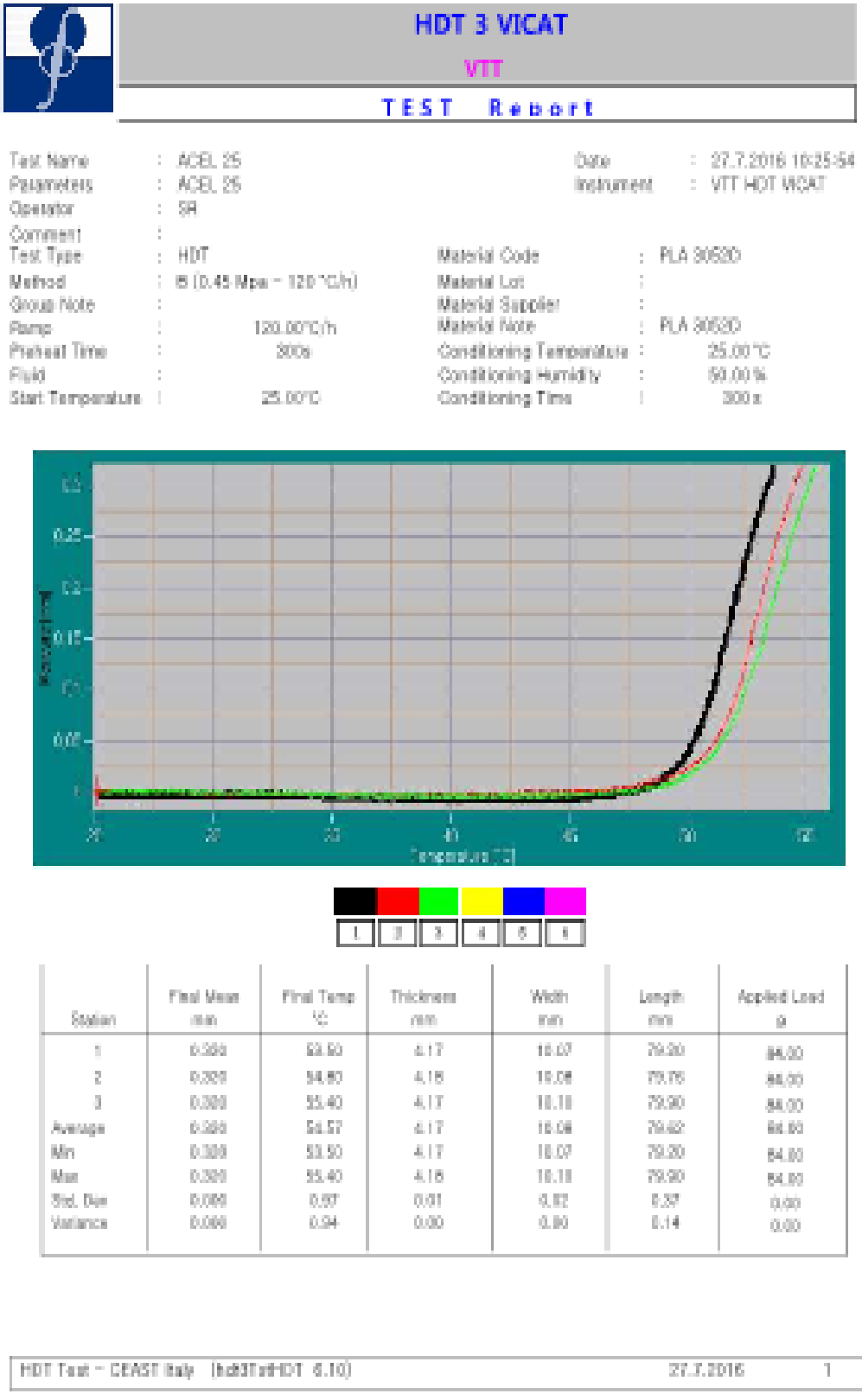
Station	Final Meas mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.320	57.00	4.16	10.03	79.37	83.00
2	0.320	55.90	4.17	10.02	79.70	83.00
3	0.320	59.10	4.16	10.04	78.93	83.00
Average	0.320	57.00	4.16	10.03	79.33	83.00
Min	0.320	55.90	4.16	10.02	78.93	83.00
Max	0.320	59.10	4.17	10.04	79.70	83.00
Std. Dev	0.000	1.10	0.01	0.01	0.39	0.00
Variance	0.000	1.21	0.00	0.00	0.15	0.00

HDT Test – CEAST Italy (hdt3TstHDT 6.10) 26.7.2016 1

PICTURE 79. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 50% and additive ELO 5 % (5).



PICTURE 80. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 40% and additive sorbitol derivative 5 % (6).



HDT 3 VICAT

VTT

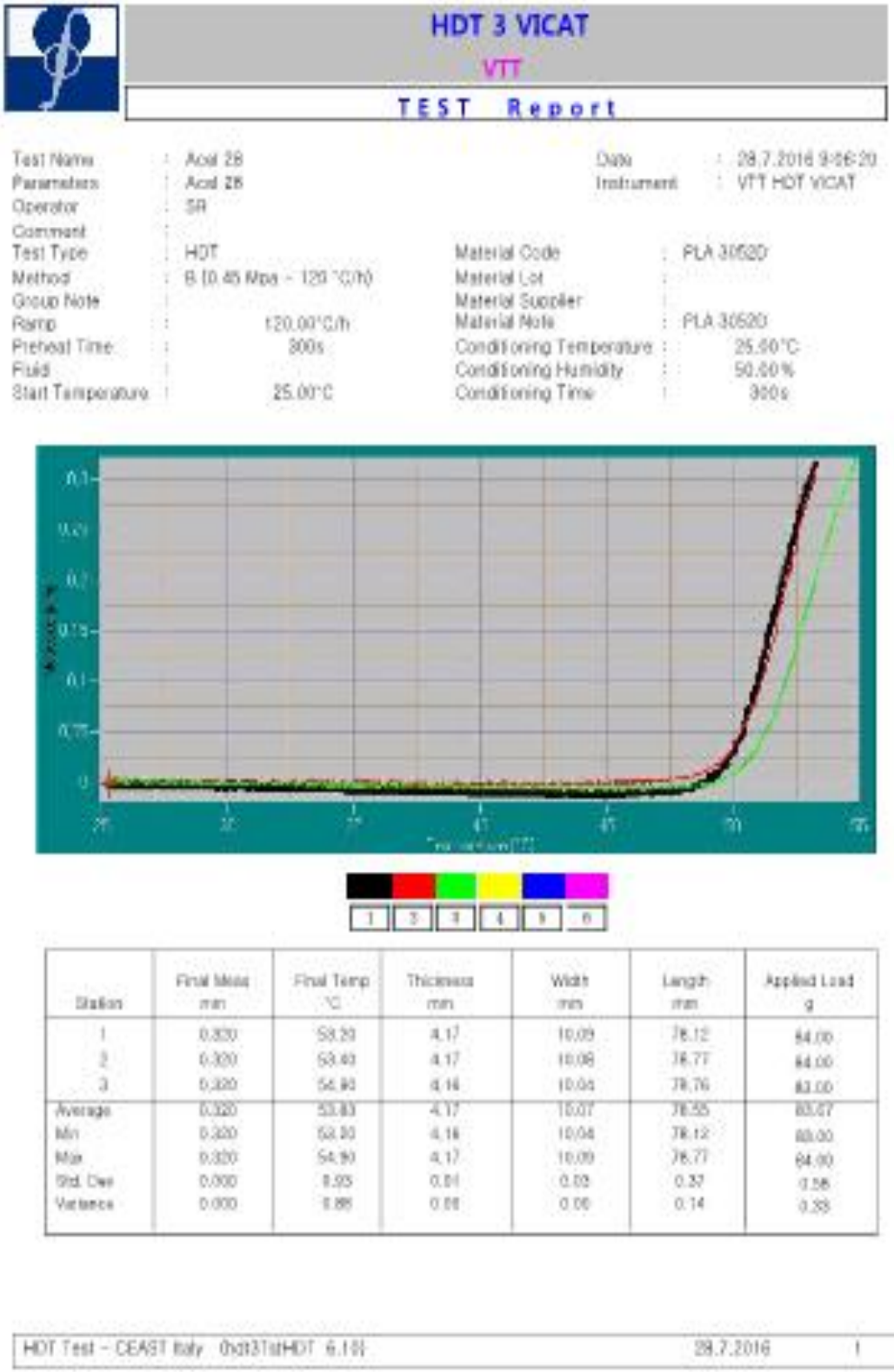
TEST Report

Test Name	: ACEL 25		Date	:	27.7.2016 10:25:54
Parameters	: ACEL 25		Instrument	:	VTT HDT VICAT
Operator	: SR				
Comment	:				
Test Type	: HDT	Material Code	:	PLA 30520	
Method	: B (0.45 Mpa – 120 °C/h)	Material Lot	:		
Group Note	:	Material Supplier	:		
Ramp	: 120.00°C/h	Material Note	:	PLA 30520	
Preheat Time	: 300s	Conditioning Temperature	:	25.00 °C	
Fluid	:	Conditioning Humidity	:	50.00 %	
Start Temperature	: 25.00°C	Conditioning Time	:	300 s	

Station	Final Mean mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.320	53.50	4.17	10.07	79.20	84.00
2	0.320	54.80	4.16	10.08	79.75	84.00
3	0.320	55.40	4.17	10.10	79.90	84.00
Average	0.320	54.57	4.17	10.08	79.62	84.00
Min	0.320	53.50	4.17	10.07	79.20	84.00
Max	0.320	55.40	4.16	10.10	79.90	84.00
Std. Dev	0.000	0.97	0.01	0.02	0.37	0.00
Variance	0.000	0.94	0.00	0.00	0.14	0.00

HDT Test – CEAST Italy (hdt3Tst-HDT 6.10) 27.7.2016 1

PICTURE 81. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 50% and additive sorbitol derivative 5 % (7).



HDT 3 VICAT

VTT

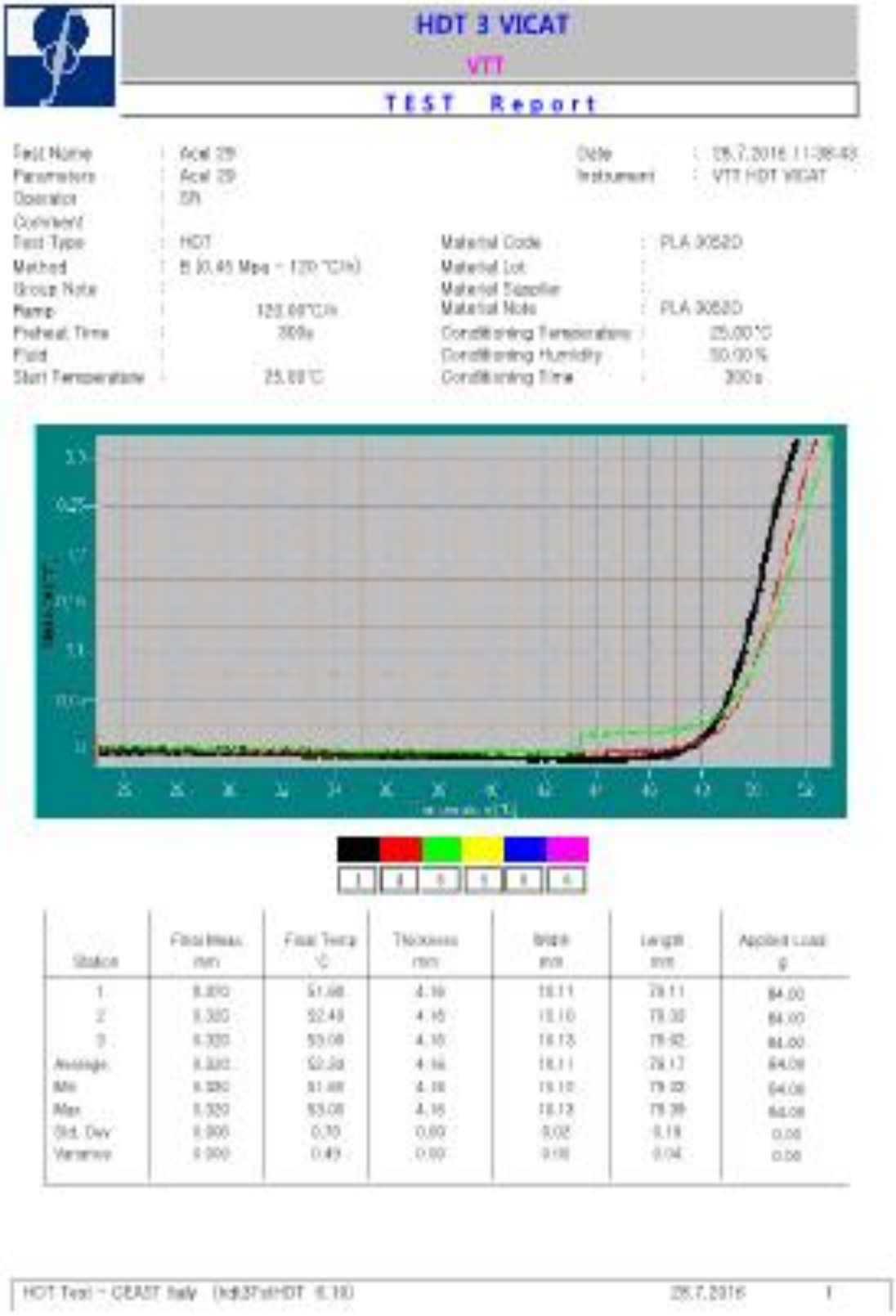
TEST Report

Test Name	: Acid 2B		Date	: 28.7.2016 9:56:20	
Parameters	: Acid 2B		Instrument	: VTT HDT VICAT	
Operator	: SR				
Comment	:				
Test Type	: HDT		Material Code	: PLA 3052D	
Method	: B (0.45 Mpa - 120 °C/h)		Material Lot	:	
Group Note	:		Material Supplier	:	
Ramp	: 120.00°C/h		Material Note	: PLA 3052D	
Preheat Time	: 300s		Conditioning Temperature	: 25.50°C	
Fluid	:		Conditioning Humidity	: 50.50%	
Start Temperature	: 25.00°C		Conditioning Time	: 300s	

Station	Final Mass mm	Final Temp °C	Thickness mm	Width mm	Length mm	Applied Load g
1	0.320	53.20	4.17	10.09	78.12	64.00
2	0.320	53.40	4.17	10.06	78.77	64.00
3	0.320	54.90	4.16	10.04	78.76	63.00
Average	0.320	53.83	4.17	10.07	78.55	63.67
Min	0.320	53.20	4.16	10.04	78.12	63.00
Max	0.320	54.90	4.17	10.09	78.77	64.00
Std. Dev	0.000	0.95	0.01	0.02	0.37	0.58
Variance	0.000	0.89	0.00	0.00	0.14	0.33

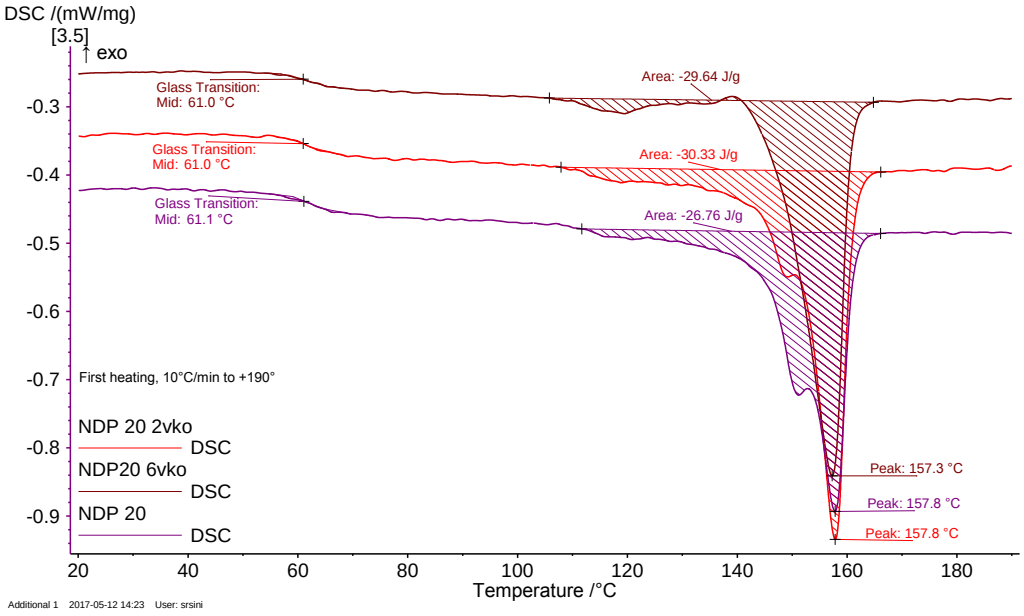
HDT Test - CEAST Italy 0hdt3TstHDT 6.10 28.7.2016 1

PICTURE 82. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 40% and additive ELO 8 % (8).

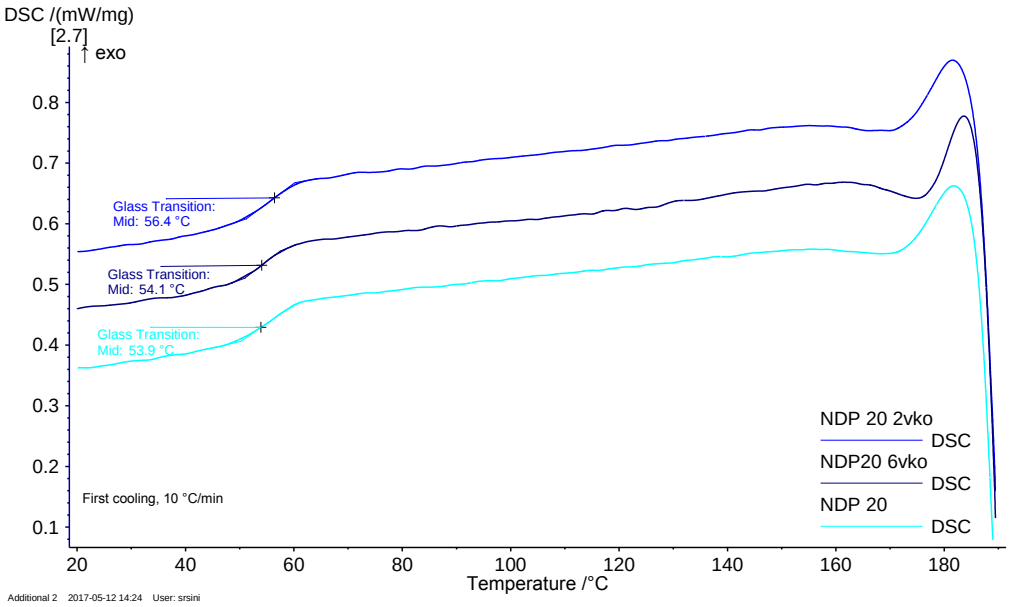


PICTURE 83. HDT test results by method B (0,45 MPa), PLA -NDP composite with fibre content 40% and additive ELO 12 % (12).

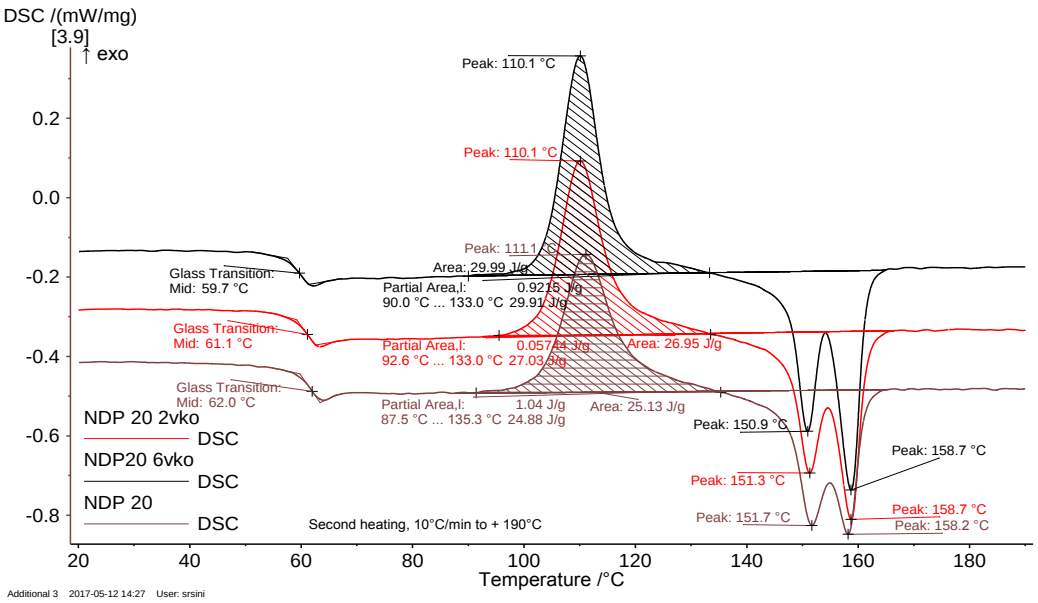
Appendix 9. NDP series, DSC sample graphs.



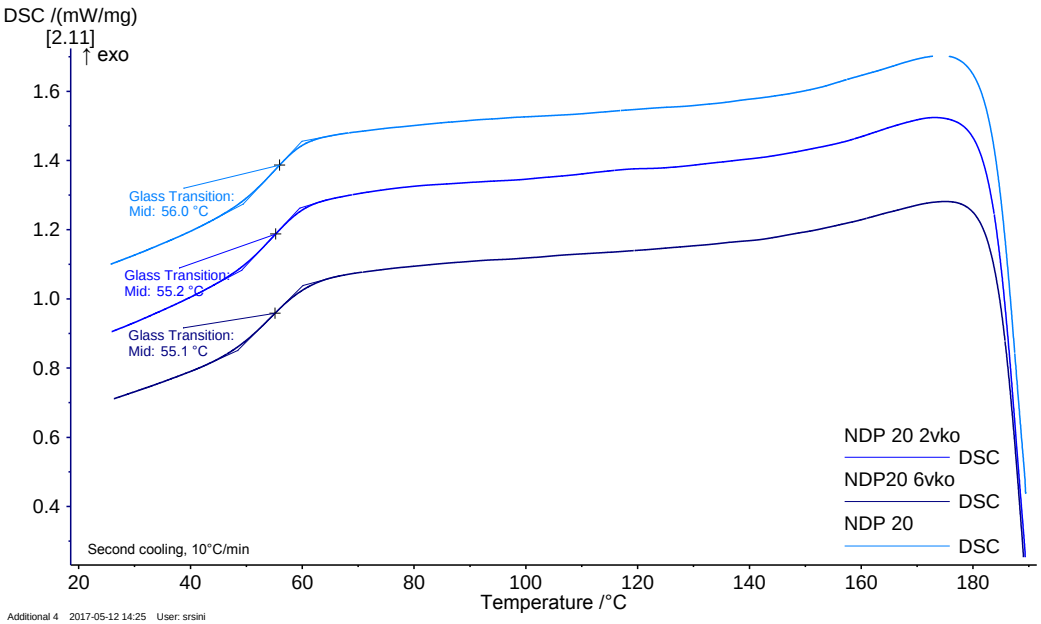
PICTURE 84. NDP 40 % cellulose original sample, two weeks exposed sample and six week exposed sample. First heating time obtained by the differential scanning calorimetry.



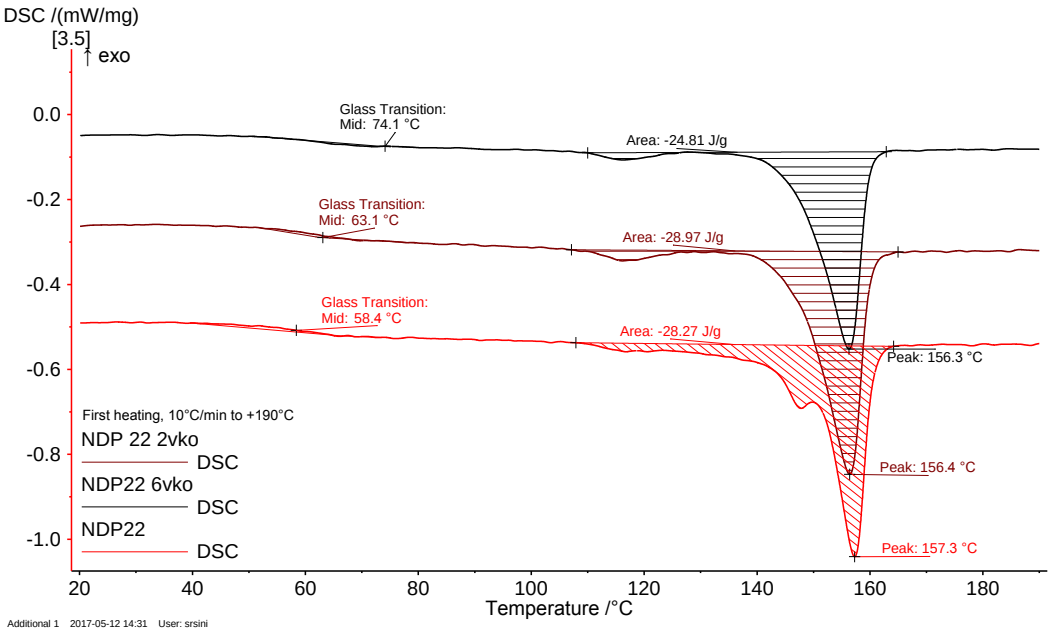
PICTURE 85. NDP 40 % cellulose original sample, two weeks exposed sample and six week exposed sample. First cooling time obtained by the differential scanning calorimetry.



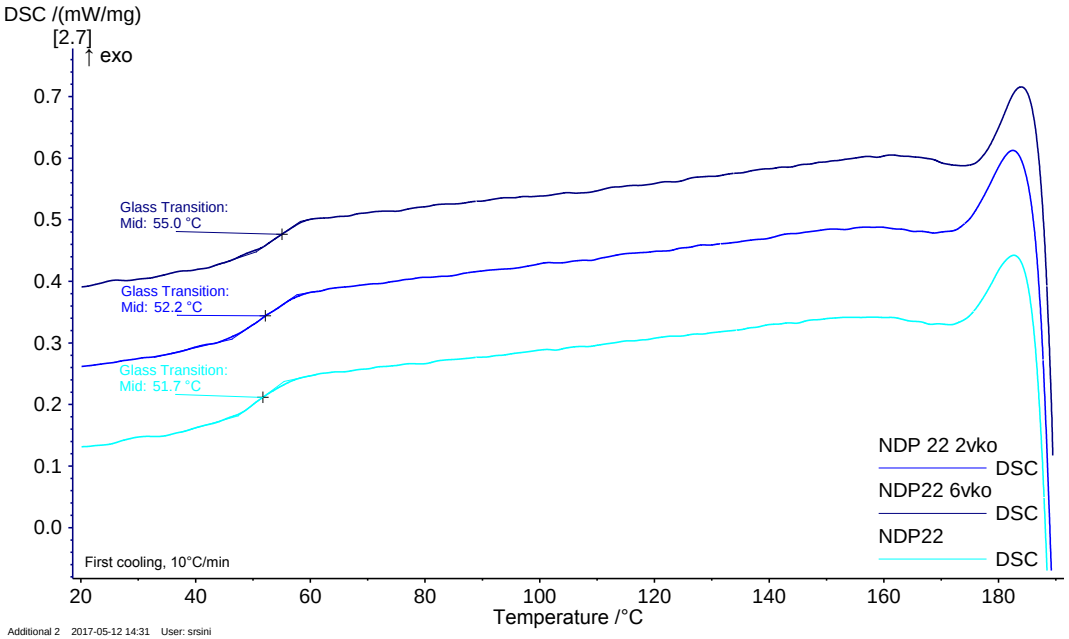
PICTURE 86. NDP 40 % cellulose original sample, two weeks exposed sample and six week exposed sample. Second heating time obtained by the differential scanning calorimetry.



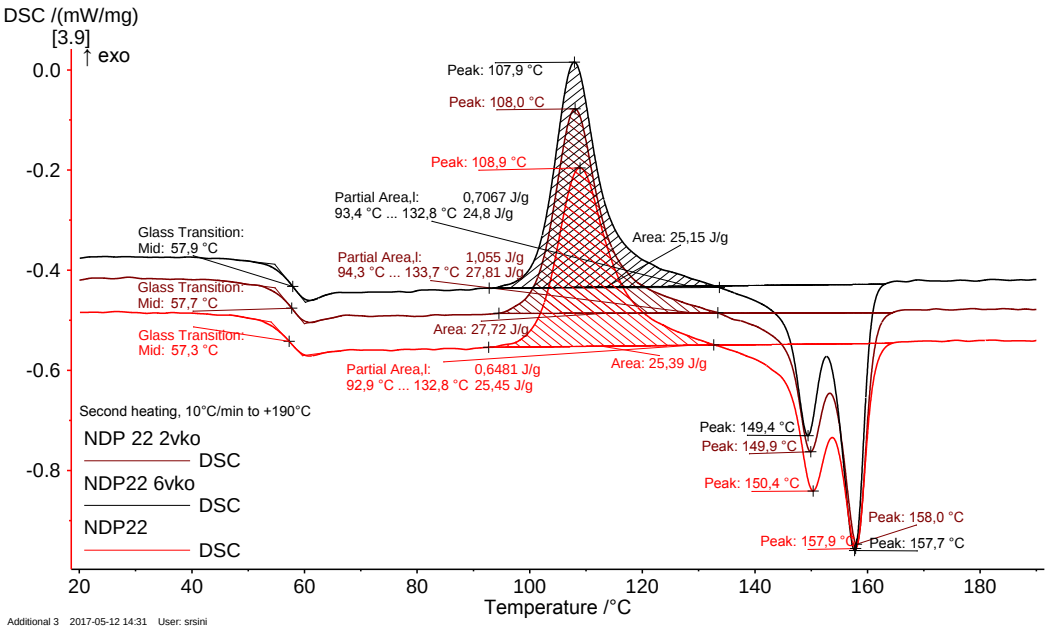
PICTURE 87. NDP 40 % cellulose original sample, two weeks exposed sample and six week exposed sample. Second cooling time obtained by the differential scanning calorimetry.



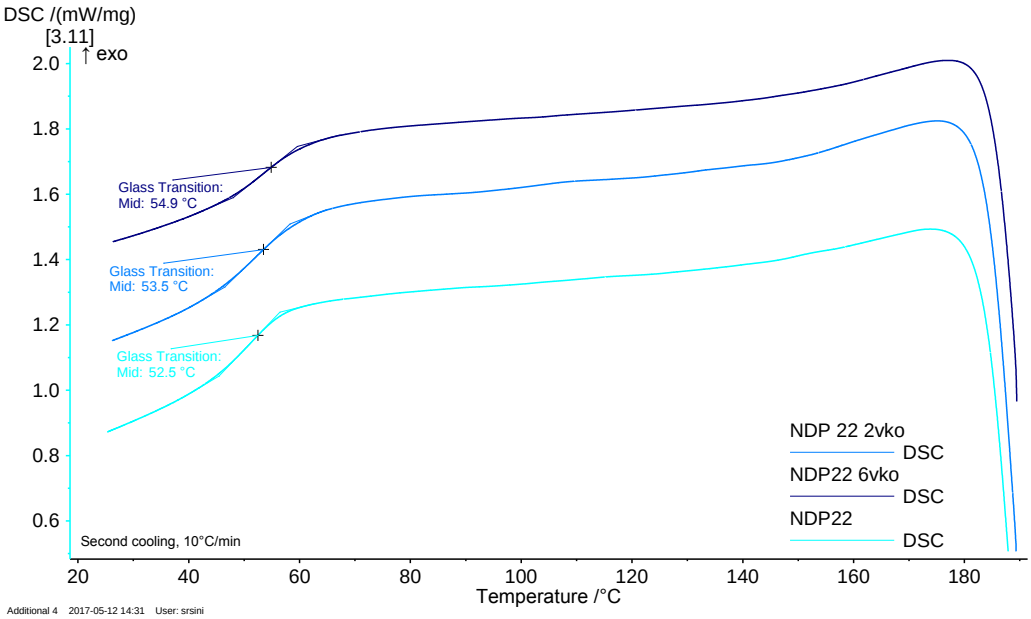
PICTURE 88. NDP 40 % cellulose + epox 5 % original sample, two weeks exposed sample and six week exposed sample. First heating time obtained by the differential scanning calorimetry.



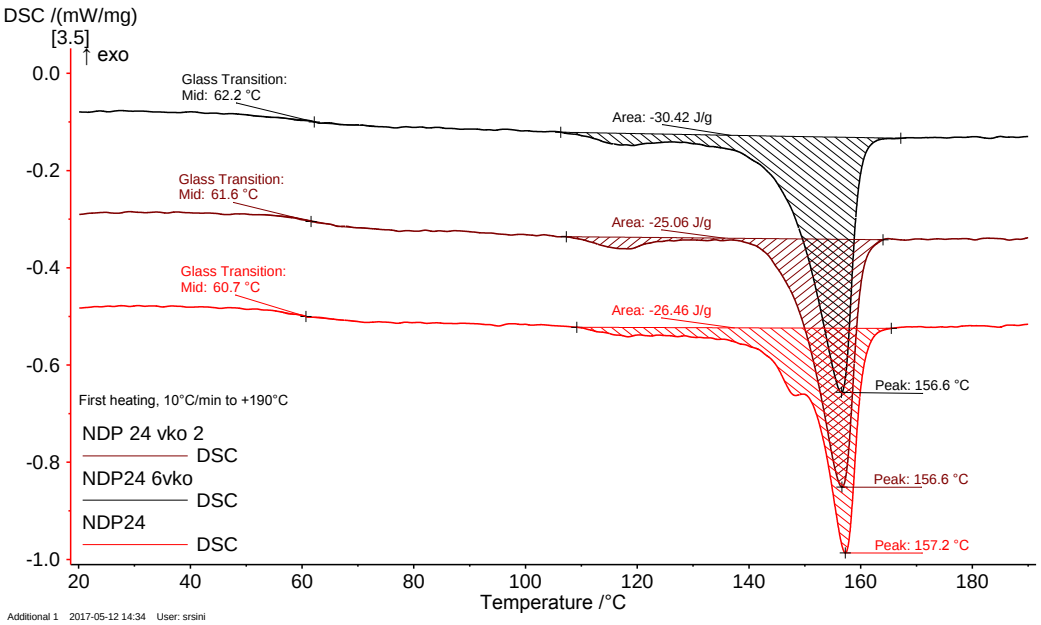
PICTURE 89. NDP 40 % cellulose + epox 5 % original sample, two weeks exposed sample and six week exposed sample. First cooling time obtained by the differential scanning calorimetry.



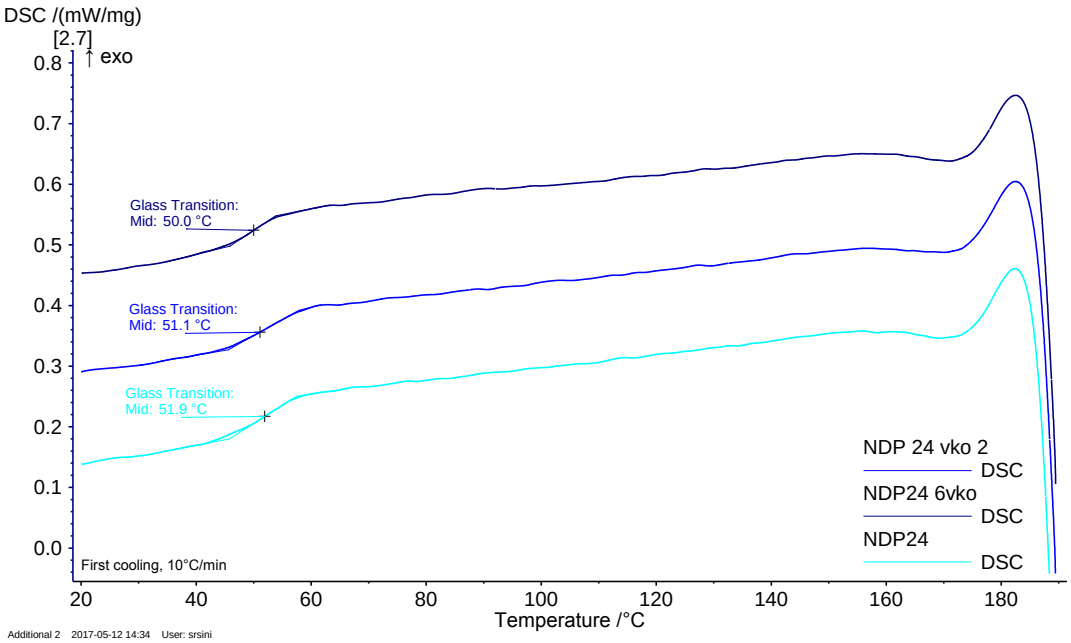
PICTURE 90. NDP 40 % cellulose + epox 5 % original sample, two weeks exposed sample and six week exposed sample. Second heating time obtained by the differential scanning calorimetry.



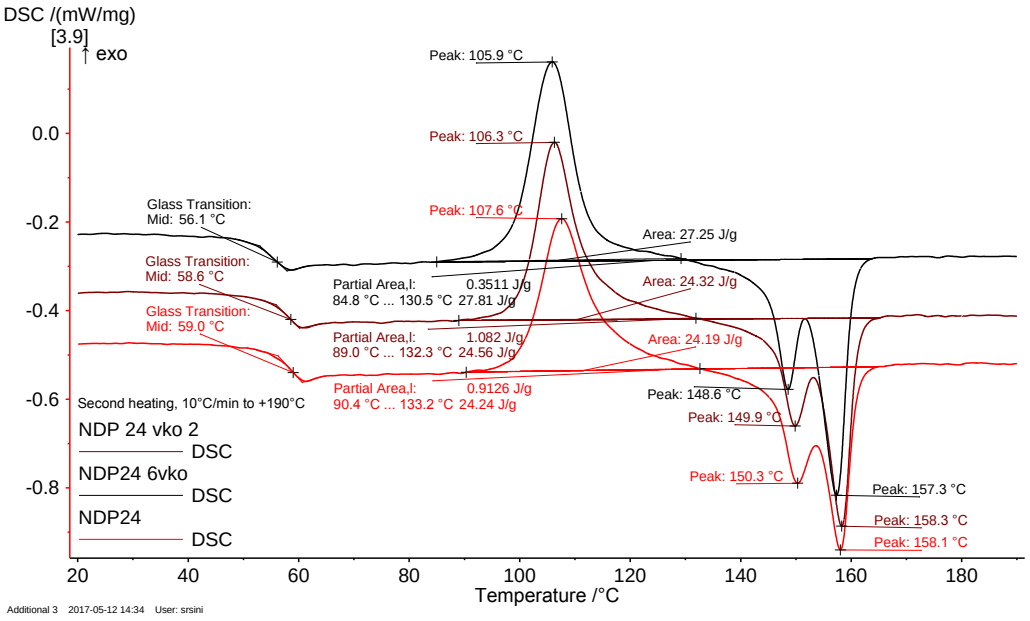
PICTURE 91. NDP 40 % cellulose + epox 5 % original sample, two weeks exposed sample and six week exposed sample. Second cooling time obtained by the differential scanning calorimetry.



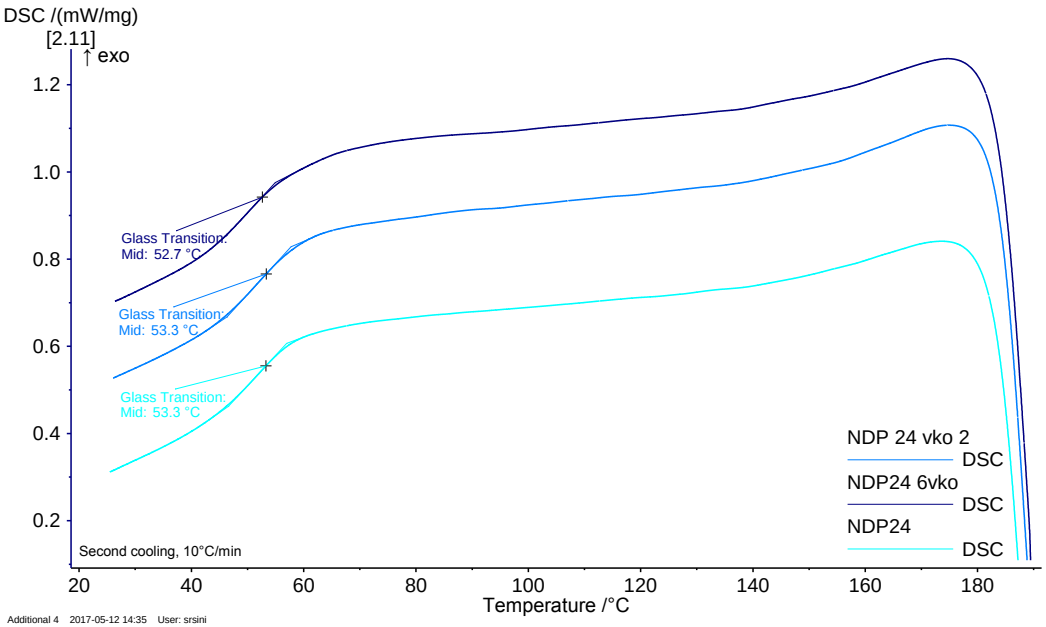
PICTURE 92. NDP 40 % cellulose +sorbitol 5 % original sample, two weeks exposed sample and six week exposed sample. First heating time obtained by the differential scanning calorimetry.



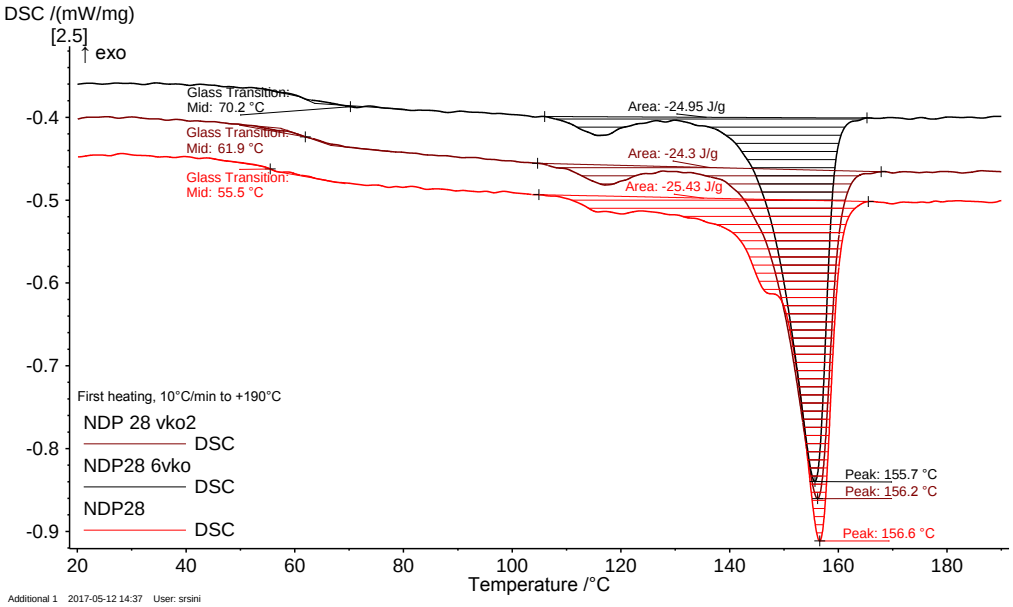
PICTURE 93. NDP 40 % cellulose +sorbitol 5 % original sample, two weeks exposed sample and six week exposed sample. First cooling time obtained by the differential scanning calorimetry.



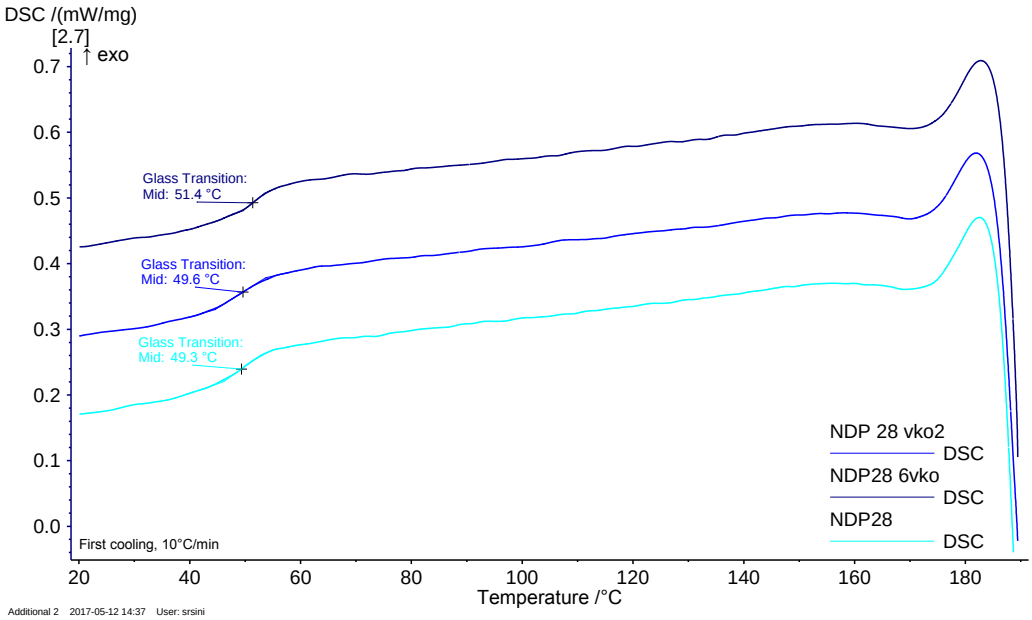
PICTURE 94. NDP 40 % cellulose +sorbitol 5 % original sample, two weeks exposed sample and six week exposed sample. Second heating time obtained by the differential scanning calorimetry.



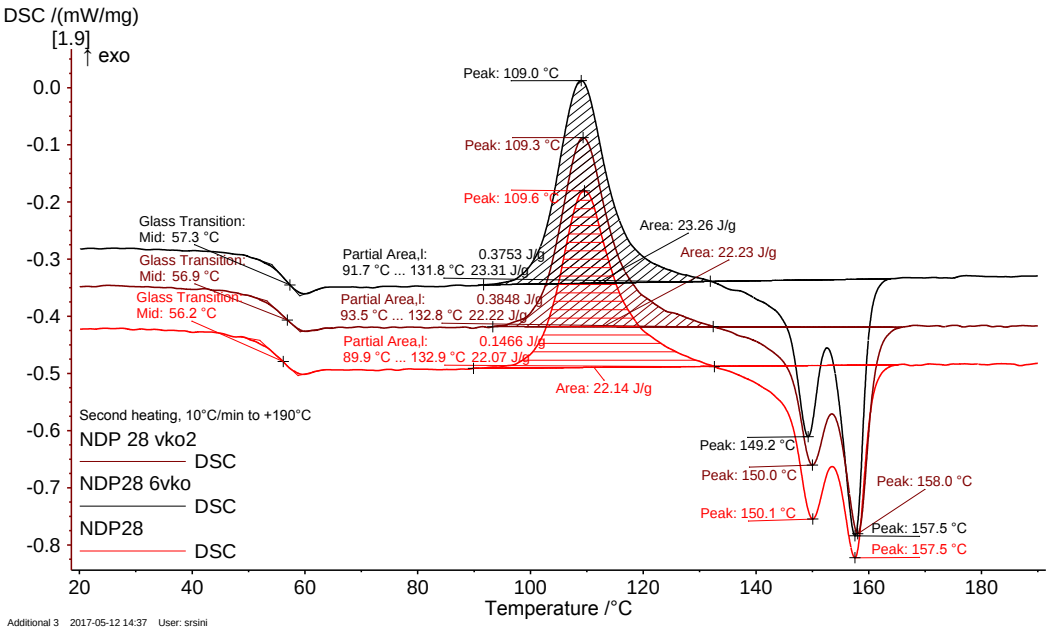
PICTURE 95. NDP 40 % cellulose +sorbitol 5 % original sample, two weeks exposed sample and six week exposed sample. Second cooling time obtained by the differential scanning calorimetry.



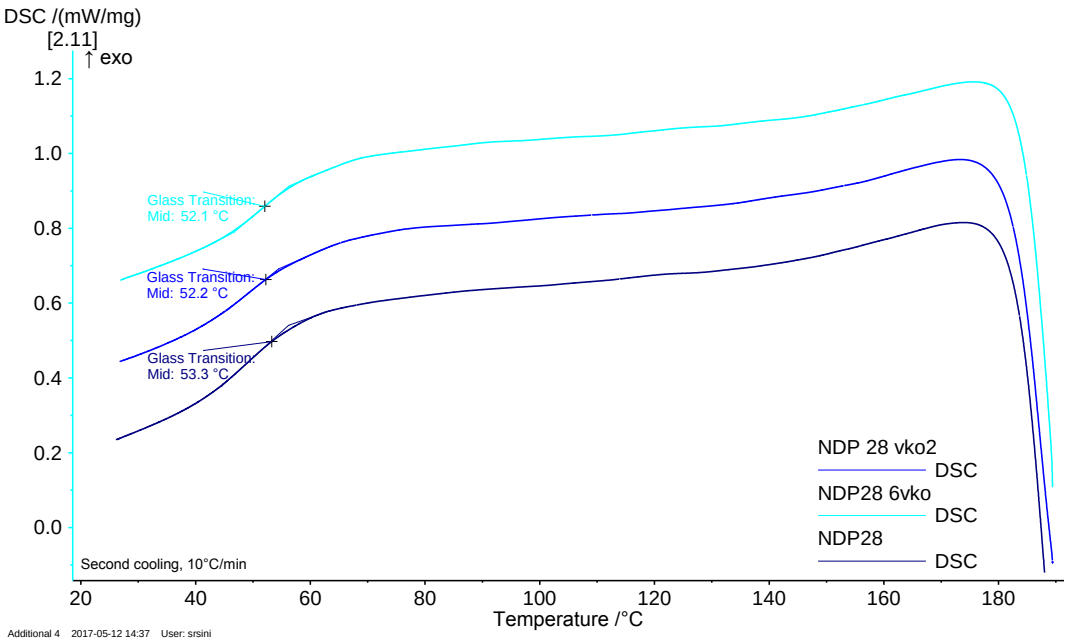
PICTURE 96. NDP 40 % cellulose + epox 8 % original sample, two weeks exposed sample and six week exposed sample. First heating time obtained by the differential scanning calorimetry.



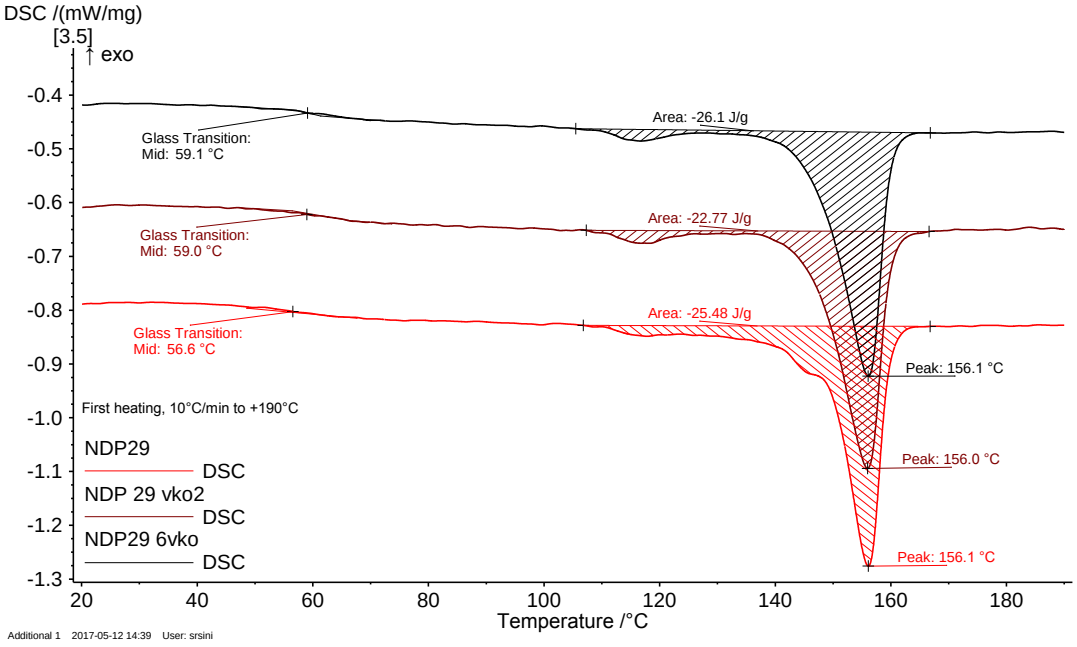
PICTURE 97. NDP 40 % cellulose + epox 8 % original sample, two weeks exposed sample and six week exposed sample. First cooling time obtained by the differential scanning calorimetry.



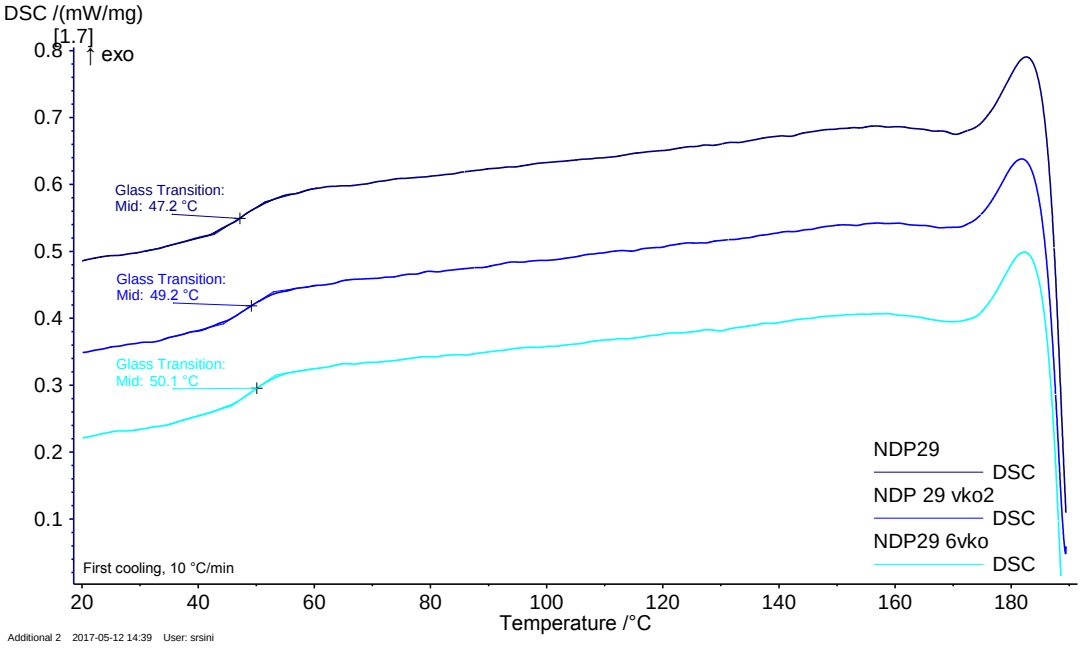
PICTURE 98. NDP 40 % cellulose + epox 8 % original sample, two weeks exposed sample and six week exposed sample. Second heating time obtained by the differential scanning calorimetry.



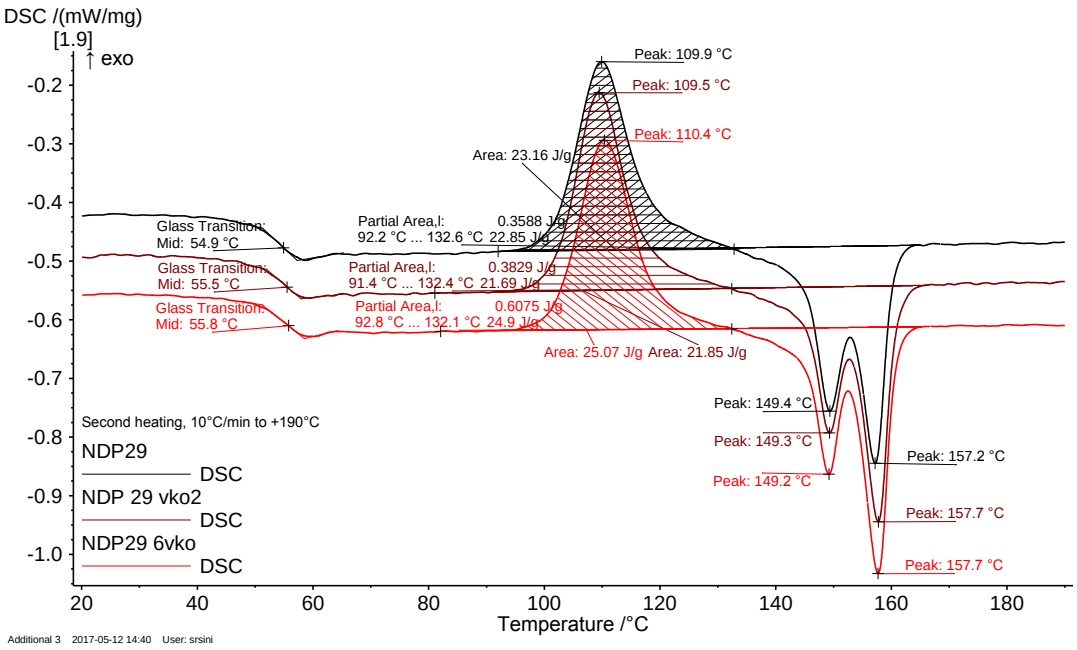
PICTURE 99. NDP 40 % cellulose + epox 8 % original sample, two weeks exposed sample and six week exposed sample. Second cooling time obtained by the differential scanning calorimetry.



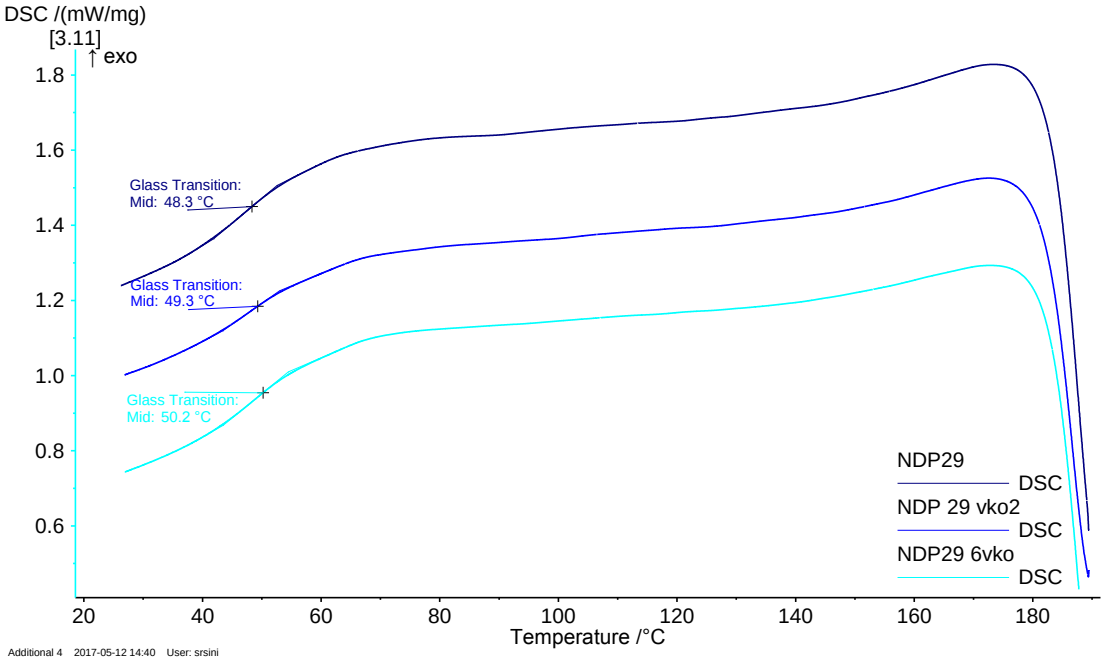
PICTURE 100. NDP 40 % cellulose + epox 12 % original sample, two weeks exposed sample and six week exposed sample. First heating time obtained by the differential scanning calorimetry.



PICTURE 101. NDP 40 % cellulose + epox 12 % original sample, two weeks exposed sample and six week exposed sample. First cooling time obtained by the differential scanning calorimetry.



PICTURE 102. NDP 40 % cellulose + epox 12 % original sample, two weeks exposed sample and six week exposed sample. Second heating time obtained by the differential scanning calorimetry.



PICTURE 103. NDP 40 % cellulose + epox 12 % original sample, two weeks exposed sample and six week exposed sample. Second cooling time obtained by the differential scanning calorimetry.

Appendix 10. Determination of water absorption, NDP series and PLA

TABLE 10. Measurement protocol of determination of water absorption for PLA 3052D and NDP series.

		Initial 4.4.20	24 h 5.4.2016 klo 10:30		48 h 6.4.2016 klo 10:30		1 weeks 11.4.2016.klo 10:3		2 weeks 18.4.2016 klo 10:3		3 weeks 25.4.2016 klo 10:30		4 weeks 2.5.2016 klo 10:30		2 month 2.6.2016 klo 10:30		3 month 2.7.2016 klo 10:30		4 month 2.8.2016 klo 10:30	
Code	Number	Weight (g)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)
Acel 20	1	2,2312	2,2524	0,95	2,2611	1,34	2,2897	2,62	2,3154	3,77	2,3332	4,57	2,3437	5,04	2,3593	5,74	2,3642	5,96	2,3656	6,02
	2	2,1956	2,2160	0,93	2,2250	1,34	2,2531	2,62	2,2784	3,77	2,2960	4,57	2,3063	5,04	2,3219	5,75	2,3269	5,98	2,3286	6,06
	3	2,2396	2,2610	0,96	2,2707	1,39	2,3004	2,71	2,3276	3,93	2,3457	4,74	2,3562	5,21	2,3714	5,88	2,3757	6,08	2,3780	6,18
	M.A.			**0,94**		**1,36**		**2,65**		**3,82**		**4,63**		**5,10**		**5,79**		**6,01**		**6,09**
	S.D.	**0,02**	**0,0239**	**0,01**	**0,02**	**0,03**	**0,02**	**0,05**	**0,03**	**0,09**	**0,03**	**0,10**	**0,03**	**0,09**	**0,03**	**0,08**	**0,03**	**0,06**	**0,03**	**0,08**
Acel 21	1	2,2238	2,2446	0,94	2,2543	1,37	2,2830	2,66	2,3091	3,84	2,3262	4,60	2,3365	5,07	2,3510	5,72	2,3553	5,91	2,3570	5,99
	2	2,2617	2,2922	1,35	2,3051	1,92	2,3477	3,80	2,3888	5,62	2,4170	6,87	2,4299	7,44	2,4435	8,04	2,4481	8,24	2,4493	8,29
	3	2,2602	2,2903	1,33	2,3037	1,92	2,3458	3,79	2,3868	5,60	2,4159	6,89	2,4297	7,50	2,4430	8,09	2,4470	8,26	2,4491	8,36
	M.A.			**1,21**		**1,74**		**3,42**		**5,02**		**6,12**		**6,67**		**7,28**		**7,47**		**7,55**
	S.D.	**0,02**	**0,0270**	**0,23**	**0,03**	**0,32**	**0,04**	**0,65**	**0,05**	**1,02**	**0,05**	**1,31**	**0,05**	**1,39**	**0,05**	**1,35**	**0,05**	**1,35**	**0,05**	**1,35**
Acel 22	1	2,1895	2,2161	1,21	2,2267	1,70	2,2630	3,36	2,2962	4,87	2,3159	5,77	2,3253	6,20	2,3355	6,67	2,3398	6,86	2,3414	6,94
	2	2,2013	2,2288	1,25	2,2408	1,79	2,2766	3,42	2,3115	5,01	2,3316	5,92	2,3394	6,27	2,3499	6,75	2,3544	6,95	2,3558	7,02
	3	2,1941	2,2202	1,19	2,2313	1,70	2,2659	3,27	2,2994	4,80	2,3204	5,76	2,3277	6,09	2,3403	6,66	2,3435	6,81	2,3454	6,90
	M.A.			**1,22**		**1,73**		**3,35**		**4,89**		**5,82**		**6,19**		**6,69**		**6,88**		**6,95**
	S.D.	**0,01**	**0,0065**	**0,03**	**0,01**	**0,06**	**0,01**	**0,07**	**0,01**	**0,10**	**0,01**	**0,09**	**0,01**	**0,09**	**0,01**	**0,05**	**0,01**	**0,07**	**0,01**	**0,06**
Acel 23	1	2,1899	2,2425	2,40	2,2606	3,23	2,3141	5,67	2,3639	7,95	2,3863	8,97	2,3927	9,26	2,4026	9,71	2,4074	9,93	2,4084	9,98
	2	2,2109	2,2655	2,47	2,2853	3,37	2,3402	5,85	2,3951	8,33	2,4149	9,23	2,4207	9,49	2,4289	9,86	2,4319	10,00	2,4336	10,07
	3	2,2121	2,2638	2,34	2,2844	3,27	2,3380	5,69	2,3900	8,04	2,4109	8,99	2,4178	9,30	2,4278	9,75	2,4314	9,91	2,4335	10,01
	M.A.			**2,40**		**3,29**		**5,74**		**8,11**		**9,06**		**9,35**		**9,77**		**9,95**		**10,02**
	S.D.	**0,01**	**0,0128**	**0,07**	**0,01**	**0,07**	**0,01**	**0,10**	**0,02**	**0,20**	**0,02**	**0,14**	**0,02**	**0,12**	**0,01**	**0,08**	**0,01**	**0,04**	**0,01**	**0,05**
Acel 24	1	2,2080	2,2476	1,79	2,2655	2,60	2,3268	5,38	2,3734	7,49	2,3811	7,84	2,3855	8,04	2,3910	8,29	2,3931	8,38	2,3950	8,47
	2	2,2083	2,2475	1,78	2,2651	2,57	2,3252	5,29	2,3733	7,47	2,3817	7,85	2,3833	7,92	2,3917	8,31	2,3946	8,44	2,3966	8,53
	3	2,2022	2,2402	1,73	2,2593	2,59	2,3190	5,30	2,3659	7,43	2,3741	7,81	2,3780	7,98	2,3841	8,26	2,3881	8,44	2,3890	8,48
	M.A.			**1,76**		**2,59**		**5,33**		**7,47**		**7,83**		**7,98**		**8,28**		**8,42**		**8,49**
	S.D.	**0,00**	**0,0042**	**0,04**	**0,00**	**0,02**	**0,00**	**0,05**	**0,00**	**0,03**	**0,00**	**0,02**	**0,00**	**0,06**	**0,00**	**0,02**	**0,00**	**0,03**	**0,00**	**0,03**
Acel 25	1	2,2513	2,3160	2,87	2,3431	4,08	2,4370	8,25	2,4804	10,18	2,4848	10,37	2,4873	10,48	2,4937	10,77	2,4985	10,98	2,5000	11,05
	2	2,2513	2,3138	2,78	2,3405	3,96	2,4317	8,01	2,4761	9,99	2,4823	10,26	2,4837	10,32	2,4909	10,64	2,4956	10,85	2,4978	10,95
	3	2,2532	2,3171	2,84	2,3461	4,12	2,4379	8,20	2,4818	10,15	2,4869	10,37	2,4892	10,47	2,4954	10,75	2,4992	10,92	2,5012	11,01
	M.A.			**2,83**		**4,05**		**8,15**		**10,10**		**10,33**		**10,43**		**10,72**		**10,92**		**11,00**
	S.D.	**0,00**	**0,0017**	**0,05**	**0,00**	**0,08**	**0,00**	**0,12**	**0,00**	**0,10**	**0,00**	**0,06**	**0,00**	**0,09**	**0,00**	**0,07**	**0,00**	**0,06**	**0,00**	**0,05**
Acel 28	1	2,1880	2,2200	1,46	2,2337	2,09	2,2741	3,94	2,3126	5,69	2,3315	6,56	2,3385	6,88	2,3480	7,31	2,3512	7,46	2,3530	7,54
	2	2,2002	2,2305	1,38	2,2444	2,01	2,2865	3,92	2,3269	5,76	2,3463	6,64	2,3513	6,87	2,3629	7,39	2,3648	7,48	2,3668	7,57
	3	2,1900	2,2222	1,47	2,2382	2,20	2,2801	4,11	2,3192	5,90	2,3369	6,71	2,3427	6,97	2,3531	7,45	2,3566	7,61	2,3585	7,69
	M.A.			**1,44**		**2,10**		**3,99**		**5,78**		**6,64**		**6,91**		**7,38**		**7,52**		**7,60**
	S.D.	**0,01**	**0,006**	**0,05**	**0,01**	**0,10**	**0,01**	**0,11**	**0,01**	**0,10**	**0,01**	**0,07**	**0,01**	**0,06**	**0,01**	**0,07**	**0,01**	**0,08**	**0,01**	**0,08**
Acel 29	1	2,1883	2,2191	1,41	2,2321	2,00	2,2737	3,90	2,3132	5,71	2,3317	6,55	2,3384	6,86	2,3486	7,33	2,3513	7,45	2,3530	7,53
	2	2,1981	2,2282	1,37	2,2415	1,97	2,2832	3,87	2,3230	5,68	2,3411	6,51	2,3488	6,86	2,3579	7,27	2,3610	7,41	2,3622	7,47
	3	2,1826	2,2117	1,33	2,2250	1,94	2,2665	3,84	2,3057	5,64	2,3238	6,47	2,3304	6,77	2,3400	7,21	2,3435	7,37	2,3432	7,36
	M.A.			**1,37**		**1,97**		**3,87**		**5,68**		**6,51**		**6,83**		**7,27**		**7,41**		**7,45**
	S.D.	**0,01**	**0,0083**	**0,04**	**0,01**	**0,03**	**0,01**	**0,03**	**0,01**	**0,03**	**0,01**	**0,04**	**0,01**	**0,05**	**0,01**	**0,06**	**0,01**	**0,04**	**0,01**	**0,09**
PLA 3052D	1	1,9645	1,9699	0,27	1,9718	0,37	1,9766	0,62	1,9779	0,68	1,9787	0,72	1,9792	0,75	1,9796	0,77	1,9799	0,78	1,9802	0,80
	2	1,9528	1,9583	0,28	1,9601	0,37	1,9649	0,62	1,9665	0,70	1,9670	0,73	1,9674	0,75	1,9680	0,78	1,9683	0,79	1,9687	0,81
	3	1,9578	1,9633	0,28	1,9650	0,37	1,9701	0,63	1,9715	0,70	1,9722	0,74	1,9726	0,76	1,9731	0,78	1,9734	0,80	1,9737	0,81
	M.A.			**0,28**		**0,37**		**0,62**		**0,69**		**0,73**		**0,75**		**0,78**		**0,79**		**0,81**
	S.D.	**0,01**	**0,0058**	**0,00**	**0,01**	**0,00**	**0,01**	**0,01**	**0,01**	**0,01**	**0,01**	**0,01**	**0,01**	**0,00**	**0,01**	**0,01**	**0,01**	**0,01**	**0,01**	**0,01**

Appendix 11. Determination of water absorption, wood samples

TABLE 11. Measurement protocol of determination of water absorption for wood samples.

		Initial 4.4.20	24 h 5.4.2016 klo 10:30		48 h 6.4.2016 klo 10:30		1 weeks 11.4.2016.klo 10:3		2 weeks 18.4.2016 klo 10:3		3 weeks 25.4.2016 klo 10:30		4 weeks 2.5.2016 klo 10:30		2 month 2.6.2016 klo 10:30		3 month 2.7.2016 klo 10:30		4 month 2.8.2016 klo 10:30	
Code	Number	Weight (g)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)	Weight (g)	Weight change (%)
painekylläst etty	1	0,6882	1,1722	70,33	1,2501	81,65	1,4783	114,81	1,6640	141,79	1,8015	161,77	1,8901	174,64	1,9344	181,08		-100,00		-100,00
	2	0,6180	1,0462	69,29	1,1375	84,06	1,3664	121,10	1,5461	150,18	1,7018	175,37	1,7840	188,67	1,8398	197,70		-100,00		-100,00
	3	0,6302	1,1193	77,61	1,2001	90,43	1,4118	124,02	1,5742	149,79	1,7175	172,53	1,8039	186,24	1,8711	196,91		-100,00		-100,00
	M.A.			**72,41**		**85,38**		**119,98**		**147,25**		**169,89**		**183,19**		**191,90**		**-100,00**		**-100,00**
	S.D.	**0,04**	**0,06**	**4,53**	**0,06**	**4,54**	**0,06**	**4,71**	**0,06**	**4,74**	**0,05**	**7,18**	**0,06**	**7,50**	**0,05**	**9,37**	**#DIV/0!**	**0,00**	**#DIV/0!**	**0,00**
lista	1	0,9643	1,4641	51,83	1,5536	61,11	1,8142	88,14	1,9504	102,26	2,0811	115,81	2,1334	121,24	2,1537	123,34		-100,00		-100,00
	2	0,9321	1,4272	53,12	1,5953	71,15	1,7008	82,47	1,8571	99,24	2,0111	115,76	2,0880	124,01	2,1262	128,11		-100,00		-100,00
	3	1,1665	1,5510	32,96	1,6067	37,74	1,7567	50,60	1,8800	61,17	1,9882	70,44	2,0570	76,34	2,1405	83,50		-100,00		-100,00
	M.A.			**45,97**		**56,67**		**73,73**		**87,55**		**100,67**		**107,20**		**111,65**		**-100,00**		**-100,00**
	S.D.	**0,13**	**0,06**	**11,28**	**0,03**	**17,14**	**0,06**	**20,24**	**0,05**	**22,90**	**0,05**	**26,18**	**0,04**	**26,76**	**0,01**	**24,50**	**#DIV/0!**	**0,00**	**#DIV/0!**	**0,00**
koivuhalko	1	1,0537	1,6652	58,03	1,7307	64,25	1,9218	82,39	1,9715	87,10	2,0083	90,60	2,0434	93,93	2,1243	101,60		-100,00		-100,00
	2	0,9986	1,6196	62,19	1,6767	67,91	1,8322	83,48	1,8854	88,80	1,9311	93,38	1,9767	97,95	2,0736	107,65		-100,00		-100,00
	3	0,9964	1,6145	62,03	1,6909	69,70	1,8818	88,86	1,9721	97,92	2,0121	101,94	2,0468	105,42	2,1358	114,35		-100,00		-100,00
	M.A.			**60,75**		**67,29**		**84,91**		**91,28**		**95,30**		**99,10**		**107,87**		**-100,00**		**-100,00**
	S.D.	**0,03**	**0,03**	**2,35**	**0,03**	**2,78**	**0,04**	**3,47**	**0,05**	**5,82**	**0,05**	**5,91**	**0,04**	**5,83**	**0,03**	**6,38**	**#DIV/0!**	**0,00**	**#DIV/0!**	**0,00**