Examining the influence of injection speed and mould temperature on the tensile strength of polypropylene and ABS

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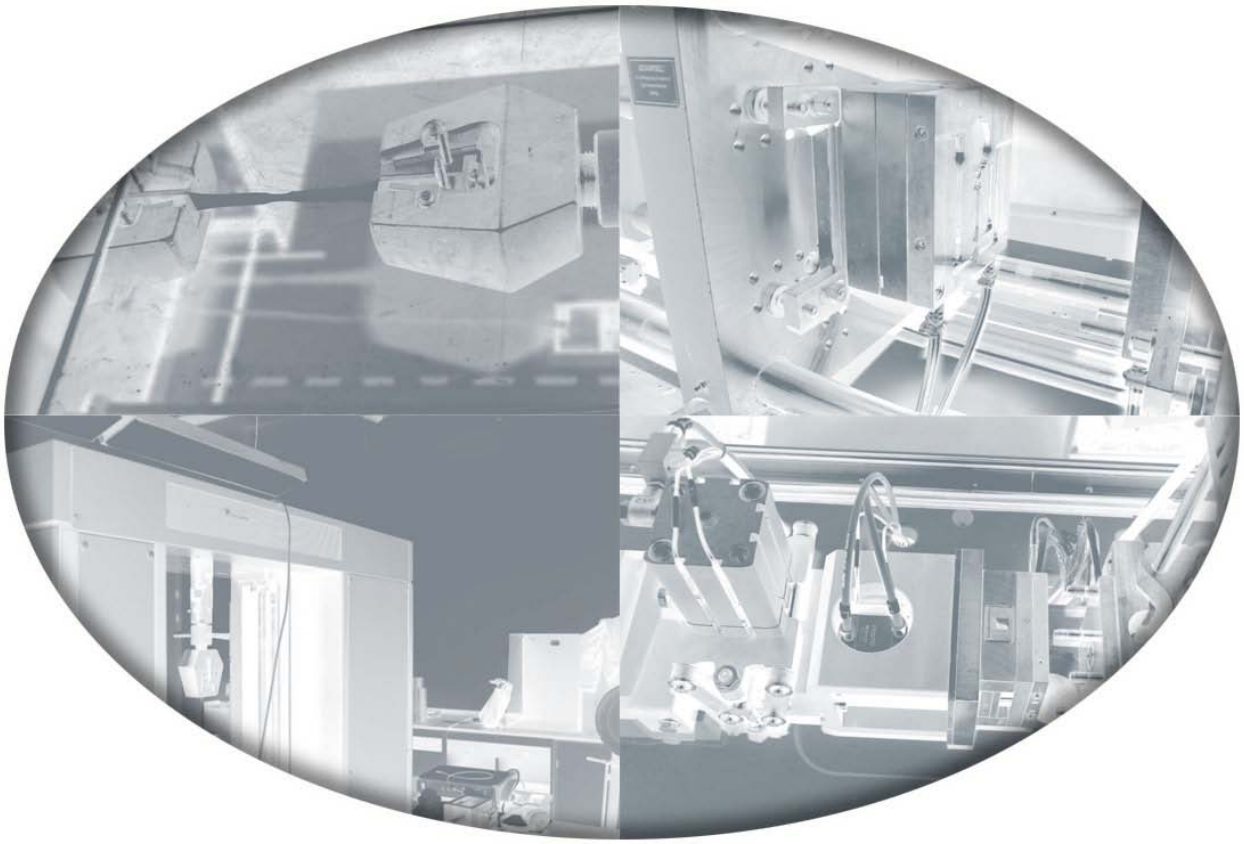

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Abstract

This report is the final task of course "41738 Experimental Plastics Technology" in the three weeks period of June 2009 at DTU, IPL.

The aim of this project has been to investigate the ultimate tensile strength behaviour of two different polymers, with different structural composition, by varying the injection speed and the mold temperature independently while keeping all other process parameters fixed. In addition the scaling from production of large to small geometries has been investigated by doing two parallel productions and test setups of respectively injection moulded and micro injection moulded specimens. After production and tensile testing the specimens were examined with a microscope to underpin conclusions from the tensile test data.

It was experienced that the injection speed in general increased the the tensile strength by orienting the polymeric-chains lengthwise in the specimens and thus increasing the strength in the tensile strength. This observation was however disturbed by the test results for small ABS specimens where an increased injection speed in general meant lower tensile strength, which though can be explained by the extremely rapid cooling that the small specimens in general were subjected to.

The influence of the mould temperature was generally less significant and usually lay within the uncertainty of the standard deviation, but can superficially be said to affect the semicrystaline PP in a way where higher mould temperature induce slightly higher tensile strength, which is seen as a consequence of the slower cooling speed and thus a longer crystalisation time that this implies. In relation to the amourphous ABS the influence of the mould temperature is found to be of an insignificant character.

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1 Introduction

This report is submitted for evaluation to mark the completion of the three-weeks course "41738 – Eksperimentel Plastteknologi" in june 2009 at The Technical University of Denmark, Lyngby.
The report is a documentation of the experimental work conducted in the course and an analysis of the results from this.

Polymeric materials have for decades been widely used for mass productions with injection moulding. The reason this is that plastic is preferred as a material is due to: easy formability, light weight, resistance to various chemicals, low electric conductivity, ability to be transparent and colored, and always relatively cheap. In the more recent years though plastic is becoming more popular for its ability as an engineering material that can adopt specific properties as a result of the polymeric-mix and also to a high extent the processing conditions under which it is produced. This subject of controlling mechanical behavior of materials has acquired much attention because of the obvious commercial interest that lies in this field.

It is though the fact that polymers are incredibly multifarious and behave very differently, which makes this subject very large, interesting and somehow a pioneering field. The overall different constitution and structure of a polymer can be of great importance when trying to control the mechanical properties by regulating processing conditions.

This project focuses on exploring, not only the influence of different process parameters on two different polymeric structures but also the influence of specimen scaling.

1.1 Report structure

The report is divided into chapters where this introductorily chapter marks the first of eight.

Chapter two deals with the selection and description of the materials used in the investigation defined in the previous chapter

Chapter three describes the production setup, how different production process parameters were chosen and how the practical setup of the two involved injection molding machines was handled.

Chapter four threats the experimental investigation of the produced specimens, more specifically the tensile testing and the microscope analysis machines used, the adopted procedures for using these and the outcome of this.

Chapter five discussed the possible sources of error involved with the investigational design of this project. This chapter divides sources of error into the categories of relation to respectively the production procedure and the investigation procedure.

Chapter six deals with the theoretical background knowledge relevant for tensile testing and uses examples from the microscope pictures to underpin interesting theories that will be relevant in the following chapter where the results are analyzed.

Chapter seven analyses the data results from the tensile testing and discusses these with the knowledge from the prior chapter and tries to explain the achieved results with this knowledge. Further the statistically credibility is assed for the four test sets.

Chapter eight constitute an overall conclusion on both the achieved results and the way to them.

The appendixes are to be found after the references.

1.2 Project definition

The original project definition has been altered several times during the course due to, technical difficulties, inaccesability of testing equipment, inadequate manufacturer data on materials and busyness at Pulse. The initial project definition was as follows:

“The aim of this project is to study the combine effects of material class and process conditions on the mechanical properties of micro moulded PP parts.” (from the Project Description document by supervisor dr. M. A. Islam)

Since the mould for producing the micro moulded parts was not accessible until halfway into the project the focus on the micro moulded parts has been decreased. Furthermore it was not possible to conduct the tensile tests of the small specimens at the company “Pulse” as the original plan was. Instead there has been an increased focus on regular injection molded parts and there has been introduced variations in process parameters in the large parts as well as in the small parts – in the original definition only the small parts should have varying process conditions. After these alterations or enlargements of the project scope were made the project definition can be formulated as follows.

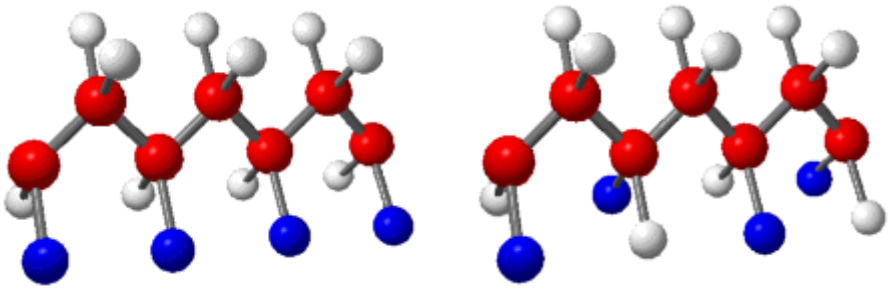
- Study variations in maximum tensile strength due to different process conditions for PP and ABS
- Study the different influence that the changed process parameters have on respectively a semi-crystaline and amorphous polymer in relation to tensile strength
- Study the changing effects on maximum tensile strength of varying process properties when scaling a specimen.
- Study the breaks of the test specimens as a result of varied process conditions for the two materials with different polymeric structure.

2 Material selection

This chapter defines the process parameters and the materials selected due to literature study and the project definition in the previous chapter. The main focus in this report is on a homo-polypropylene polymer and a ABS block polymer. The properties of these will be investigated and two different polymers and the suitable process parameters will be chosen in the following sections.

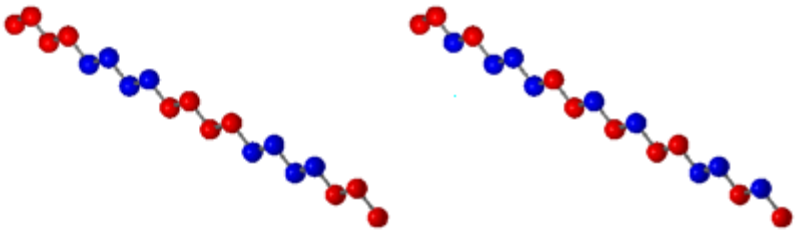
2.1 Polypropylene

Polypropylene is a semi-crystalline thermoplastic polymer where the level of crystallinity can vary due to factors like process parameters etc. Most commercial polypropylene is isotactic. An illustration of the differences between an isotactic and syndiotactic polymer chain can be seen below



On the left an example of an isotatic polymer chain, and on the right a syndiotactic polymer chain. From: http://plc.cwru.edu/tutorial/enhanced/files/polymers/struct/struct.htm

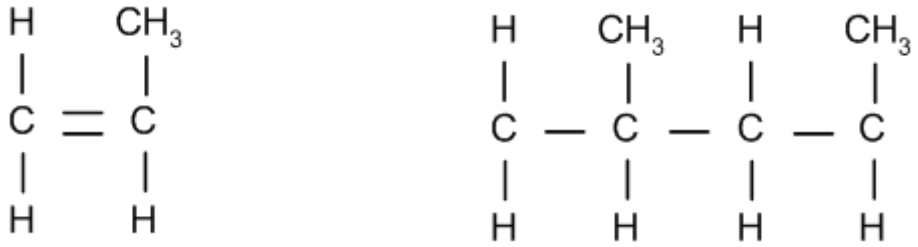
The isotactic structure normally gives high crystallinity, but the PP has a low to intermediate level of crystallinity. There are three general types of PP: homo-polymer, random co-polymer and block co-polymer. Homo-polymer only consists of PP. The main difference between random and block co-polymer is – as the names indicate – the ordering monomers in the polymer chain; for random co-polymer the different monomers are arranged randomly amongst each other, where the monomers in the block co-polymer are ordered in blocks of the same type, which is illustrated below.



On the left an illustration of a block co-polymer. On the right a random co-polymer is illustrated. From: http://plc.cwru.edu/tutorial/enhanced/files/polymers/struct/struct.htm

The co-monomer used is typically ethylene which in general makes the PP more tough and flexible. Ethylene-propylene rubber or EPDM added to a PP homopolymer increases its low temperature impact strength. Randomly polymerized ethylene monomer added to PP homopolymer decreases the polymer crystallinity and makes the polymer more transparent.

The structural formula of polypropylene is shown in the figure below:



To the left the propylene monomer. To the right a chain segment of a polypropylene chain. From: http://www.tangram.co.uk/TI-Polymer-PP_Controlled-Rheology.html

2.1.1 Specific polymer: Borealis HH315MO

A specific homo-PP polymer was selected for production of the test specimens from a list of available polymers at the plastic laboratory under supervision by a plastic expert at the laboratory. The chosen homo-PP is: **Borealis HH315MO**.

HH315MO is a polypropylene homopolymer intended for injection moulding. Its high melt flow makes it especially suitable for products with long flow length. This grad is designed for high-speed injection moulding and contains nucleating, antistatic and slip additives. This polymer is a controlled rheology (CR) polymer. CR means that normal PP is degraded which gives a high melt flow index, lower molecular weight and a narrow molecular weight distribution giving a more consistent flow and low warpage (http://www.tangram.co.uk/TI-Polymer-PP_Controlled-Rheology.html). Products originating from this grade have excellent demoulding properties, very high stiffness, good transparency and gloss and good impact strength at ambient temperatures.

Some of the applications for this type of material is thin wall containers, rectangular and flat products like lids and trays. See more applications and further information in the appendix 2.1.

A list of physical properties form the producer can be seen below – all relative to the ISO standard by which they were tested.

Physical properties for Borealis HH315MO with respect to the ISO standard test method		
Property	Typical value	**Test Methods**
Density	910 kg/m3	**ISO 11833**
Melt Flow Rate	35 g/10min	**ISO 1133**
Tensile Modulus (1 mm/min)	1.650 MPa	**ISO 527-2**
Tensile Strain at Yield (50 mm/min)	8 %	**ISO 527-2**
Deflection Temperature (0,45 N/mm²)	105°C	**ISO 75-2**
Charpy Impact Strength, notched (23 °C)	2,5 kJ/m²	**ISO 179/1eA**
Hardness, Rockwell (R-scale)	102	**ISO 2039-2**
Tensile stress at Yield (50 mm/min)	**36 MPa**	**ISO 527-2**

2.1.2 Supplier production guidelines

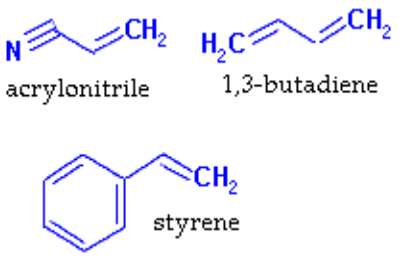
Borealis provide some guidelines for the injection moulding parameters when using Borealis HH315MO, which can be seen below

Processing parameters for Borealis HH315	
Melt temperature	210 - 250 °C
Holding pressure	200 - 500 bar Minimum to avoid sink marks.
Mould temperature	15 - 60 °C
Injection speed	High

2.2 ABS

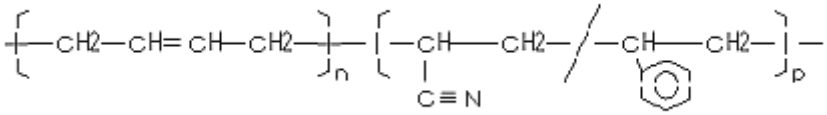
In order to evaluate the properties of the homo PP we wanted to compare it with properties of a co-polymer. Initially a PP-PE co-polymer was selected produced and tested from which we found that the PP-PE specimens were extremely ductile making it impossible for us to break them in the tensile testing machine. Instead we chose a more brittle block co-polymer: ABS.

ABS is an abbreviation Acrylonitrile Butadiene Styrene. This name refers monomers that the ABS consists of. The three monomers can be seen below.



The three different monomers in ABS

The chemical formula for ABS is $(C8H8 \cdot C4H6 \cdot C3H3N)_n$ the structure is shown below



ABS structure. From: http://mits.nims.go.jp/matnavi/polymer/U900073.png

ABS is a thermoplastic and amorphous polymer. It is used to make light and rigid moulded parts. A well known example could be the LEGO brick. This co-polymer is made by polymerizing the styrene and acrylonitrile in the presence of polybutadiene. The amount of the different substances can vary as can be seen in the table below.

Variations of the percentages of the different substances	
Acrylonitrile	15-35 %
Butadiene	5-30 %
Styrene	40-60 %

The long chain of polybutadiene mingles with sorter chains of poly-styrene-co-acrylonitrile, and the polar nitrile groups from different chains attract each other and bind the chains together. This makes the ABS stronger than pure polystyrene.

The different substances bring different properties to the ABS. The styrene gives the polymer a shinny surface, the butadiene gives resilience. The mechanical properties of ABS vary due to temperature but most ABS polymers can be used between -25 and 60 °C. The most important mechanical properties of ABS are resistance and toughness.

2.2.1 Specific polymer: BASF Terluran GP-35

The specific ABS polymer was as well as for the PP polymer found in the plastic laboratory with supervision from a plastic expert. The chosen polymer is Terluran GP 35 produced by BASF. The product sheet from BASF (see appendix product sheet Terluran GP 35) describes the polymer as an easy flow injection moulding product with good ductility, intended for moulds with thin walls and/or adverse flow length to wall ratio.

Furthermore a schematic overview of the properties from this plastic is given with respect to the ISO standard from which they were tested:

Properties of the BASF Terluran GP 35 polymer with respect to the ISO standard tests		
Property	Typical Value	**Test Methods**
Tensile modulus	2300 MPa	**ISO 527-1-/2**
Yield stress	44 MPa	**ISO 527-1-/2**
Yield strain	2.4 %	**ISO 527-1-/2**
Nominal strain at break	12 %	**ISO 527-1-/2**
Charpy impact strength (23°)	130 kJ/m²	**ISO 179-1eU**
Charpy impact strength (23°)	19 kJ/m²	**ISO 179-1eA**
Water absorption	0.95 %	**ISO 62**
Humidity absorption	0.24%	**ISO 62**
density	**1040 kg/m³**	**ISO 1183**

2.2.2 Production guidelines

The production guidelines injection moulding is delivered by Comsol (see appendix 2.1) and can be seen below.

Processing properties for BASF Terluran GP-35	
Melt temperature	250 °C
Mold temperature	83 °C
Injection velocity	60 mm/sec

3 Process parameter selection

The production of the test specimens are made on an common injection molding machine, for the large specimens and on a micro injection moulding machine, for the small one test specimens. Both machines are located at the polymer laboratory. The following sections will first deal with the selection of the variable process parameters due to aim of report and then how the specimens are produced on two machines.

3.1 Production setup

Selecting two different materials and different production types are the basis of this report. However the really interesting test input is not only the different materials and machines, but rather the chosen production process parameters and their influence on the tensile strength.

In order to be able to limit our production, tests and analysis-work to the scope of the course, it was not possible to investigate the influence of all production process parameters. This meant that it was necessary to choose which parameters should be varied and which should be fixed. By reading scientific articles on the subject (Lamminmäki, Lindgren, Silén, & Vesanto) it was assed that it would be possible to detect the greatest tensile strength variations by varying respectively the injection speed Vi and the mold temperature Mt, while keeping all other production process parameters fixed.

As it would be interesting to see if the changed process parameters seemed to have a linear effect or some other influence on the tensile strength it was chosen to have three values of each changeable parameter, which can be described as low, medium and high in relation to the manufacturer's suggested value.

In order to achieve some statistical credibility it was further decided to produce and perform tests of five specimens from each parameter combination. This was also chosen as a precaution that would enable us to discard a few flawed tests without reducing the scope of the project.

These experiment prerequisites meant that the project scope treated production and test of four sets, each with 9 different settings of process parameters, conducted with five specimens of each parameter setting,which sums up to a total of 180 produced and tested specimens when not considering the numerous amount of specimens that were produced and tested in an investigational purpose in order to calibrate and get familiar with the production and testing equipment. Schemes of the four production process plans can be seen below.

Set 1 PP Big dogbone specimens			
	Mt = 30 C	**Mt = 45 C**	**Mt = 60 C**
Vi = 100 mm/s	Proces 1	Proces 4	Proces 7
Vi = 250 mm/s	Proces 2	Proces 5	Proces 8
Vi = 400 mm/s	Proces 3	Proces 6	Proces 9

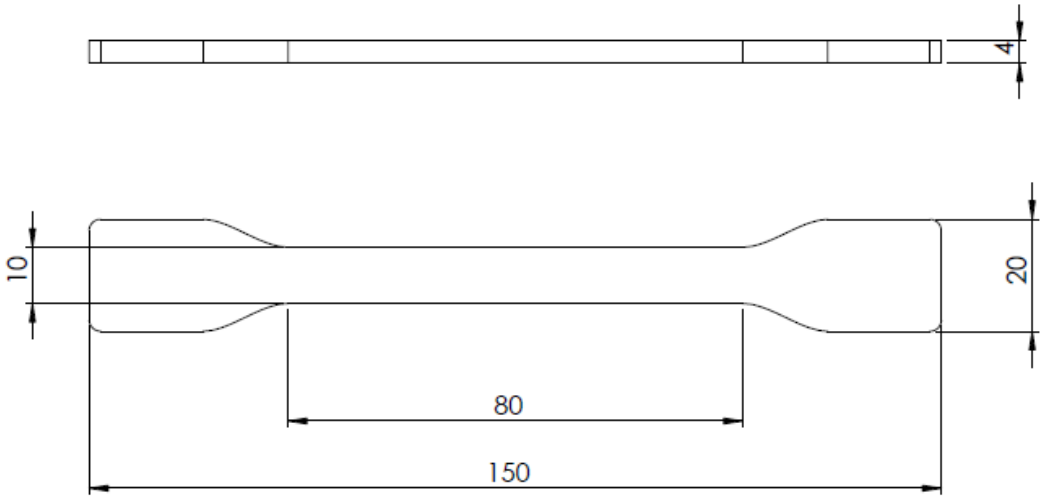
Set 2 ABS Big dogbone specimens			
	Mt = 40 C	**Mt = 60 C**	**Mt = 80 C**
Vi = 25 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 400 mm/s	Proces 3	Proces 6	Proces 9

Set 3 PP Small dogbone specimens			
	Mt = 30 C	**Mt = 45 C**	**Mt = 60 C**
Vi = 50 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 250 mm/s	Proces 3	Proces 6	Proces 9

Set 4 ABS Small dogbone specimens			
	Mt = 45 C	**Mt = 60 C**	**Mt = 75 C**
Vi = 50 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 250 mm/s	Proces 3	Proces 6	Proces 9

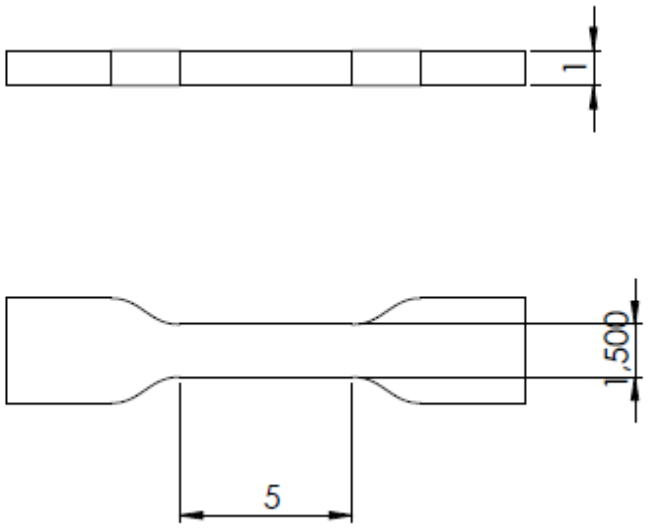
3.2 Test specimen geometry

The geometry of the large test specimensthat was produced on the Ferromatic Milacron K60-S resemblesthe ISO 3167 standard which prescribes a multipurpose test specimen for a wide variety of testing (Inertek). The used test specimen geometry though differs slightly from the ISO prescribed geometry, since the used dog bone does not have a length of exactly 80 mm with a uniform cross section (10 mm x 4 mm), as the standard prescribes, but a little less.



Dimensions of large dog bone. The author´s own remake of the specimen.

The small test specimen is approximately one-tenth of the large dog bone and thus does not conform to the ISO 3167 standard.

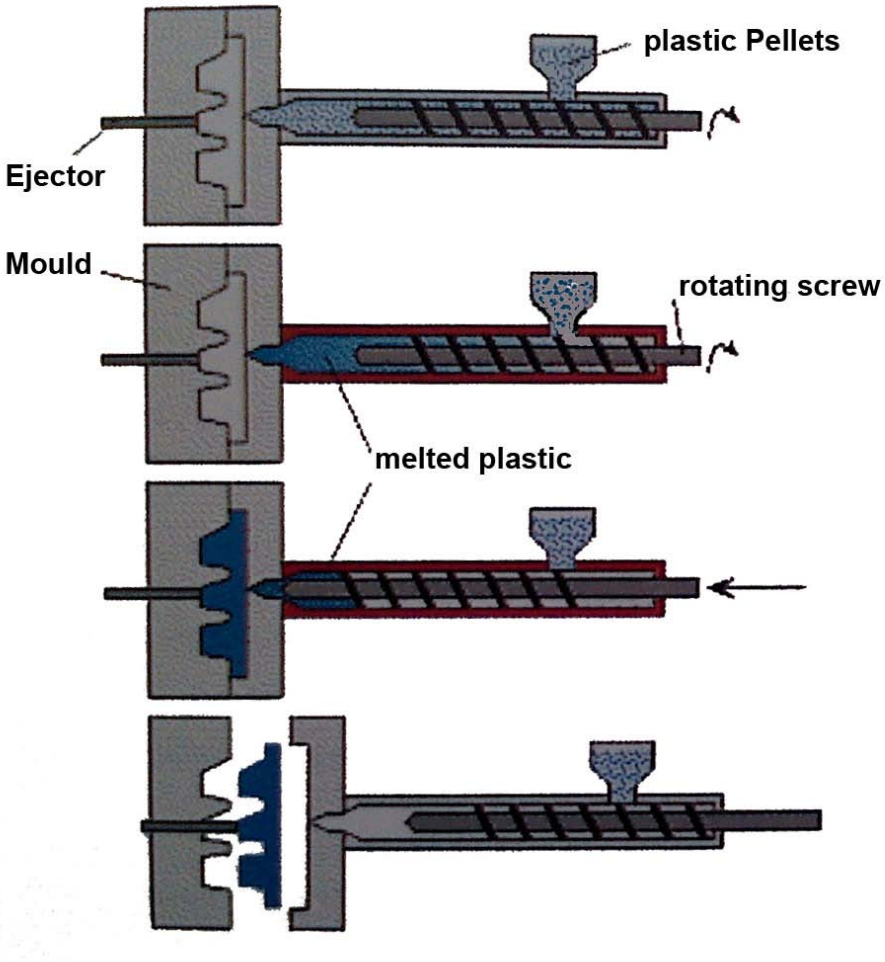


The important dimensions of the small dog bone. The author´s own remake of the specimen.

3.3 Production

3.3.1 Injection moulding

Injection moulding is mainly used in the field of polymer processing, most used for thermoplastics, but it could be also used to shape thermosets or elastomers as well. The principle of injection moulding is used to manufacture products of the weight of some grams up to double digit kilograms products. With injection moulding products of high precision could be achieved, and more or less every surface roughness or quality which is wished. But in most cases injection moulding is only economical in case of mass production, because the production of the mould is very costly.



The basic elements of a standard injection moulding machine, From: www.design-insite.dk

3.3.1.1 Process description

A basic injection moulding machine consists of four sections. These are the motor-hydraulics unit, the plastification unit, the tool (mould) unit, and the clamping device unit.

- The plastic in form of resins is put into the plastification unit via a hopper. The material will then be plastificated by the friction between the material, the cylinder and the screw, and by heating devices around the cylinder.
- The clamp device closes the mould
- The screw forces the plastificated material through a nozzle into the mould
- After a certain cooling time the material in the mould is solidified and ejector pins remove the moulded part out of the mould
- The clamping device opens again

3.3.2 Producing the large dog bones

The large dog bones are produced on the Ferromatic Milacron K 60 injection moulding machine as seen in the picture below.

The injection moulding machine used to produce the large dog bones

The mould temperature is controlled separately on heat control machine that is seen in the figure below.

The mould temperature control device

3.3.2.1 Setting up the machine

From the materials data sheets and from support from our supervisor and a material expert at the plastic laboratory the production values have been set up. All the process parameters was kept constant except the mould temperature that is controlled on the separate temperature device, and the injection speed that is control on the control panel of the injection moulding machine. A list of some of the process parameters is shown below.

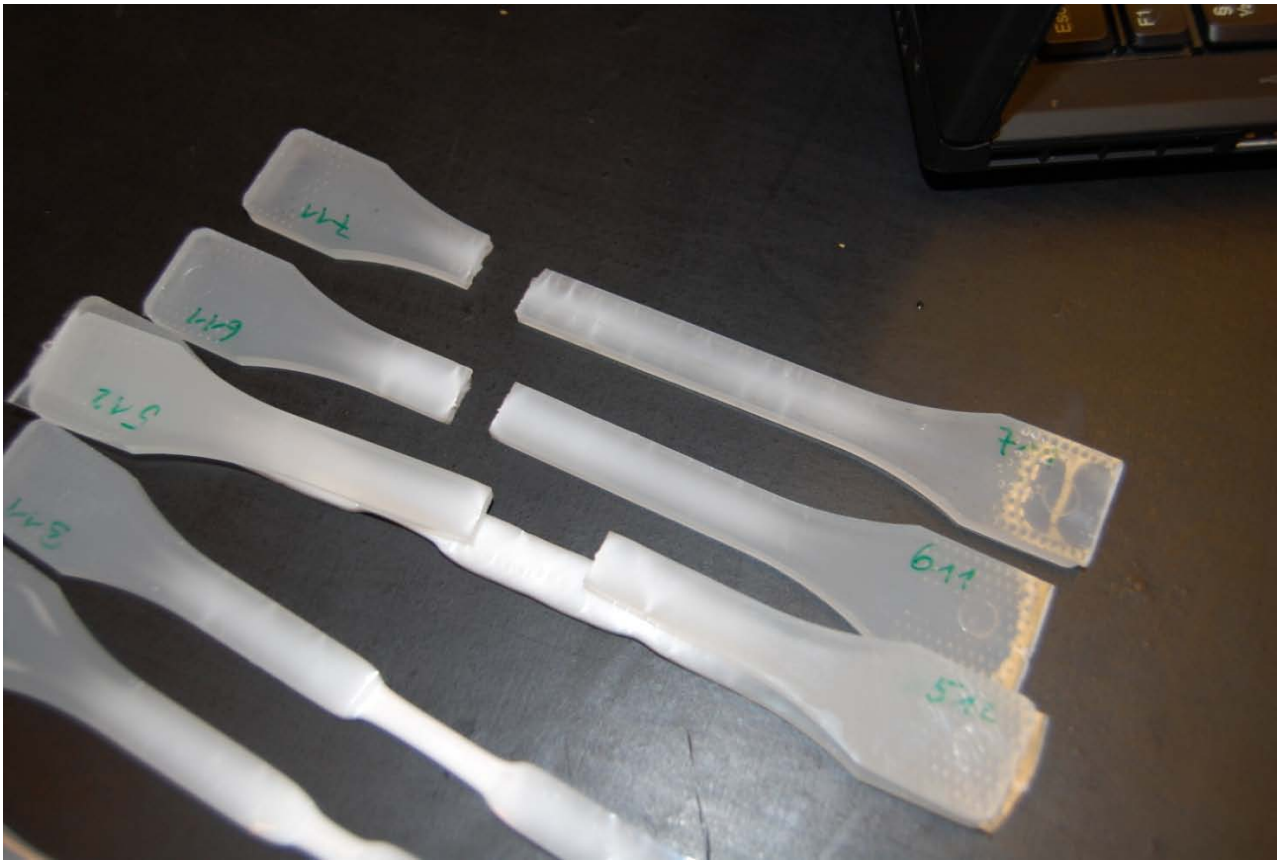
Process parameters for injection moulding machine	
Injection speed	100-400 mm/sec
Mould temperature	30-80
Plasticization “road”	21 mm
Injection pressure	150 bar
Injection time	2 sec
Change-over pressure (omkoblingstryk)	50 bar
Change-over point (omkoblingspunkt)	5 mm

3.3.2.2 Procedure

1. The polymer granulate is filled into the hopper
2. The non variable process parameters are set up
3. The desired temperature is set at the temperature control system.
4. The system warms up for about 20 minutes
5. The injection speed is controlled on the panel of the injection moulding machine as seen in the figure below.
6. A series of control specimens are made until the specimens are acceptable
7. First the lowest temperature specimens are made with the different injection speeds. Then the mould temperature is changed and production continues when the desired temperature is reached
8. A series of five to six specimens for each different process parameter variation are produced
9. The specimen is manually removed from the mould
10. The five to six specimens with the same process parameters get catalogued, that there is no way of mixing up.

Control panel for the injection moulding machine

To keep track of every dog bone from finished production to after the testing they were all given a sequential three digit identifying number that made every dog bone within a set unique.



The dog bone naming; first the process number, then material identification and finally a number that differentiates the specimens from the same process and material type from each other.

The first number identifies the process number 1 -9, the second number identifies the material 1 – 3 and the final number is unique to the dog bone normally 1 – 5, but in some cases when it due to test failure was necessary to produce and test more specimens up to 15.

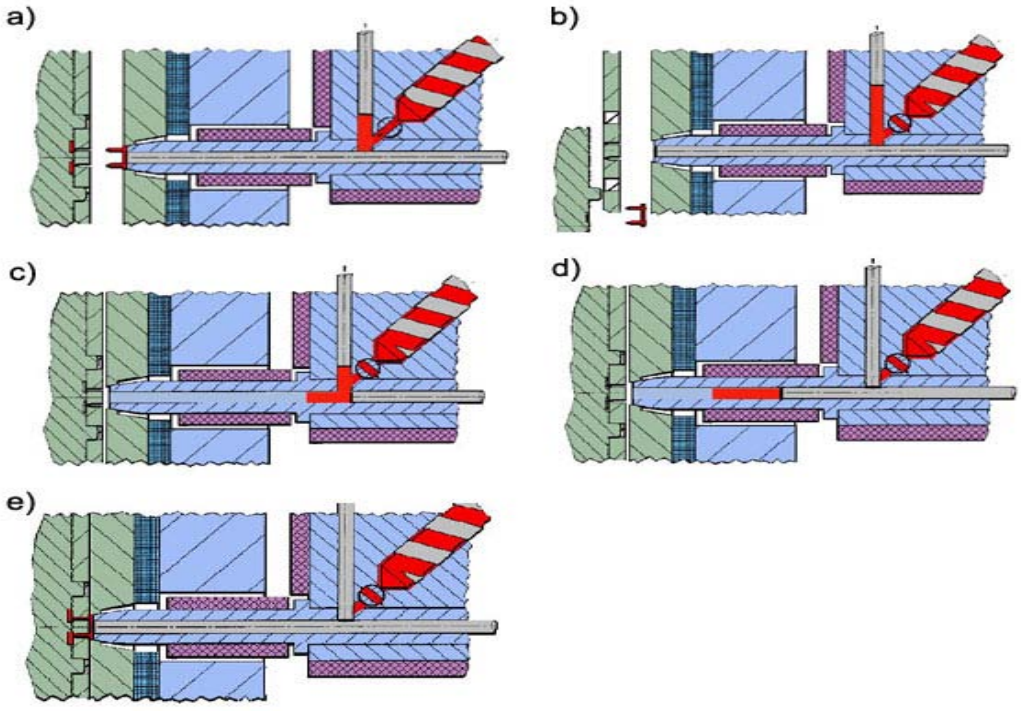
3.3.3 Micro injection moulding

Micro injection moulded parts weigh a few milligrams to a fraction of a gram and possibly have dimensions on the micrometer scale. Traditionally smaller parts have been molded on standard molding machines with limited success. Micro molding is suited for most all materials from high-temperature engineering plastics to commodity resins. With the advent of micro-molding machines small parts can now be molded easily.

3.3.3.1 Process Description

a) Plastic pellets are plasticized by a fixed extruder screw and fed into the metering chamber.
b) The shut-off valve closes in order to avoid backflow from the metering chamber.
c) Set volume is achieved and the plunger in the dosage barrel delivers the shot volume to the injection barrel.
d) Injection plunger pushes the melt into the cavity.
e) Plunger injection movement is completed, a holding pressure is applied to the melt

→ slight forward movement (maximum 1 mm) of the injection plunger.



The basic elements in a micro injection moulding machine, From: slides of course 41737 - design of plastic products - DTU 2009

3.3.4 Producing the small dog bones

To produce our small dog bone specimens we used a micro injection moulding machine called FormicaPlast by Desma Tec.

Picture of the micro injection moulding machine used to produce the small dog bones

The machine has a 2-phase piston injection unit with an user friendly visual system and a precise process control. Servo electric injection drive ensures speed and flexibility. It is possible to adjust the smallest incremental adjustments. The system is suitable for all standard granulates. Further key facts: variable mould sizes, short runners, toggle lever clamp unit.

3.3.4.1 Machine parameters

In the table below u can see the achievable parameter values of the DesmaTec.

Setup of the micro injection moulding machine		
Clamping unit information		
Clamping force	10	[kN]
Max. mould installation height	135	[mm]
Opening stroke	40	[mm]
Ejection force	300	[N]
Ejection stroke	10	[mm]
Injection unit information		
Pre-plasitfication piston	Ø6	[mm]
Injection piston	Ø3	[mm]
Maximum injection	3000	[Bar]

pressure		
Maximum injection volume	150	150mm³
Maximum injection speed	500	[mm/sec]

Procedure

1. The polymer granulate is filled into the filling hopper.
2. The non variable process parameters are set up
3. The desired temperature is set at the temperature control system.
4. The system warms up for about 10 minutes
5. The injection speed is controlled on the panel of the injection moulding machine A series of control specimens are made until the specimens are acceptable
6. First the lowest temperature specimens are made for the different injection speeds. Then the temperature is changed and production continues when the desired temperature is reached
7. A series of five to six specimens for each different process parameter variation is made
8. The specimens get ejected by the ejector and fall into a collector box
9. The five to six specimens with the same process parameters get catalogued, that there is no way of mixing up.

4 Experimental investigation

This chapter treats the experimental work conducted in this project. The chapter is ordered in a chronological way, where the first sections treat the tensile testing of the dog bones. After these sections a section on the setup for the microscope analysis is presented.

4.1 Tensile testing

Four experiments have been carried out; two with the large dog bones and two for the small ones. In this section a description of the experimental work for both sizes of dog bones will be made, starting with the large one.

1. Tensile tests of large dog bone specimens in PP
2. Tensile tests of large dog bone specimens in ABS
3. Tensile tests of small dog bone specimens in PP
4. Tensile tests of small dog bone specimens in ABS

In this project the elongation speed for the large and the small dog bone test has been the same. Another approach could have been to scale the elongation speed with the same factor as the relationship between the cross sections of the two different sizes of dog bones.

The numbers of test to run are:

2 types of polymer x 2 sizes x 9 process parameters x 5 specimens of each =180 tests

4.1.1 Objective

- Measurement of the differences in tensile strength for two polymers of two different sizes and 9 different process parameters.

4.1.2 The tensile test system

The tensile test consists of different machines which together can perform and process the test results. There is the tensile machine itself that is connected to the amplifier. The amplifier is connected to a computer. This computer is programmed with an excel plugin that can process the data from the amplifier.

Pictures of the elements of tensile test setup in the order of which the data moves. First the tensile test, then the amplifier and the computer

4.1.3 The test machine

The tensile test machine consists of two clamps that fasten the specimen. There is a broad variety of clamps, with various size, roughness and shape for different purposes. The upper clamp is stationary while the lower traverse. The speed of the lower clamp can be set to five different speeds and is controlled by the panel on the right as seen in picture below.

The tensile testing machine with small clamps mounted

The test machine has a weigh cell that detects the load. There are two different weigh cells; the large one is able to handle up to ten tons and the small one can handle up to 500 kg. In the weight cell a straingauge is glued on to a spring, hereby a force is converted to a distance by the spring and the straingauge converts the distance to an electrical resistance.

4.1.4 The measure amplifier

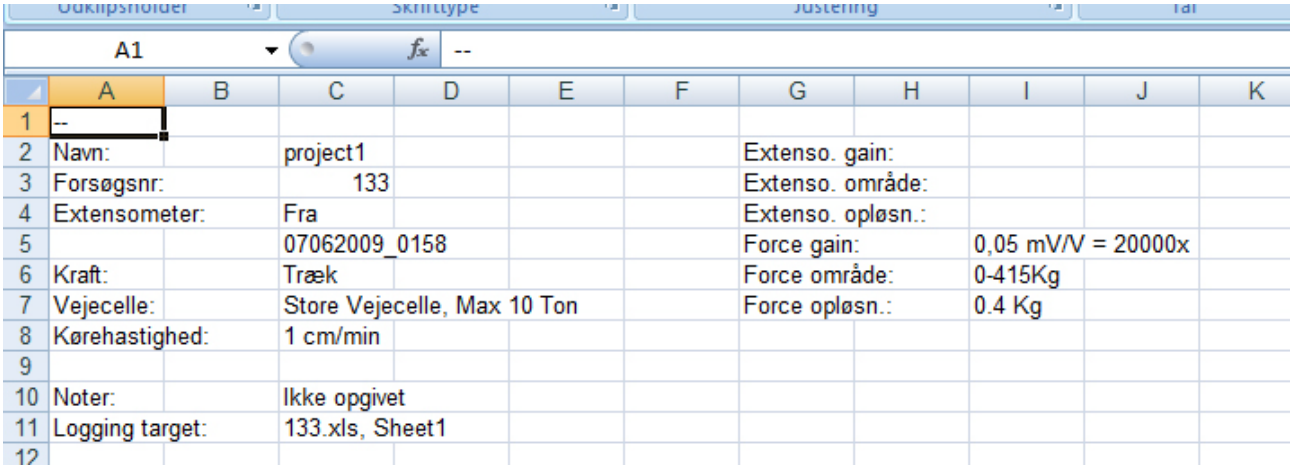
The measure amplifier is placed between the tensile machine and computer. The function of this amplifier is to convert electrical resistance from the tensile testing machine to voltage that is interpretable for the computer. The machine must be calibrated due to the test setup on the computer. The calibration relies on the weight cell on the test machine and the load measurement interval chosen on the computer. By choosing the measurement interval on the computer, a certain value is given by the computer program, which the amplifier should be set to. The machine has to be adjusted so there is a small positive number on the scale on the amplifier, since negative values cannot be processed, see the picture below.

The measure amplifier. The red marking shows where the amplifier is adjusted due to force measurement area from the computer. Further adjustment (where the measurement is given a small positive start value) is made in the green area.

4.1.5 Data collection

The amplifier has made it possible for the computer to interpret the test machine data and can now process the data. An excel add-in has been developed where the load measure interval and the elongation speed can be chosen (elongation speed still has to be controlled on the test machine). The data collection is started before the tensile machine is started and stopped before the tensile machine is stopped.

A screen shot of the excel data sheet can be seen below. The data sheet is from a test with the large dog bones.



	A	B	C	D	E	F	G	H	I	J	K
1	--										
2	Navn:		project1				Extenso. gain:				
3	Forsøgsnr:		133				Extenso. område:				
4	Extensometer:		Fra				Extenso. opløsn.:				
5			07062009_0158				Force gain:		0,05 mV/V = 20000x		
6	Kraft:		Træk				Force område:		0-415Kg		
7	Vejecelle:		Store Vejecelle, Max 10 Ton				Force opløsn.:		0.4 Kg		
8	Kørehastighed:		1 cm/min								
9											
10	Noter:		Ikke opgivet								
11	Logging target:		133.xls, Sheet1								
12											

Screen shot from the excel sheet. Here with the information for the tensile test for large dog bone

The variables that can be found from the excel sheet are:

Variables derived from the excel sheet	
Test time, T	[s]
Elongation, ε	[mm]
Load, m	[Kg]

4.1.6 Calibration of the test setup

There are three different elements in the calibration of the tensile test that has to be taken into account:

1. The measured distance travelled
2. The force measured by the test
3. The deflection of the tensile machine

These parameters had already been tested and calibrated lately by the supervisor of the machinery regarding the large weight cell, but for the small weight cell a new test was made:

The length was tested by setting the machine to travel for 10 minutes at a speed of 10 mm/min. The travelled distance was physically measured between the clamps with a vernier caliper and compared with the values given by the computer.

The force measurement can be tested with either a weight or another weight cell that can be trusted. This test used a 10 kg weight and registered the load before and after the weight was applied.

$$m_{before} = 3.83\ kg$$

$$m_{after} = 13.95\ kg$$

This gives a difference of 0.12 kg per 10 kg, meaning a variation of 1.2 %.

To make up for this variation the conversion between load in kg and force in N can be made as follows.

$$10.120\ kg \sim 98.2\ N$$

Where it is normally found as:

$$10\ kg \sim 98.2\ N$$

The deflection in the tensile machine occurs when it is exposed to high forces, but since the tensile machine is made for metal tensile tests where the forces are a much greater, it is not found necessary to take the deflection into account. If it was necessary to take into account an optical extensometer could be used to avoid the presence of deflection in the data.

4.1.7 Setup for large dog bones tests

For the tensile test a regular tensile testing machine is used. Two clamps holds on to the specimen while the lowest clamp elongates the specimen at a constant velocity. The velocity is manually controlled at the machine. The tensile testing machine is connected to a computer where the information is collected in an excel sheet. In the setup of the test a number of values where kept constant:

Test machine setup – large dog bone test	
Measurement type	Tensile
Weight cell	Large one (10 tons)
Velocity	10 mm/min
Force gain	0.05 mV/V = 20000x
Load measurement interval	0-415 kg
Load resolution	0.4 Kg

4.1.8 Setup for the small dog bone test

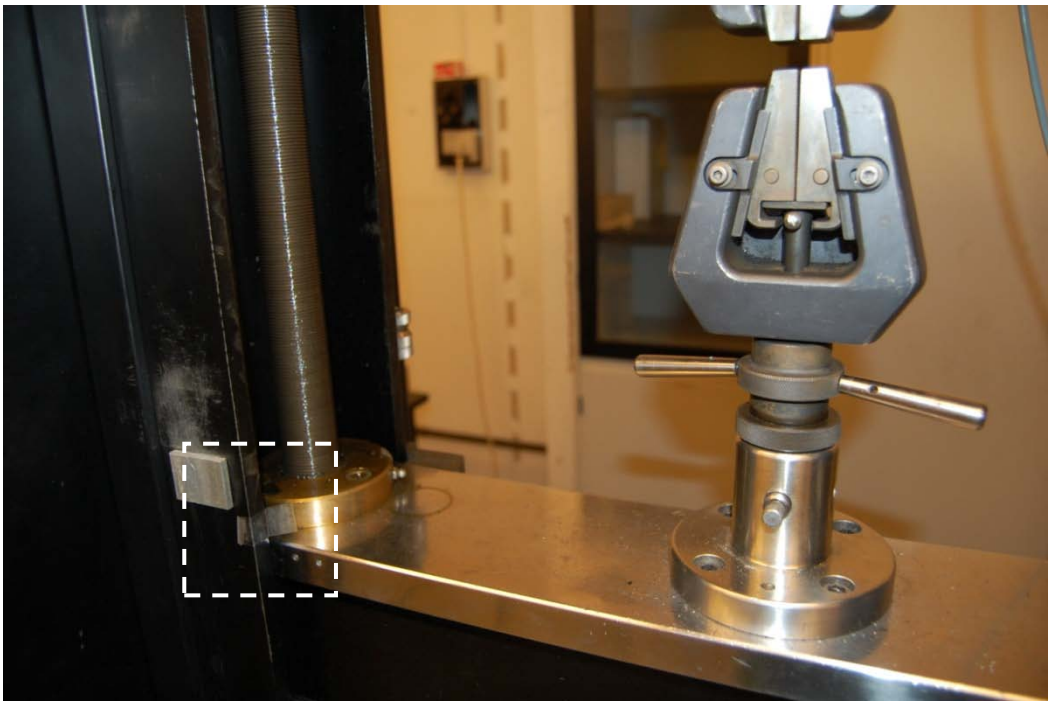
For this test the large weight cell is replaced with the small one, since the load to be measured is a lot smaller then with the large dog bones. As can been seen from the table below, the force resolution is 0.032 kg which gives a sufficient accuracy in the measurements.

Test machine setup – small dog bone test	
Measurement type	Tensile
Weight cell	Small one (500 kg)
Velocity	10 mm/min
Force gain	0.1 mV/V = 10000x
Load measurement interval	0-32 kg
Load resolution	0.032 Kg

4.1.9 Procedure

Before starting the test the computer and amplifier is set up. The force gain on the amplifier has to be adjusted to the load measurement interval from the computer and weight cell on the test machine.

When testing series with the same dimensions it is useful to indicate on the machine where the position of the clamps is optimal before start. This is done by clamping a pre-test test specimen and adjusting the distance between the clamps until it is satisfying, and then applying an indication mark on the machine, e.g. a piece of tape as seen in the figure below.



Mark on the tensile machine indicating the start position for the test

Then the testing can begin. The procedure is now as follows:

1. Setup the computer – name, load interval and speed
2. Ready the tensile machine – adjust the position of the clamps due to the indication mark and ensure that the speed is the same as one the computer, i.e. 10 mm/min
3. Clamp the test specimen – first the lower clamp and then the upper
4. Start the measurement on the computer
5. Start the tensile machine
6. After break or after the desired results are reached the computer measurement is stopped
7. The tensile machine is stopped

4.2 Microscope analysis

The microscopic analysis took place at microscope analysis laboratory at DTU. Three series of specimens is tested; large ABS dog bones, small ABS dog bones and large PP dog bones. The small PP dog bones did not break and will therefore not be examined.

4.2.1 Objective

- Analyze contours of the break of the dog bone seen from the side
- Examine the topology in the cross section of the breaks
- Document findings in microscope pictures

4.2.2 Test setup

The optical microscope used for the test is a LEICA DFC320 as seen in the figure below.

Picture of the optical microscope LEICA DFC320 that was used for the microscope analysis

The lowest magnification level is an 8 times magnification and the highest is 100 times magnification. The microscope has an installed camera which is connected to a computer. It is possible to see the live view of the camera on the computer, but for details it is easier to look through the microscope.

The test setup for the microscope analysis. The microscope is connected to the computer that can process the pictures from the microscope camera

4.2.3 Procedure

A specimen from each series was picked out for analysis, so a specimen for each different process condition and each different material and size was analyzed.

The microscope is set at the lowest magnification level 8 for the test of the large dog bones. First every specimen was examined from the side and from the top.

For the small specimen the microscope´s magnifying level is increased to 50 and in the same way first analyzed from the top and the from the side. None of the small specimens for PP was analyzed in the microscope since they did not break in the tensile test.

When a satisfying view of the specimen is reached a picture is taken on the computer. With the software on the computer it is possible to apply a scaling indicator, so a bar showing 2 mm is applied for all the large dog bones and a bar showing 0.5 mm is applied for all the small dog bones. To apply these bars a table for conversion between pixels and mm related to the magnification level is used.

Afterwards all pictures are submitted to appendix (see appendix 2.3-2.5).

The results and a discussion of the microscope test are found in section 6.

5 Sources of error

5.1 Sources related to specimen production

5.1.1 No validation of data given by machine

While producing the test specimens we did not validate the data given by the injection-moulding machine. Therefore there might be inaccuracies in stated values such as Mould Temperature, injection speed, injection pressure and so forth, which could be sources of error.

5.1.2 Temperature

For some of the low mould temperatures the injection machine was not able to keep a steady low temperature of the mould due to a relatively high room temperature and the warm polymer. Therefore the actual mould temperature was a few degrees Celsius above the intended temperature, which has affected some of properties of the specimens produced with very low mould temperatures.

5.1.3 Use of two different machines- hard to compare

The large and small specimens were not produced by the same injection-moulding machine, which would have been preferable, but not possible due to the physical limitations of the two machines respectively. If we were able to produce all specimens at the same machine, the process parameters would have been more comparable and thus diminishing the sources of error in this regard.

5.1.4 Humidity of the materials

The humidity of polymers is likely to influence on the properties of the produced specimens. Regarding our PP specimens the influence of humidity is not critical and therefore we did not dry the granulate before the specimens were produced. For ABS the humidity is of greater importance and we therefore had to dry the granulate for three hours before it was ready for production. However, it is possible that the granulate has adopted some humidity from the surroundings after being dried due to especially the temperature difference. Furthermore the ABS might also have obtained some humidity from the surroundings after being produced. In both cases the humidity of ABS influences the mechanical properties and because we did not have complete control with the humidity of the specimens, this could be a source of error.

5.1.5 Time from production to test

During the testing of the different materials we found that the time from when a specimen was produced until it was tested was of great importance for the behaviour of the material. If a specimen was tested shortly after production it had a tendency to break much sooner than specimens that had rested for more hours. We did one test series of specimens that was produced only few hours before the testing and found that we had to repeat that test series due to incomparable results.

After this incident we decided not to test specimens that were produced within five hours. By doing that the test results was much more alike, but we were not able to test every specimen at the exact same time after production, which might influence the results.

5.1.6 Impurities and air bubbles

In most of the cracks from the broken specimens we are able to detect impurities and sometimes even small air bubbles in the material. These impurities and air bubbles are related to the production process and can be caused by different factors such as material leftovers from earlier produced specimens, the use of additives and colour pigments, impurities in the granulate, dust in the injection moulding machine etc.

Microscope picture of the cross section of a specimen showing the topology of the break, notice the air bobble in the center and the circular formation around it

5.2 Sources of error related testing procedure

When evaluating the test results it is important to be aware of potential sources of error, which will be discussed in the following section.

5.2.1 Elongation was measured without extensometer

For the test results to be as accurate as possible, it would be preferable to use an extensometer to measure the elongation of the specimen. An extensometer was unfortunately not available in the institute where the tensile tests were performed. We have instead used the elongation data given by how far the jaws of the tensile testing machine were moved apart from each other.

The data given by the movement of the jaws might not be an exact measure of the actual elongation of the test specimen because there is a risk that some machine parts will deform slightly and thereby make the measurement inaccurate. Taken into consideration that the tensile testing machine is able to perform tests with a load of 10tons we do not find it likely that the machine would deform significantly during the tests that we performed where the maximum load was not more than 150kg. However there is a possibility that some of the machine parts will move slightly in relation to each other and thereby make the results inaccurate.

Another possible source of error related to the use of jaw movement as a measure of elongation, is that if there is a slip in the clamping of the specimen, then there will be jaw movement without any elongation of the test specimen. This will especially influence the calculation of Young's Modulus. We only observed this incidence a few times during the tensile tests of the small specimens, but every such test was discarded and

redone with a new specimen. The incidence can be seen in the load-elongation graph as a straight line, which can be seen in the figure below.

Example of "slip" in the clamping, which is represented by the flat section of the curve marked by the red circle.

5.2.2 The measure interval

While testing the large specimen, the measure interval for the Instron tensile testing machine was 0,4kg due to the used weigh cell. From this we can evaluate the inaccuracy (Ia_L) of the tensile tests of the large specimen related to the measure interval by a simple formula stated below. From this formula it can be derived that the inaccuracy is highest in the beginning of the tensile test (when the load is small), which might influence the calculation of Young's Modulus.

$$Ia_L = \frac{0{,}4kg \cdot 100\%}{x}, \quad 0 < x < 150kg$$

Here x represents the load in kg. (The interval is an approximation of the measured load interval with 150kg as x_{max})

The inaccuracy related to the measure interval at the approximated maximum load is for the large test specimens

$$Ia_{L,MaxLoad} = \frac{0{,}4kg \cdot 100\%}{150kg} = 0{,}26\%$$

A similar formula can be derived from the tensile testing of the small specimen. The measure interval related to the small weight cell used while testing these specimens were 0,032kg.

$$Ia_S = \frac{0{,}032kg \cdot 100\%}{x}, \quad 0 < x < 8kg$$

The weight interval is an approximation of the measured load interval with 8kg as x_{max}.

The inaccuracy related to the measure interval at the approximated maximum load is for the small specimens

$$Ia_{S,MaxLoad} = \frac{0,032kg \cdot 100\%}{8kg} = 0,4\%$$

5.2.3 Use of measure amplifier

The computer program, which records the test data, cannot handle negative values and thus the measure amplifier has to be levelled just above the nominal zero when no load is applied. The measure amplifier can be seen in the picture below after it has been levelled just above zero.

Picture of the measure amplifier that has to be leveled above 0

In order to correct for this inaccuracy we have to subtract the measured load after the break (L_{ab}) of the test specimen.

Regarding the large specimens $L_{ab,L}$ was 6,5kg ± 0,02kg while for the small specimens $L_{ab,S}$ was 3,92kg ± 0,02kg.

Regarding the specimen that broke during the tensile tests the differing L_{ab} did not influence the results, because the exact value of L_{ab} was subtracted from the test results.

The diverging L_{ab} does however influence the specimens that did not brake because the exact value of L_{ab} was never obtained. We therefore subtracted the standard L_{ab}'s stated above leaving an inaccuracy of ± 0,02kg for the test results of the specimens that did not break.

5.2.4 Fixation of test specimen

When fixating the specimen in the tensile testing machine there is a possibility to put stress on the specimen, which will be displayed as a starting load on the specimen in the test result. The applied stress during fixation of the specimens will presumably not affect the maximum yield strength of the test, but will make the calculation of Young's Modulus inaccurate.

Regarding the small test specimens it was necessary to tighten the jaws of the tensile testing machine very hard to make them hold on to the specimens, which for some of the test specimens meant that we incidentally came to tighten them so hard that they started to deform plastically. We have not used any of

such results but had to do them over again. However there is a theoretical possibility that even though no stress is displayed when a specimen has been fixated and is ready for testing, there might have been applied enough stress to deform the specimen plastically during the fixation process, which will influence the behaviour of the relevant specimen. In the picture below the fixation of a small specimen can be seen.

Fixation of a test specimen- risk of putting stress on the specimen or twisting it.

Another possible source of error regarding the fixation of the specimens is the possibility of twisting the specimen while performing the tensile tests. The reason for this is that the jaws can turn slightly on a vertical axis, which means that if they are not aligned accurately before the start of the tensile test, there might be an inaccuracy of the test result related to the “twisting” of the specimen.

5.2.5 Influence from the Surroundings

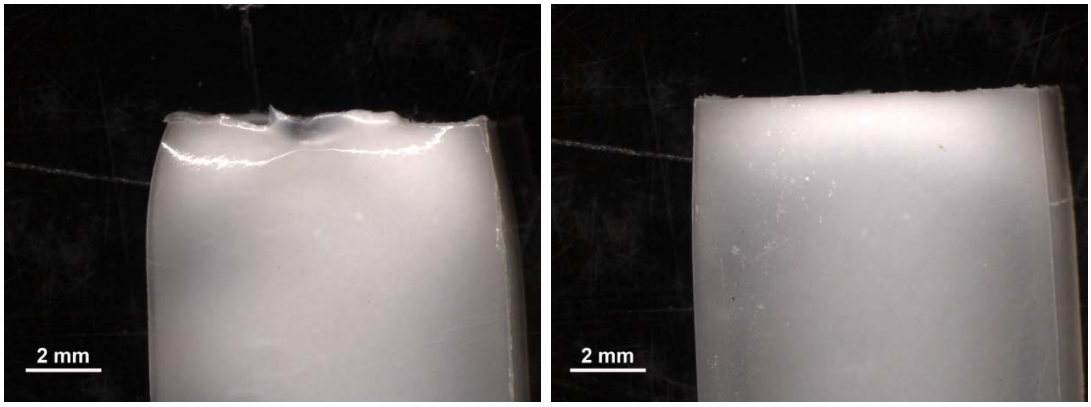
The environment in which the testing is performed is of great importance; the tensile testing machine is placed at DTU in a basement under building 204 where the environment is very stable with a room temperature of 21°C and an air humidity of 58%. Furthermore no direct sunlight is let into the room. Therefore we consider the testing environment as stable and thus not influencing the test results in a critical way.

6 Theoretical assumptions related to actual findings

6.1 Mechanical properties related to injection speed

The injection speed has influences the mechanical properties of the produced specimens. If a low injection speed is used the specimen will normally tend to become more ductile with a lower maximum tensile strength. The reason for this is that the orientation of the polymer chains in the direction of injection is not so strong, which will lower the maximum tensile strength. Furthermore when a low injection speed is used the specimen has a possibility to straighten the polymer chains in draw before fracture, which is the reason why these specimens are able to stretch more (*Lamminmäki et al.*) A low injection speed will furthermore influence the thickness of the skin layer, which will be elaborated in a separate section below (section 6.4).

The pictures below are an example of how the injection speed affects the mechanical properties of the specimens. They are both of PP specimens produced with constant production parameters except for the injection speed that was lower on the specimen to the left, making it more ductile, which the necking indicates (necking is described in section 6.3 below).



Left: **Specimen 412: injection speed 100mm/s, mould temperature 45®C.** ***Right*****: Specimen 512: injection speed 250mm/s, mould temperature 45®C. The specimen with the lowest injection speed seems to me more ductile due to necking of the semi crystalline polymer**

6.2 Mechanical properties related to mould temperature

The mould temperature is not likely to influence the properties of ABS in a significant way, because this material is amorphous and thus will not form crystals.

Regarding semi crystalline materials like PP, the mould temperature influences the mechanical properties of the produced specimens. A high mould temperature will lead to a higher maximum tensile strength and a more brittle specimen. This is because the specimen will need more time to cool down and thus the time spent in the crystallization temperature range will increase providing the crystals more time to grow and form (Mills 2005). Furthermore the slow cooling enables a better relaxation of the polymer chains, which tend to reduce the inner stresses in the specimen (*Lamminmäki et al.*).

Another important factor related to mould temperature, which influences the mechanical properties of the specimens, is that the size of the skin layer is depending on the temperature difference between the mould temperature and the melt temperature. With a high mould temperature the temperature difference is

minimized making the skin layer relatively thinner and making the specimen solidify more uniformly with a higher degree of crystallinity.

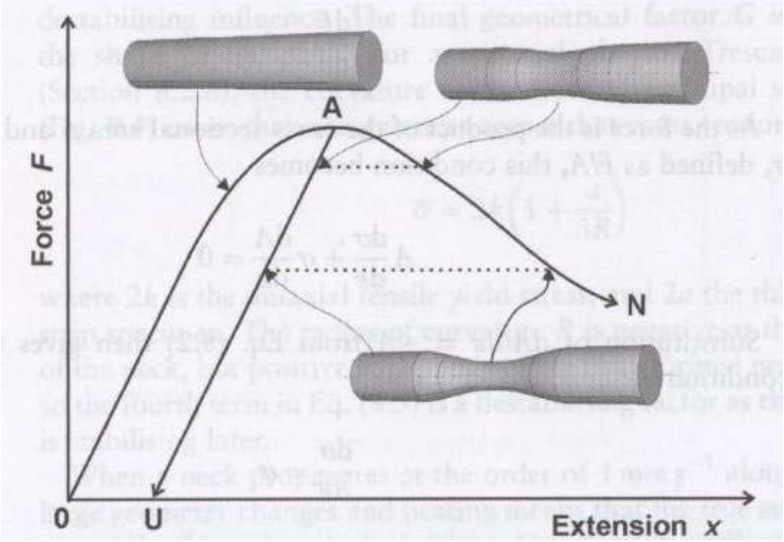
From the results in general, this tendency is hard to see unambiguously, which is assumed to be due to a relatively large temperature difference between the melt and the mould temperature making the influence from our conducted variations in mould temperature less significant.

6.2.1 Behavior of the small PP specimens

When testing the small PP specimen we found that these specimens were much more ductile than the large specimens and we never succeeded in breaking a micro PP specimen. A possible explanation to this phenomenon was found in the book “Plastics” (Mills 2005) where the effect of cooling rate on crystallinity is described. At one point Mills argues: “If the maximum possible crystal growth rate in a semi-crystalline polymer is moderate, it may be possible to cool thin moldings sufficiently fast enough to avoid any significant crystallization.”

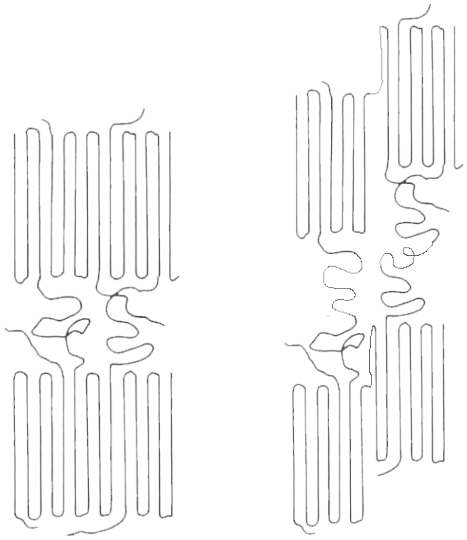
6.3 Necking

Necking occurred on many of our specimens after reaching the maximum tensile strength. We found that the more ductile a specimen the more necking occurred. A short description of necking (from position A in the figure below) was found in a book called “Plastics” (Mills 2005): “A non-uniform strain state develops, as parts of the specimen elastically unload, and the plastic strain in one region increases to form a *neck*. The plastic deformation of the neck is partially driven by elastic energy release from the rest of the specimen…”



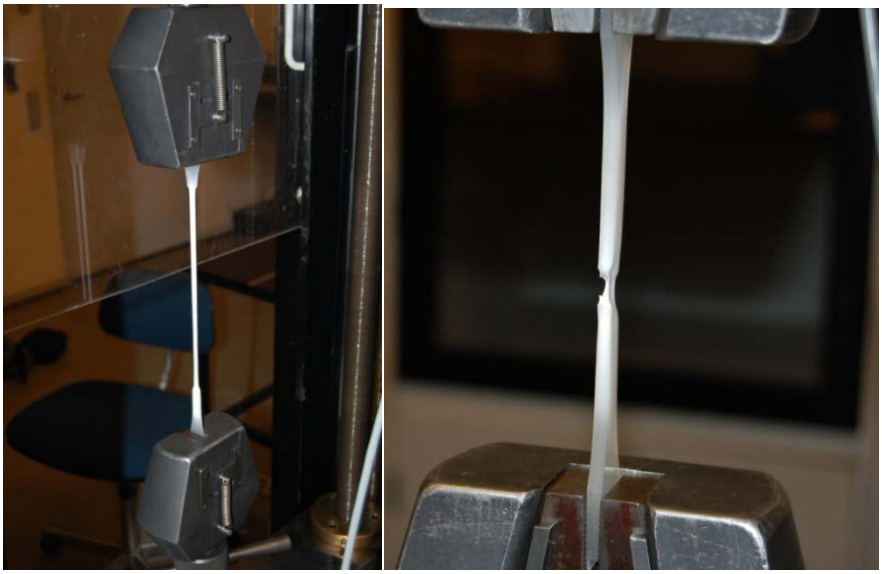
Force vs. Elongation in a tensile test. From 0 to A the specimen extends uniformly. Beyond A the end parts unload elastically along the path AU, While the necked portion proceeds along path AN

Regarding the semi crystalline PP specimens necking can furthermore be described by crystals splitting up into smaller crystals without the polymer chains breaking, which enables the material/specimen to stretch without breaking.



Semi crystalline structure changes when necking occurs. *Left:* the semi crystalline structure before necking. Right: the semi crystalline structure after necking- the crystals split into smaller crystals without the polymer chains breaking

The pictures below show two examples of different states of necking that occurred during the tensile strength tests.



***Left:* An extreme example of necking of a PP specimen (a fully necked specimen strains homogeneously.) *Right:* fracture begins in a necked section – note that transparency disappears when the material deforms plastically.**

6.4 Skin layer

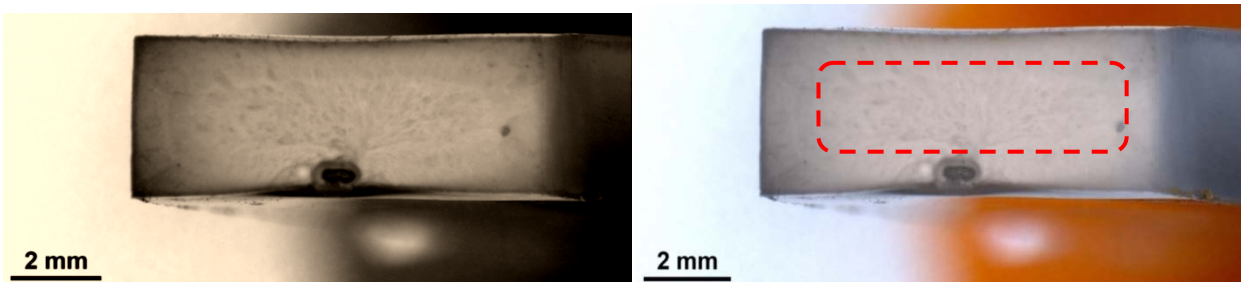
When the material is injected in a relatively colder mold, a skin layer will be created because of the material in touch with the mould will solidify sooner than the material located in the core of the specimen. The properties and the size of the skin layer are depending on both of the parameters that we have been varying during the production of specimens: Injection speed and mold temperature.

With high injection speed, the skin layer will be relatively thinner due to friction between the mold and the material and due to a more uniform solidification process. With a high mold temperature the skin layer tends to be thinner due to a more uniform solidification process (*Lamminmäki et al.*)

Regarding the ABS specimens the orientation of the polymer chains is of most significance for the mechanical properties, thus making the skin layer indirectly influencing mechanical properties of the ABS specimens.

The mechanical properties of the skin layer are different from the properties of the core layer in the semi crystalline polymers due to orientation of polymers and the solidification of the material. In general, the skin layer will cool sooner than the core and thus not be as crystalline as the core material. Also the orientation of polymers is different, and the polymers in the core of the material will tend to be more aligned (*Lamminmäki et al.*). This means in short that the skin layer is more ductile and will have a lower tensile strength and vice versa.

The pictures below are of PP specimen 512 that broke because of an air bubble in the skin layer, which caused the specimen to break before any necking occurred. In the microscope it was possible to see the skin layer, which has been marked on the picture to the right.

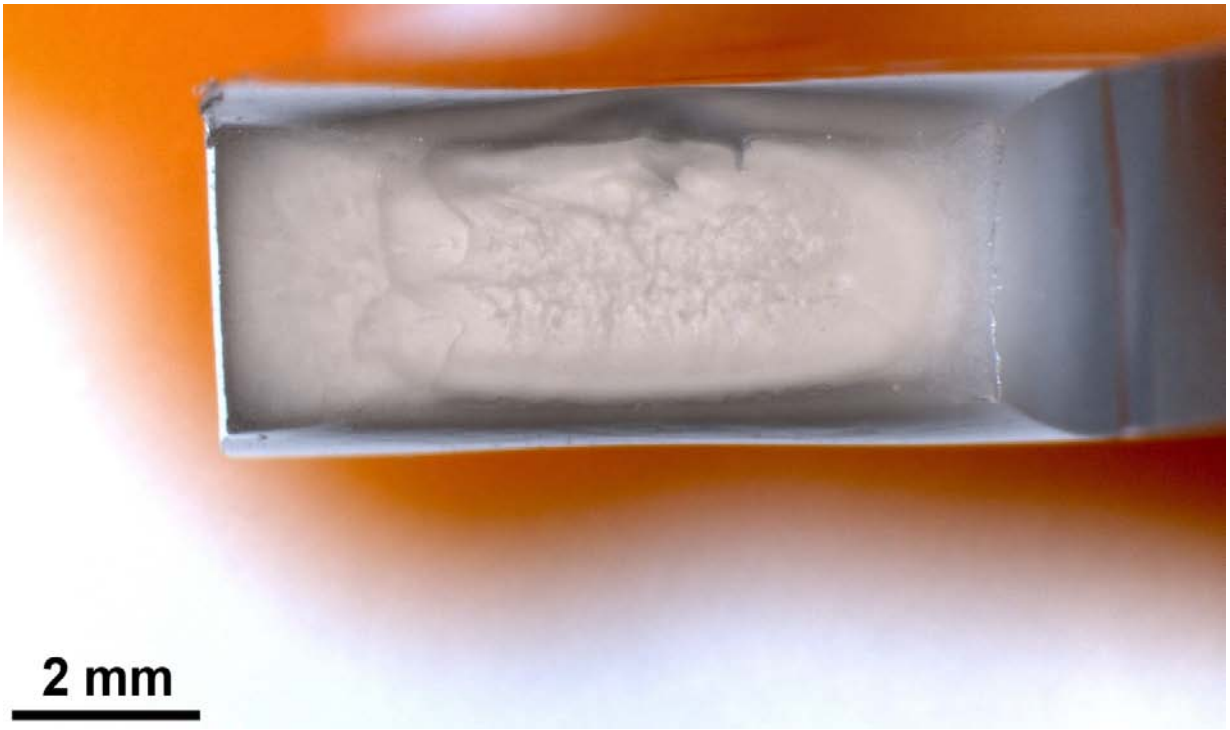


Specimen 512: *Left*adjusted light- skin layer is slightly visible. *Right* marked skin layer. Fracture caused by air bubble- no necking

The picture below is of PP specimen 412 that is produced with the same production setup as 512 except for a lower injection speed, which according to the above stated theory will cause a thicker skin layer in specimen 421.

It does not seem that specimen 421 broke because of an air bubble or an impurity in the material, but it seems that necking occurred especially of the skin layer that has been necked all the way to the core layer before the specimen broke. If we study the surface of the crack it seems that the core layer has a more brittle nature compared to the skin layer which corresponds with the theory. Another interesting aspect is

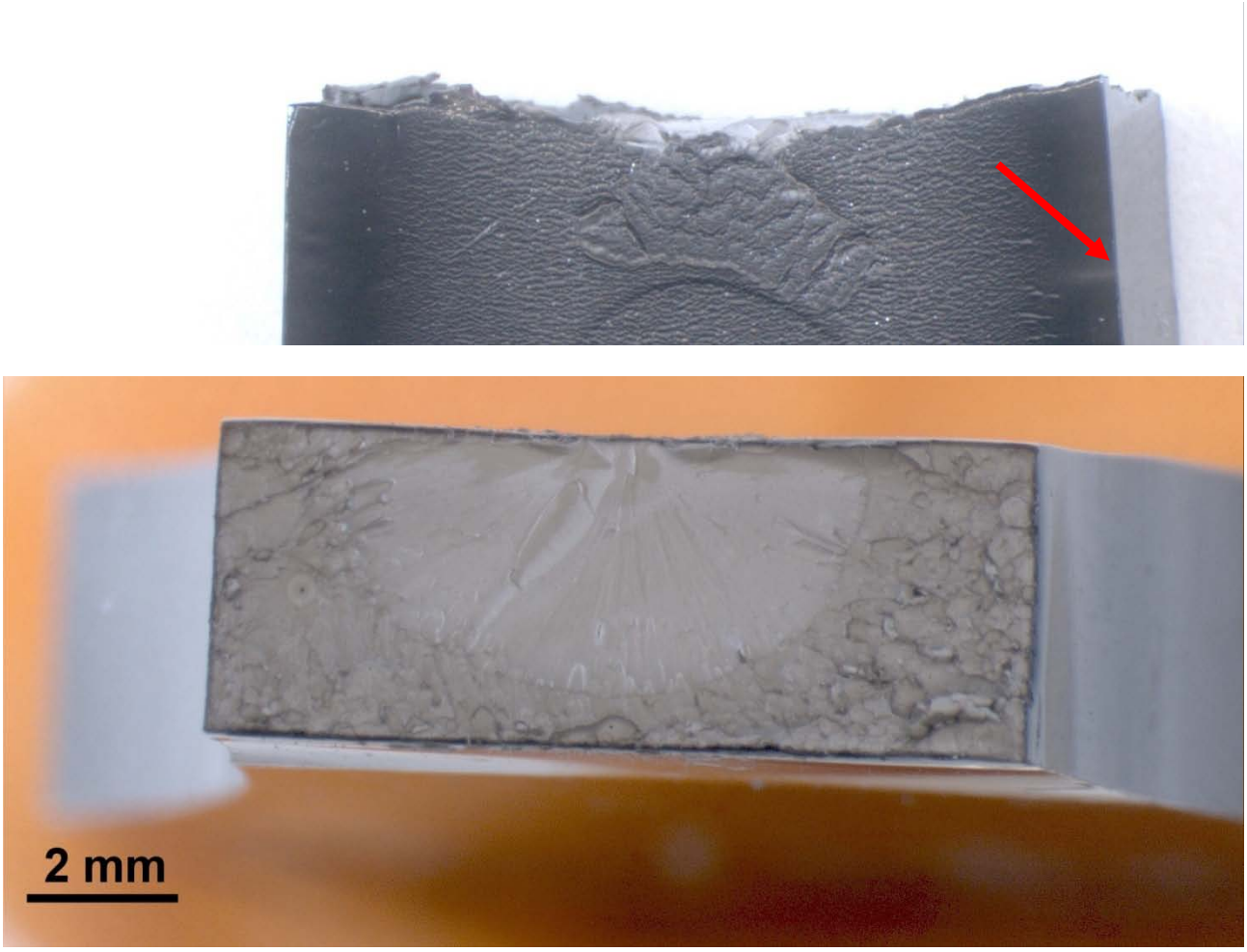
the light spread in the material, where the skin layer seems more transparent while the core seems more crystalline.



Specimen 412: Necking of the skin layer until core layer is reached

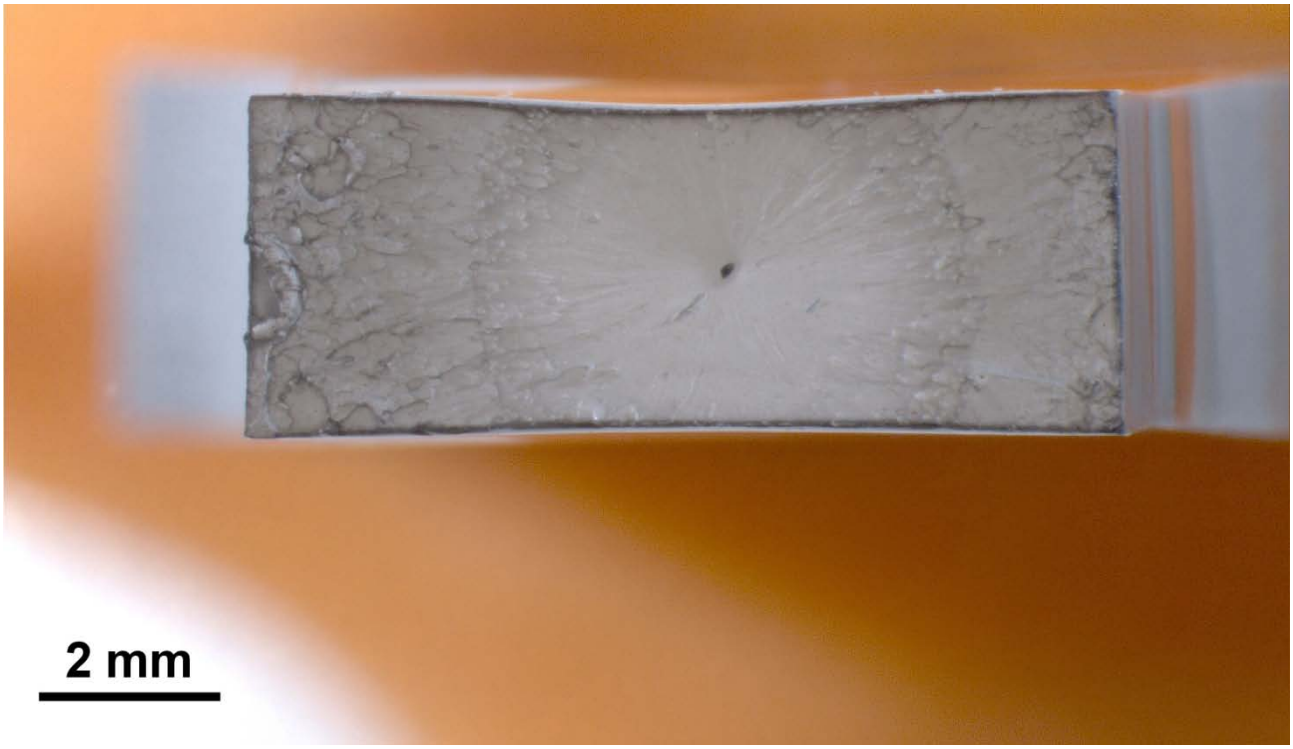
6.5 Fracture analysis

In most of the fractured specimens, the crack plane is perpendicular to the direction of the applied tensile stress. The initiation of the crack can be caused by different factors. In a perfectly shaped specimen in a perfectly performed tensile test the crack could initiate at any site as it is assumed that there is a uniform stress in the thin part of the specimen. However the crack initiation is most likely at a scratched surface where a craze will form before fail. The crack can be investigated by looking at the pictures from the microscope analysis. The resulting crack will propagate at a rapidly increasing speed leaving parabolic markings. The noses of the parabola point back towards the crack source so the direction of crack growth points back towards the crack source, so the direction of crack growth is radial from the craze. When the fracture completes the surface eventually becomes rough as subsidiary cracks initiate on planes parallel to the main crack plane (Mills 2005).An example is given below from specimen 632.



Specimen 632: *Above* the red arrow indicates another craze at the surface. *Below* the parabolic shape of the crack initiation from the craze is shown.

We did also experience internal crack initiation due to impurities or air bubbles in the material. If an impurity or air bubble is present principal stress in the surrounding material will exceed the value it would have been if the hole or impurity was absent, which creates a local stress concentration around the object. Like a surface craze the crack will spread around the hole or impurity until the specimens eventually brakes. An example is given below.



Specimen 434: Fracture caused by an air bubble

7 Results

This chapter presents and discusses the results from the experimental work described in chapter 3. First the data processing is presented including how the data is treated. After this the results from the tensile test is presented in sets, where all the specimens of the same material and size are collected in one graph. Furthermore the maximum tensile strength is represented in a diagram where all nine specimens with the same material and size are represented. Finally the statistically uncertainties are described. This is done for the four different sets; PP large, PP small, ABS large, ABS small.

Comparisons of the maximum tensile strength for PP and ABS are made after these sections. This also included a comparison with the manufactures value for maximum tensile strength.

A theoretical section is presented explaining the phenomenon observed from the results which include sections on the mechanical behavior due to injection speed and mould temperature, a fracture analysis and sections on the aspects of necking and the influence of the skinlayer.

7.1 Data processing

Since the Instron tensile testing machine could not deliver a combined output of the 180 conducted tests, it was necessary to process the test data separately and then combine interesting combinations of these. This section will describe the used data processing procedure.

All output data consist of three data rows, time [s], the elongation [mm] at the given time and finally the needed load [Kg] at the given time to produce the given elongation. The two first rows would be the same for every test since it was chosen to pull at a constant speed of 10 mm/s hence the only differentiating parameter from each test is the load.

Since the load value output from the Instron through the calibration equipment for the big and small weighing cell was respectively 6,5 Kg and 3,8 Kg too high this was corrected in excel.

7.1.1 Appropriate unit conversion

For some applications of the data, for instance representation of the load strain progress, it was fine to have the load in [Kg], but for other representations it was more scientifically correct to convert the load to a more appropriate unit. This is the fact when dealing with tensile strength which is normally referred to in Newton [N] or stress pressure [Pa]

To illustrate the data in a stress/strain graph, it is necessary to derive the stress from the load in kg and the cross section of the test specimen.

The forces are derived using Newton´s 2nd law, by multiplying the mass with the gravitational acceleration in Denmark of 9,82 m/s^2:

$$\mathbf{F = mg}$$

The stress pressure is derived by dividing the applied force with the specimen cross section, which is 39 mm^2 for the big dogbone and 1,5 mm^2 for the small.

$$\sigma = \frac{\mathbf{F}}{\mathbf{A}}$$

7.1.2 Average calculation

To achieve statistically supported results and to be able to compare the many different tests it was necessary to calculate averages from the individual tests. This was done in two ways seeking to meet different objectives.

7.1.3 Calculating the load, strain progress average

When comparing the progress of the applied load in relation to the strain for the many different tests it is desired to represent an average progress for the five specimens of each process parameter setting. This average should then be calculated by adding the respective values at a given strain and then dividing this with the number of included tests. This average gave us the opportunity to discard tests that clearly progress-wise was flawed. It could be that they started on a load value that was much too high due to over tightening of the clamps and thus of course would decrease the calculated average's representativeness of the test series.

7.1.4 Calculating the maximum tensile average

When comparing the maximum tensile strength on the other hand the average must be made from the individual maximum load values independent of the strain value. Otherwise small test imperfections will dramatically influence the result, since the slope of the curves is very high thus a small load peak location difference induces a very unreliable average maximum load value. Further this calculation method enable the inclusion of tests that were not usable in the calculation of the load progress, since the only value that matters is the maximum load independent of at what strain it is applied.

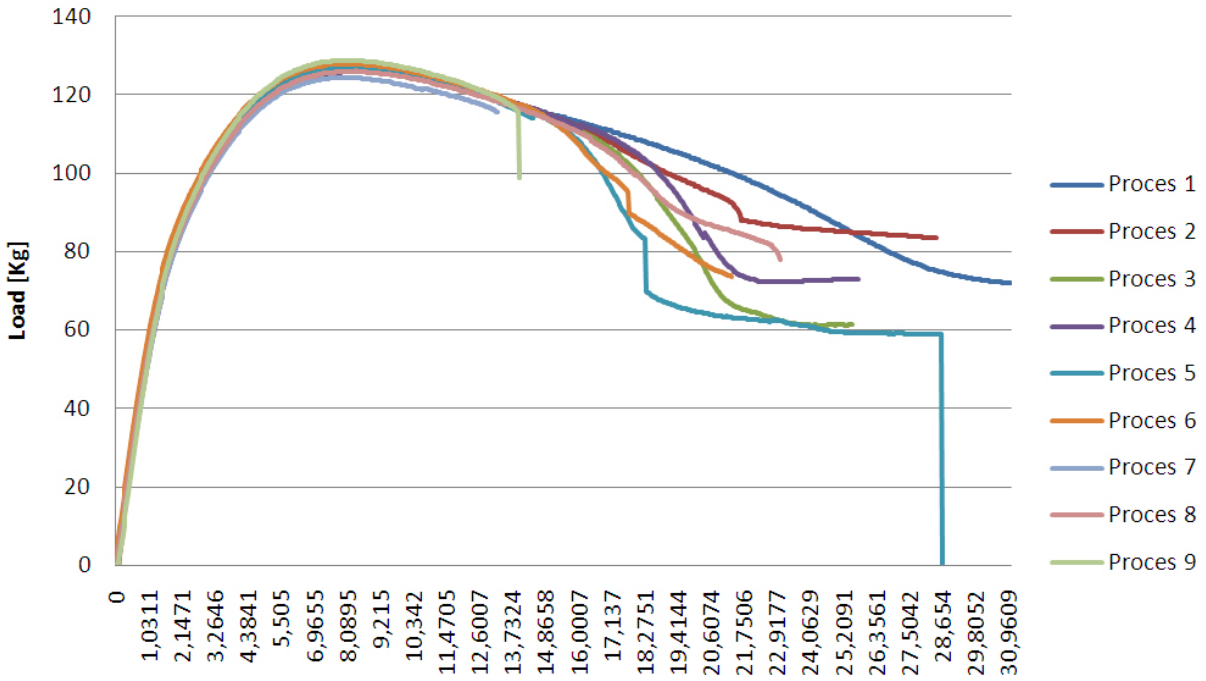
7.2 Set results

In this section the findings of the tensile testing of the four different test sets and the interesting interrelations between the sets will be presented along with a reasoning for the achieved results and a discussion of the statistically credibility of the results.

7.2.1 Set 1

Set 1 involves Big Polypropylene specimens where the mould temperature is varied from 30 C to 45 C and onwards to 60 C, which gives a range of 15 C on each side of the suggested temperature of 45 C. For each of the mold temperatures the Injection speed is varied from 100 mm/s to 250 mm/s onwards to 400 mm/s, which cannot be said to give a certain range in relation to the speed suggested by the manufacturer, since it is "as fast as possible". To see all data and more comparing graphic representations see appendix 1.2 and

1.3



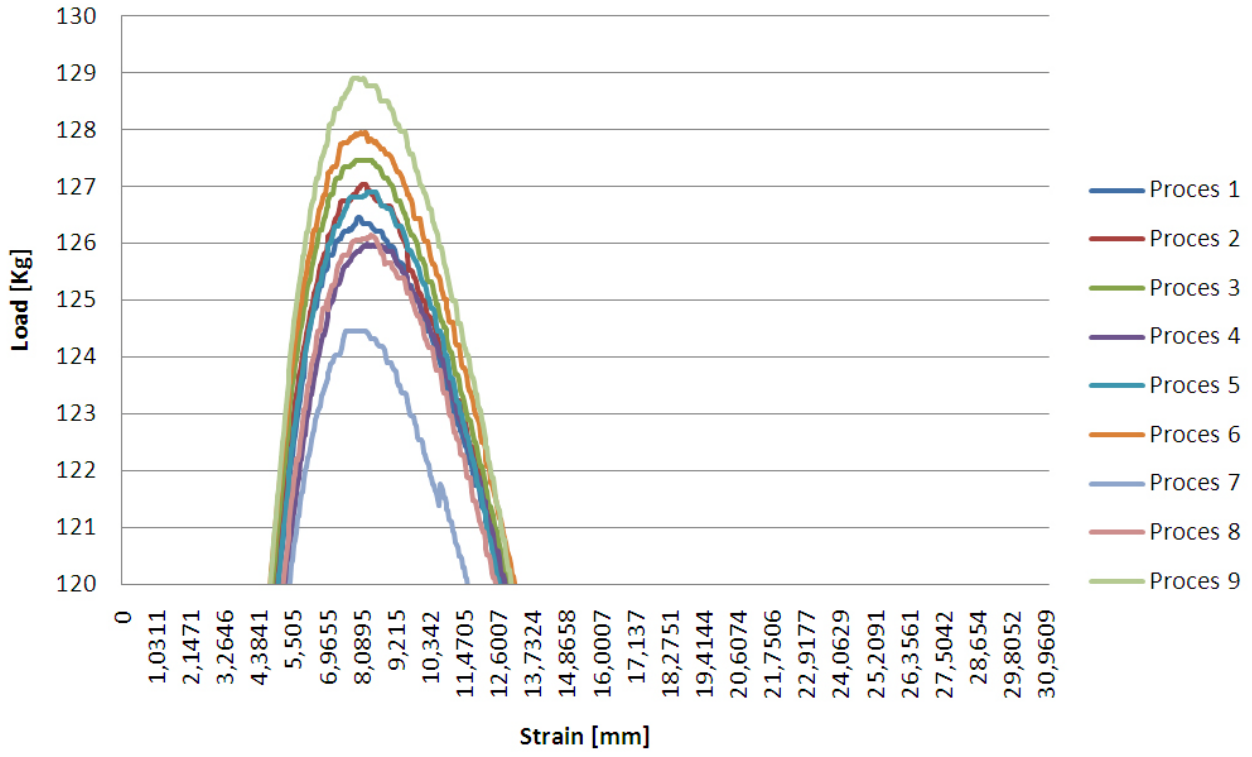
Load / Strain Big PP specimens for the 9 process parameter settings

The graph above shows the calculated load/strain average progresses of the nine different process parameter combinations of set 1.

It is remarkable that process 1 has a significantly higher ductility than the other processes, which could be caused by material leftovers in the injection-moulding machine from the previous production. Other than that it can generally be said about PP that a higher mold temperature gives a more brittle specimen behavior, which can be explained by a slower and more gradual cooling that allows the PP to adopt a more crystalline structure. A higher injection speed also seems to increase the brittleness, but to a much lower extend than the mold temperature and this cannot be concluded unambiguously on the basis of the number of tests that we have performed. This tendency can however be explained by the injection speeds influence on the polymer chain orientation which in the case of a high injection speed is oriented lengthwise in relation to the test specimen. When a lower injection speed is used the chains in the test specimen have a possibility to straighten, since they are not already straightened by the injection, and thus achieve a higher strain before fracture.

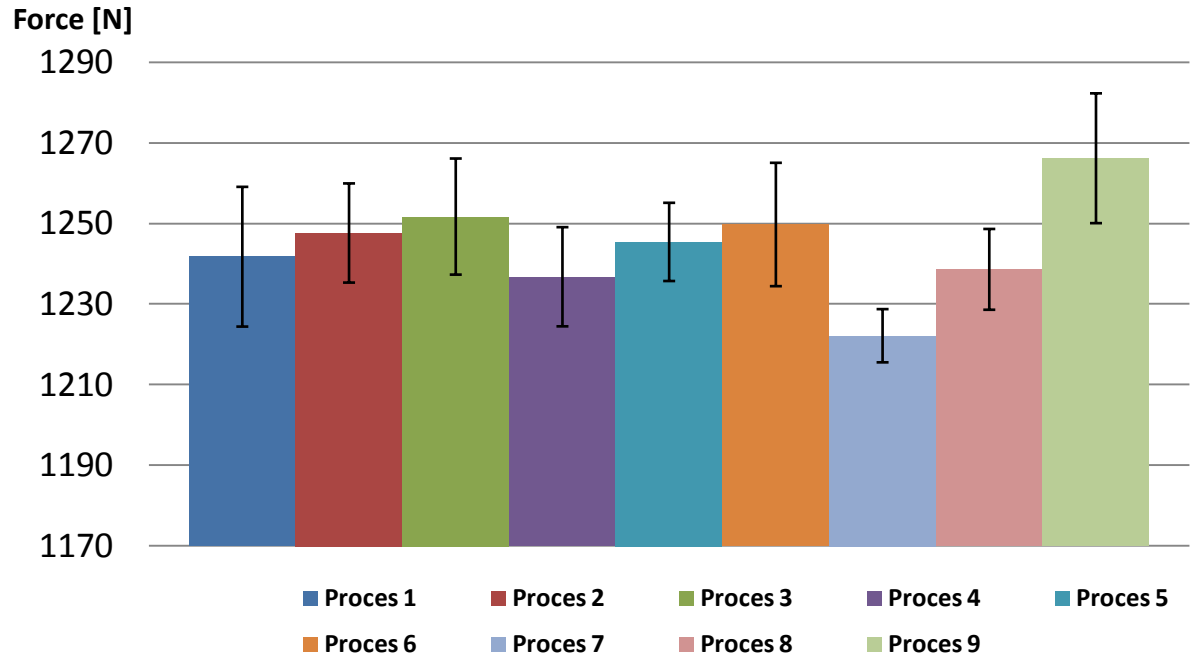
In a zoom view (below) it can be seen that the maximum tensile strength for all the different test parameters is reached at about the same strain of 8mm which is an elongation of 10 %. This similarity in the location of the peak tensile strength can be interpreted positively when assessing the homogeneity of the

test procedure and the data processing.



Load / Strain Big PP specimens Zoom view for the 9 process parameter settings

Since these graphs are build on the strain dependent average calculation they are not suited to be used for maximum tensile comparison which is why the below representation is introduced



Set 1 Bigl PP specimens maximum tensile strength comparison for the 9 process parameter settings

Here the more correctly calculated maximum average is represented in a more illustrative column diagram. The consistent tendency here is that the maximum tensile strength increases somehow linear with the injection speed, which can be explained with the prior mentioned lengthwise orientation of the polymer chains caused by high injection speeds.

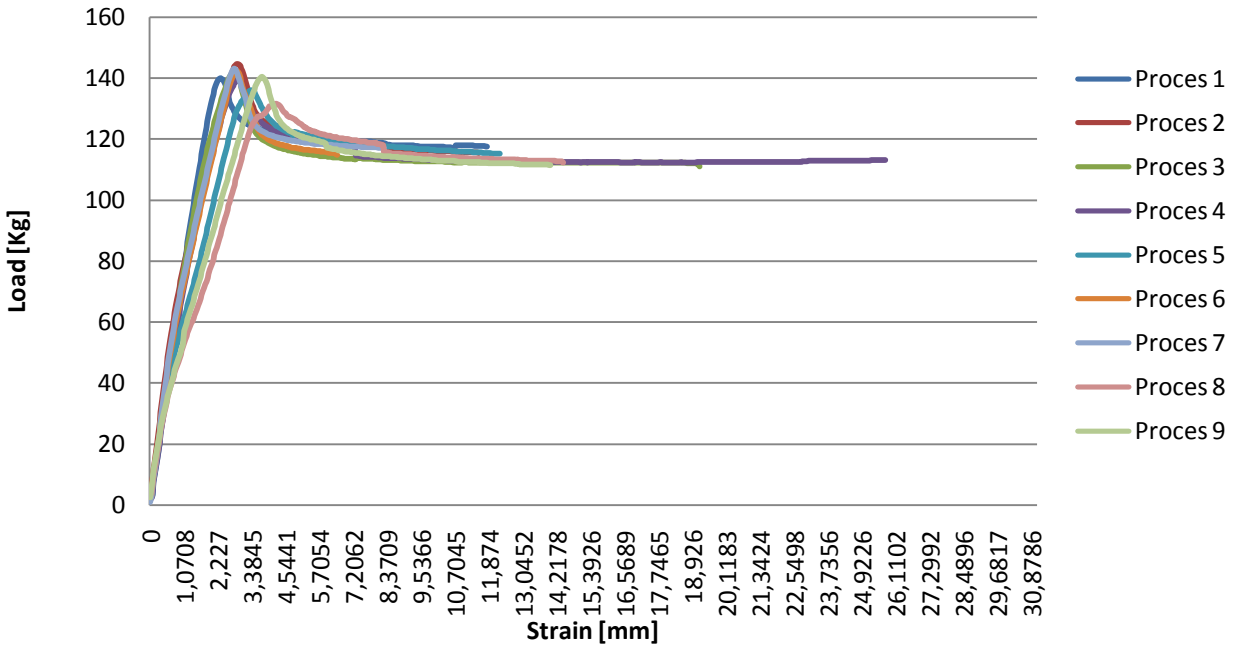
The influence of the mold temperature on the tensile strength for the large PP specimens seems to be of a secondary character, since a change in mold temperature influences the injection speeds affect on the maximum tensile strength. It could be suggested that when the temperature is low the orientating affect of the high injection speed is not achieved because of a very swift cooling that does not accommodate a homogeneous alignment of the polymer chains.

7.2.1.1 Statistical uncertainty of set 1

As seen from the tensile strength representation, where the standard deviation is showed for each process in the set, none of the above can unambiguously be concluded. Especially process 1 to 6 all lie more or less within the same maximum force range and must be characterized as weak tendencies. Process 7 to 9 on the other hand shows a much clearer tendency where there is almost no overlap of the standard deviation.

7.2.2 Set 2

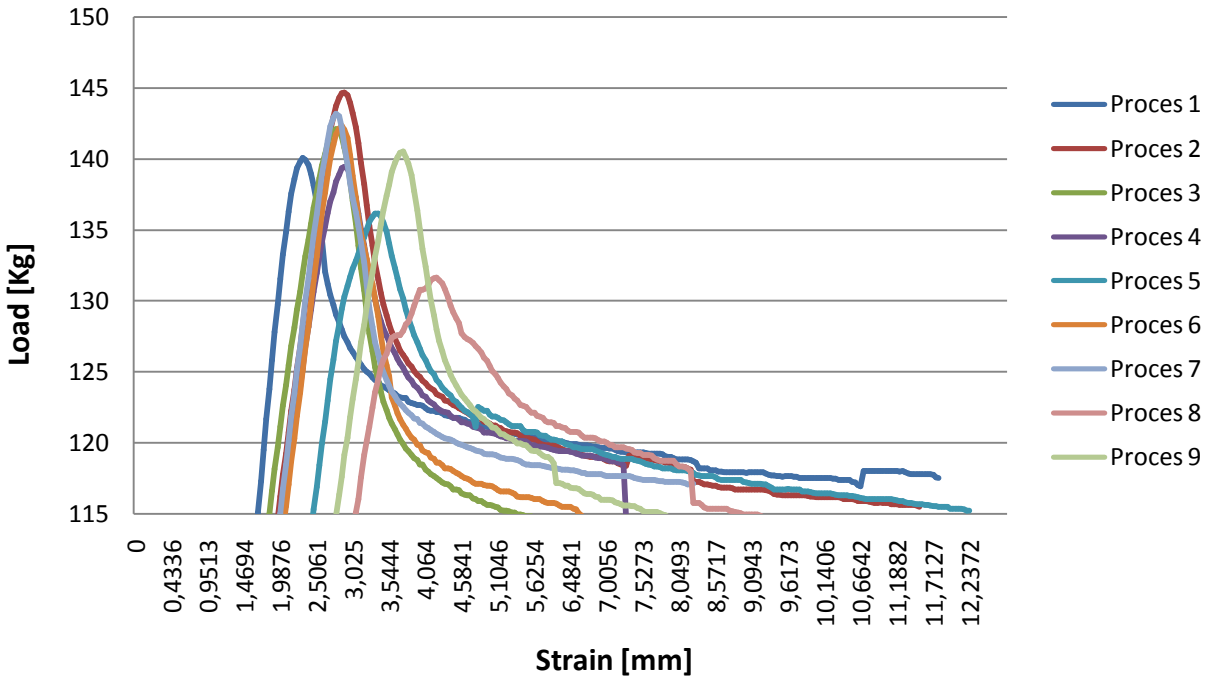
Set 2 involves Big ABS specimens where the mold temperature is varied from 40 C to 60 C and onwards to 80 C, which gives a range of 20 C on each side of the suggested mold temperature of 60 C. For each of the mold temperatures the Injection speed is varied from 25 mm/s to 100 mm/s onwards to 400 mm/s, which gives a range of respectively on fourth and four times the suggested injection speed of 100 mm/s. To see all data and more comparing graphic representations see appendix 1.4 and 1.5.



Load / Strain Big ABS specimens for the 9 process parameter settings

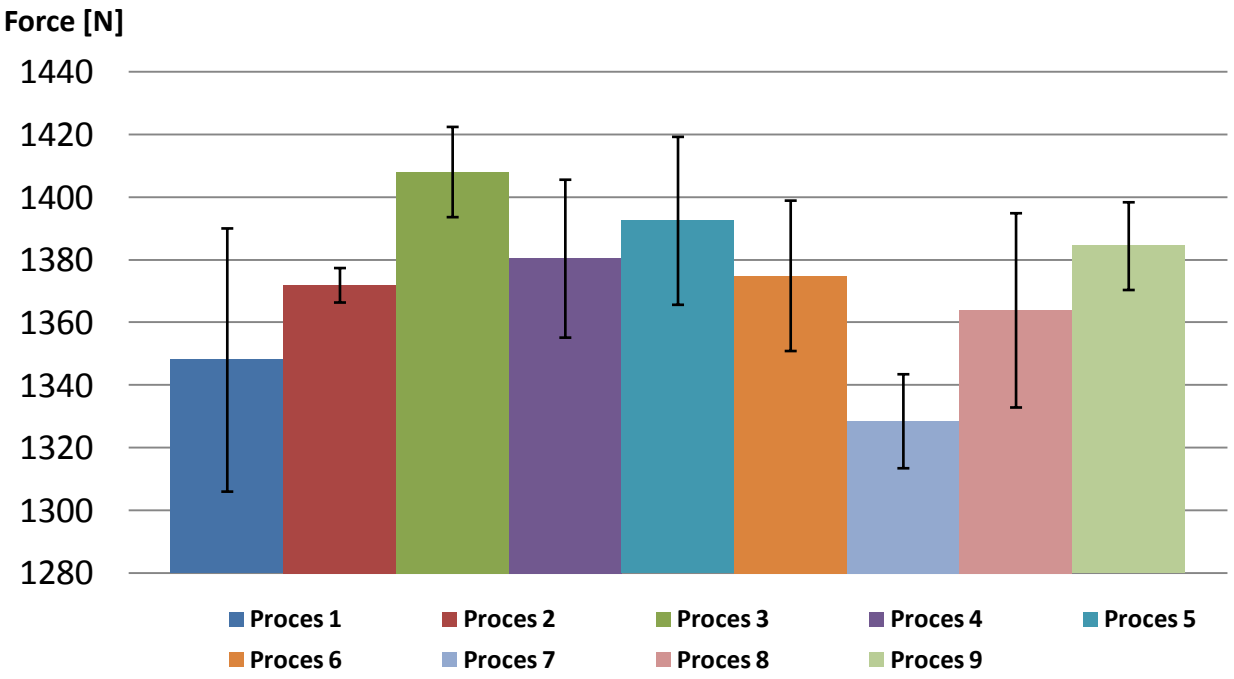
The graph above shows the calculated load/strain average progresses of the nine different process parameter combinations of set 2.

To be able to compare the load/strain develop more easily the horizontal axis is kept constant in relation to the representation of set 1. This shows that the ABS has a significantly higher stiffness than PP which was expected. Further in the zoom view below it can be seen that the peak tensile strength is distributed over a range of +-2 mm from the average peak tensile strength strain loacation at 2,5 mm, which could indicate that the varied process parameters, in opposition to with PP, influences this or that the homogeneity of the test procedure and the data processing has not been very good. This deviation should be seen in relation to the manufacturer stated maximum tensile stress elongation of 2,4 % which is 2,0 mm.



Load / Strain small ABS specimens Zoom view for the 9 process parameter settings

The more correctly maximum averages are shown below in a column representation.



Set 2 Big ABS specimens maximum tensile strength comparison for the 9 process parameter settings

Generally the same tendencies as with the large PP specimens are prevailing with exception of process 4 – 6 which are all much alike, besides these the tensile strength is increasing with the injection speed, which can be explained by the lengthwise alignment of the polymer chains caused by the high injection speed. The influence of the of the mold temperature can again not be characterized unambiguously as a clear tendency, which was also expected since ABS is amorphous and thus is not dependent on certain temperature intervals to grow crystals. It can though be said that the maximum tensile strength generally is higher for the manufacturer suggested mold temperature of 60 C. At this optimum temperature process 4-6, the maximum tensile strength seems to be more independent of the injections speed.

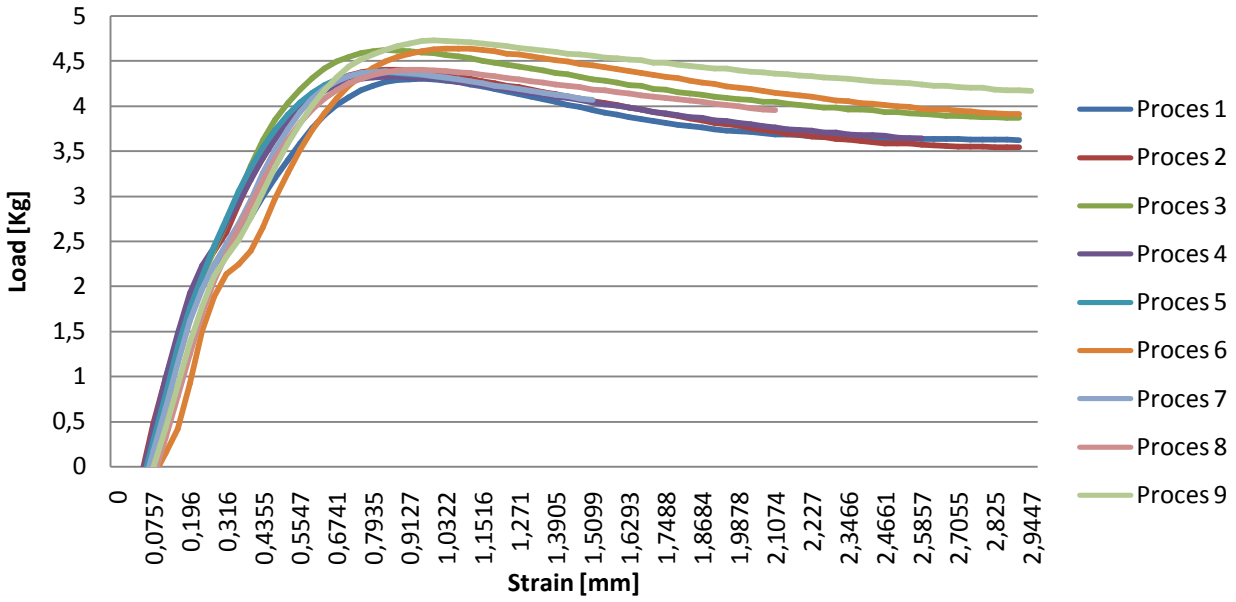
7.2.2.1 Statistical uncertainty of set 2

As seen from the tensile strength representation, where the standard deviation is showed for each process in the set, none of the above can unambiguously be concluded. In fact the deviation is relatively worse with a average standard deviation of +- 26,1 N which means that the results described are merely weak tendencies, that though can use the results from set 1 as supporting evidence. Again process 7-9 have the most ambiguous results though in relation to the big PP tests there is a substantial deviation overlap.

7.2.3 Set 3

Set 3 involves tensile testing of small PP specimens where the mold temperature is varied from 30 C to 45 C and onwards to 60 C, which gives a range of 15 C on each side of the suggested mold temperature of 45 C. This mold temperature is identical to the variation of mold temperature for the big PP specimen testing. For each of the mold temperatures the Injection speed is varied from 50 mm/s to 100 mm/s onwards to 250 mm/s, which cannot be said to give a certain range in relation to the speed suggested by the

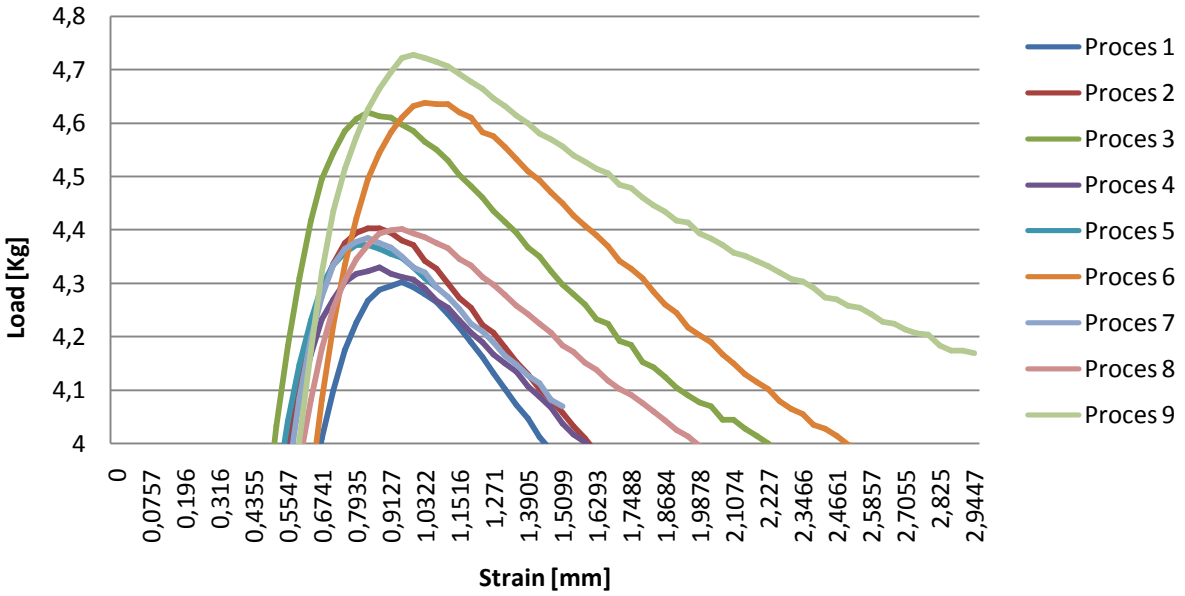
manufacturer, since it is “as fast as possible”. The injection speed variation steps is different from the steps of the big PP specimens since the micro molding machine could not exceed a speeds of 250 mm/s, for which reason it was assessed that it would be more interesting to cover a wider range of the possible injection speed spectrum allowed by the machine. To see all data and more comparing graphic representations see appendix 1.6 and 1.7.



Load / Strain small PP specimens for the 9 process parameter settings

The graph above shows the calculated load/strain average progresses of the nine different process parameter combinations of set 3.

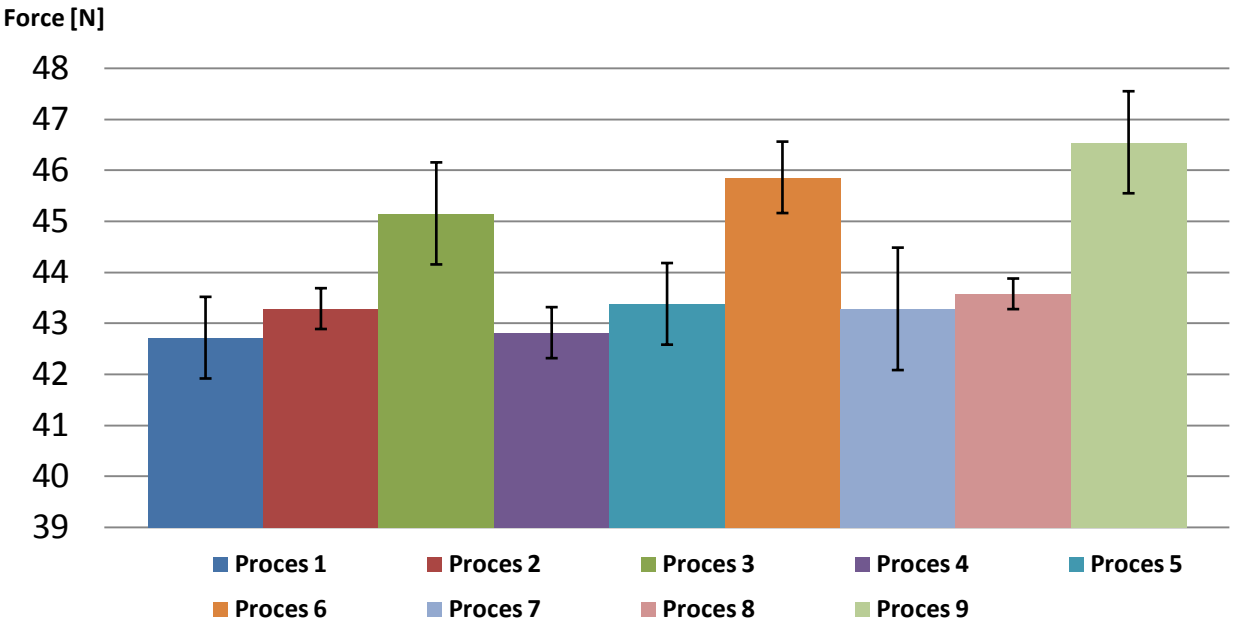
It is interesting that the conclusions that were prevailing from the tests of the big specimens now suddenly are inapplicable. The brittleness for instance does not seem to increase with the injection speed as it was the case with the big PP specimen tests, on the other hand every process is extremely ductile compared with the big specimens and the ones with highest injection speed are actually the most ductile. The average peak tensile strength is now at 18 % instead of 10 % for the big specimens, which can be explained by the very swift cooling that small specimens are subjected to because of their small mass and thus small heat capacity. This quick cooling does not allow the crystalinization process to occur and renders the small PP specimens much softer and more ductile than the big specimens where the slower cooling allows the crystal structure to grow.



Load / Strain small PP specimens Zoom view for the 9 process parameter settings

Further in the zoom view above it can be seen that the maximum tensile strength for all the different process parameter combinations is reached at about the same strain of 0,9mm. This similarity in the location of the peak tensile strength, which was also achieved with the big PP specimens, which might suggest that the location of the tensile peak in the used Borealis PP is not affected by the changing processing conditions in relation to the BASF ABS copolymer. An explanation for this could be that it is impossible to produce a homogeneous copolymer, which in the nature of things is not a problem with a homo polymer since it only consists of one mer.

The more correctly maximum averages are shown below in a column representation.



Set 3 small PP specimens maximum tensile strength comparison for the 9 process parameter settings

In relation to the maximum tensile strength the same tendencies as in set 1 and 2 are prevailing, this time though the high injection speed of 250 mm/s consequently influences the tensile strength positively to an extent where the result is no longer a weak tendency, but a fairly certain fact. Again the reason for the influence of the injection speed should be found in the high injections speed's ability to orient the mer-chains lengthwise, which increases the lengthwise tensile strength.

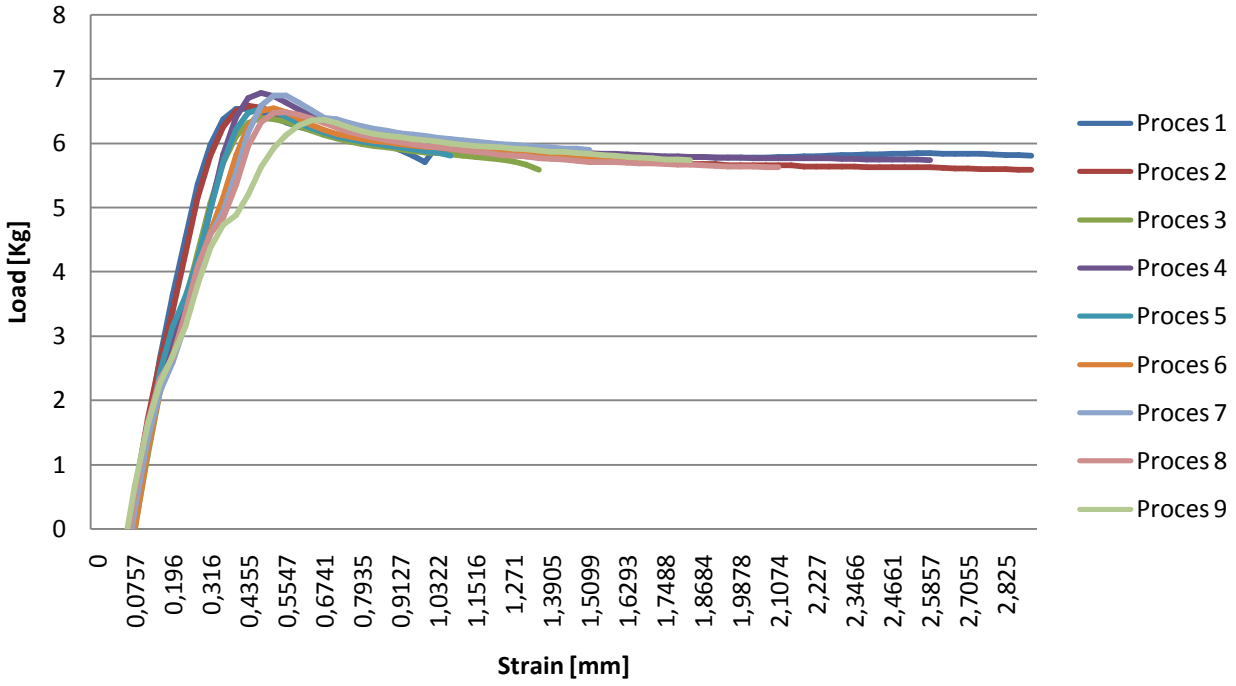
The mold temperatures does not seem to influence the tensile strength significantly, and can only be described as a weak tendency towards an increased strength concurrently with an increased mold temperature. This can be explained by the small elongation in the cooling time that this mold temperature increase induces, which enables a brief crystalinisation to occur before the specimen temperature reaches room temperature and the crystalinisation is prevented.

7.2.3.1 Statistical uncertainty of set 3

As seen from the tensile strength representation, where the standard deviation is showed for each process in the set, and mentioned above an unambiguous increase in tensile strength as a result of an increased injection speed can be concluded. The strength variation in relation to the mold temperature on the other hand cannot be proven explicitly. Generally the standard deviation achieved from the testing of the small PP specimens is fairly good, which can be caused be the higher consistency that a full automatic production can contribute with compared to the manually operated big injection molding machine.

7.2.4 Set 4

Set 4 involves tensile testing of small ABS specimens where the mold temperature is varied from 45 C to 60 C and onwards to 75 C, which gives a range of 15 C on each side of the suggested mold temperature of 60 C. This mold temperature variation is not identical to the variation of mold temperature for the big ABS specimen testing, since the micro injection molding machine was not capable of reaching mould temperatures of more than 75 C. Because of this it was assessed that instead of having a different temperature variation on each side of the suggested value, it would be better to have similar variations with a lower variation value. For each of the mold temperatures the Injection speed is varied from 50 mm/s to 100 mm/s onwards to 250 mm/s, which gives a range of respectively 0,5 and t 2,5 times the suggested injection speed of 100 mm/s. The injection speed variation steps is different from the steps of the big ABS specimens since the micro molding machine could not exceed a speeds of 250 mm/s, for which reason it was assessed that it would be more interesting to cover a wider range of the possible injection speed spectrum allowed by the machine.To see all data and more comparing graphic representations see appendix 1.8 and 1.9.

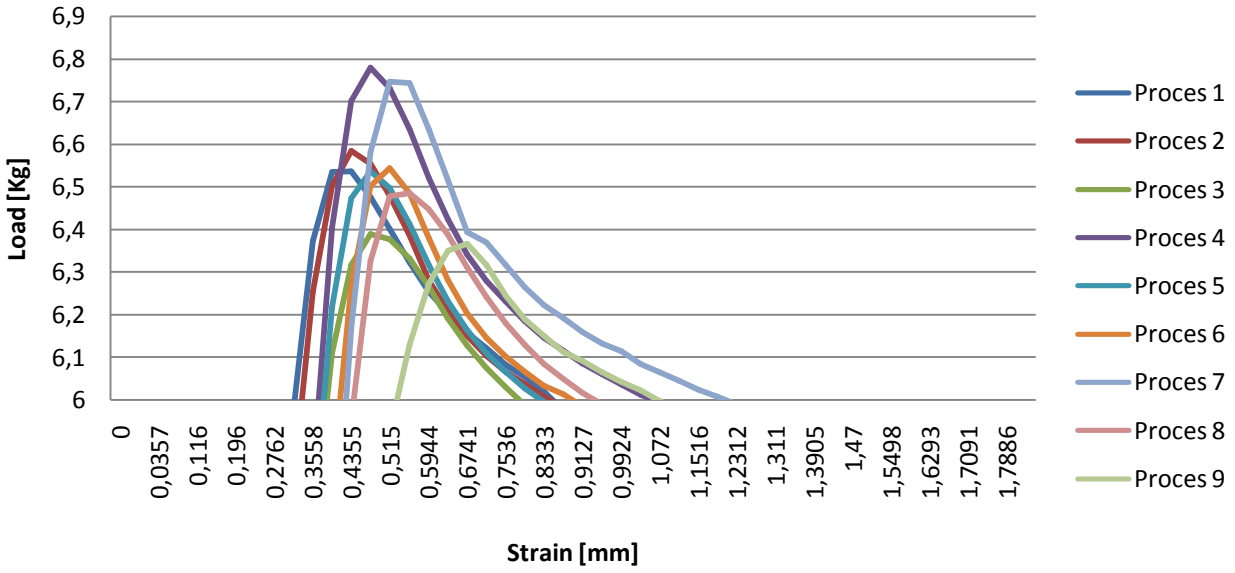


Load / Strain small ABS specimens for the 9 process parameter settings

The graph above shows the calculated load/strain average progresses of the nine different process parameter combinations of set 4.

Again the load/strain development is illustrated in a diagram where the horizontal axis is kept constant in relation to the representation of set 3 so that comparison is made easier.

This shows that the small ABS specimens has a significantly higher relative tensile strength to the small PP specimens compared with the relation between the big PP and ABS specimens. This implies that the mechanical behavior as an effect of the downscaling is different for the two materials, which could be caused be the more crystalline structure of PP that requires a long cooling time to grow crystals and hereby improve the tensile strength

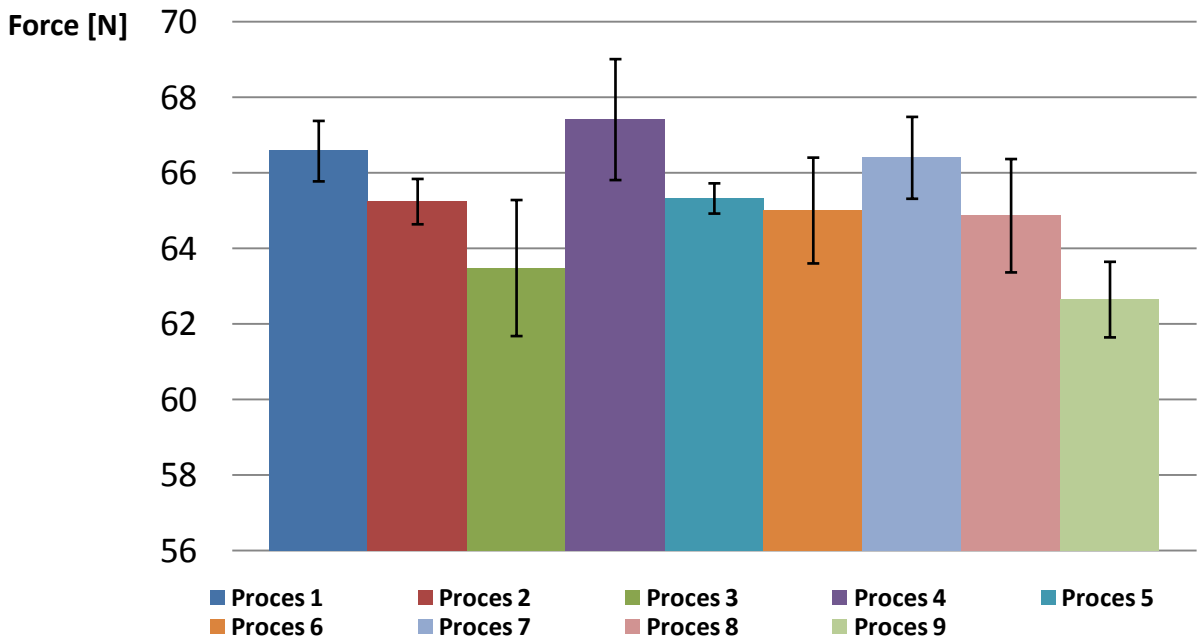


Load / Strain small ABS specimens zoom view for the 9 process parameter settings

In the zoom view above it can be seen that the maximum tensile strength for all the different process parameter combinations as with set 2, is reached within a relatively broad strain range. This observation underpins the explanation from set 3, where it was argued that material irregularities generally is more common in a copolymer since it is impossible to produce a completely homogeneous copolymer, which is not a problem with a homo polymer since it only consists of one mer.

The average tensile strength peak is achieved at around 0,5 mm, which is an elongation of 10 %. This is a significant increase compared with the elongation at which the maximum tensile strength occurs for the big ABS specimens which is at around 1 %. An explanation for this vast difference is the fact that the tensile test speed was not downscaled in accordance with the cross section area difference between the big and small dogbone.

The more correctly maximum averages are shown below in a column representation.



Set 4 small ABS specimens maximum tensile strength comparison for the 9 process parameter settings

The maximum tensile strength results from set 4 are almost in direct incongruence with the results from the other sets. Instead of having an increasing tensile strength with an increasing injection speed as has been discovered as a general tendency for the other test sets, it decreases. An explanation to this contradictorily result is that ABS's composition of acronitrille, butadiene and styrene- mer-chains are more rigid and has thus do not flow as smoothly in the mould this combined with the fact that the injection should be seen in relation to the average specimen cross section which is 40 times larger for the big specimens than for the small specimens, means that the optimum injection speed in relation to tensile strength has been exceeded. This overstepping of the optimum injection speed has enduced residual stresses in the specimen, which has reduced the tensile strength.

In this respect it is worth noticing that the maximum tensile strength for all mold temperatures is reached with the lowest injection speed, which is half of the manufacturer's suggested value. This though with referral to the above discussion about the injections speeds relation to the average cross section of the specimen is not a correct observation. Actually injection speed should from the manufacturer be stated as a speed at a certain cross section which would be a flow rate. It would in relation to the discoverery of residual stresses have been interesting to produce specimens with an even lower injection speed and see at what point the tendency curve would break, provided that it at some point would.

7.2.4.1 Statistical uncertainty of set 4

As seen from the tensile strength representation, where the standard deviation is showed for each process in the set, none of the above can unambiguously be concluded. It must though be said that a clear

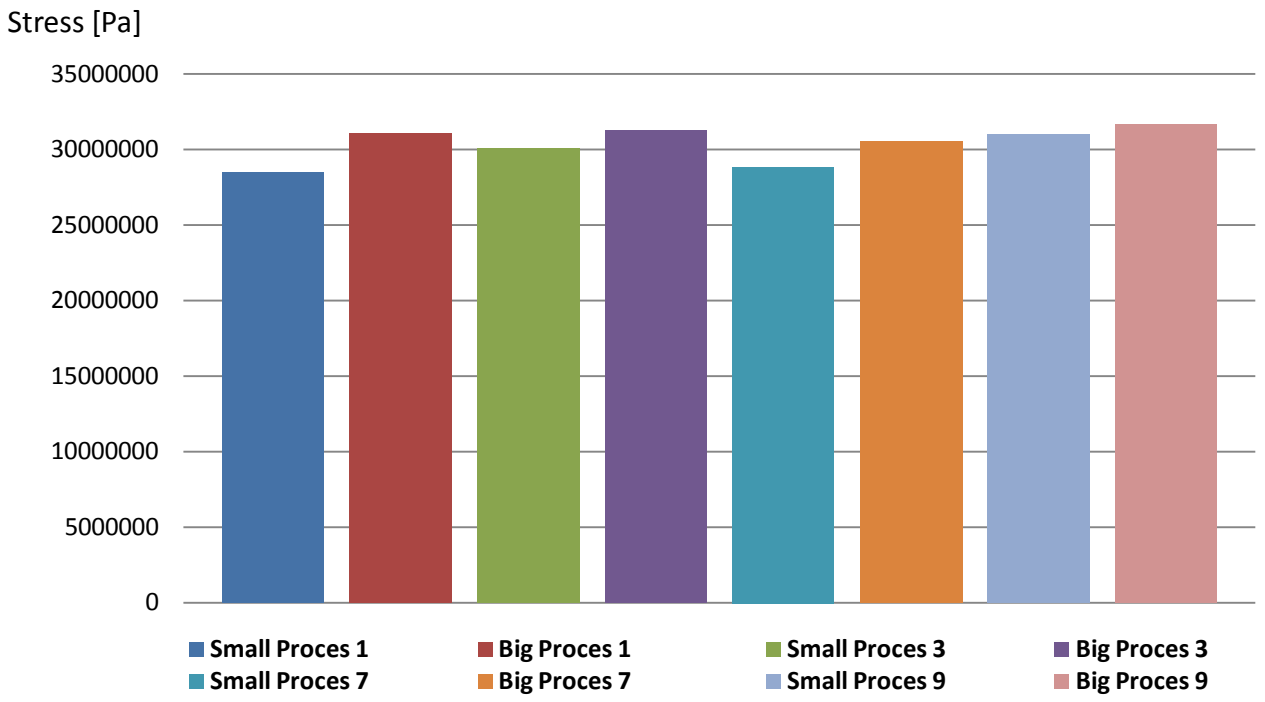
tendency where increased injection speed lowers the maximum tensile strength. The standard deviation of set 4 is relatively smaller than it was the case with set 2 (Big ABS specimens) but still larger than it was the case for set 3 (small PP specimens), which again indicates that a higher test specimen consistency is achieved with the full automatic micro injection moulding machine, and that a higher specimen consistency is also achieved when using the homogenous PP.

7.3 Set result comparison

This section will elaborate on the already identified relations between the test sets, more specifically this implies comparing the maximum tensile strength for the two materials made with different dogbone sizes. To be able to compare the tensile strength between the two different dogbone sizes the force in N was converted to the area independent stress in [Pa]. it should be noticed that the standard deviation is not included in this section, since it was assessed that it at the absolute zoom level that is used in this section to give a sufficient overview would make the standard deviation representation unreadable and thereby obstruct the information in the representations.

7.3.1 PP comparison

Generally the same tendencies were prevailing for the two sets made from polypropylene. The maximum tensile strength increased with the injection speed, this tendency was though more predominant for the small PP specimens, where the result despite the inaccuracy in the form of the standard deviation seems indisputable.

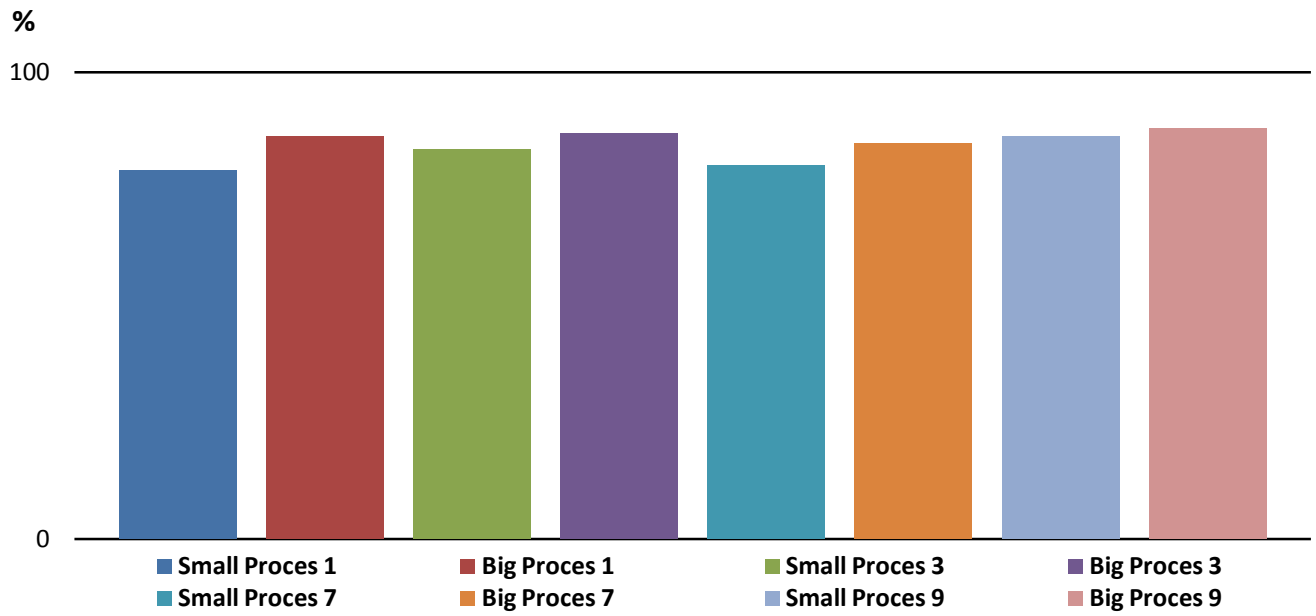


PP maximum tensile strength comparison between small and big dog bone test for selected process parameters

Above the maximum tensile strength for selected processes from the two different bogbone sizes made of PP is presented. The processes are selected due to their representation of the extreme process settings, so that the lowest mold temperature is represented with both the low and high injection speeds and that the highest mold temperature equally is presented with the low and high injection speeds.
This remarkably shows that the maximum tensile strength generally is higher for the Big specimens than for the small, which can be explained by the fact that the skin layer which will always be more amorphous due to the geometric downscaling represents a much greater percentage relative to the cross section for the small specimens. Another obvious explanation pointing in the same direction would be that the rapid cooling of the small PP specimens allow less crystals to grow and hence becomes less strong and more ductile than the larger specimens with a higher heat capacity and hence slower cooling.

7.3.1.1 Manufacturer data

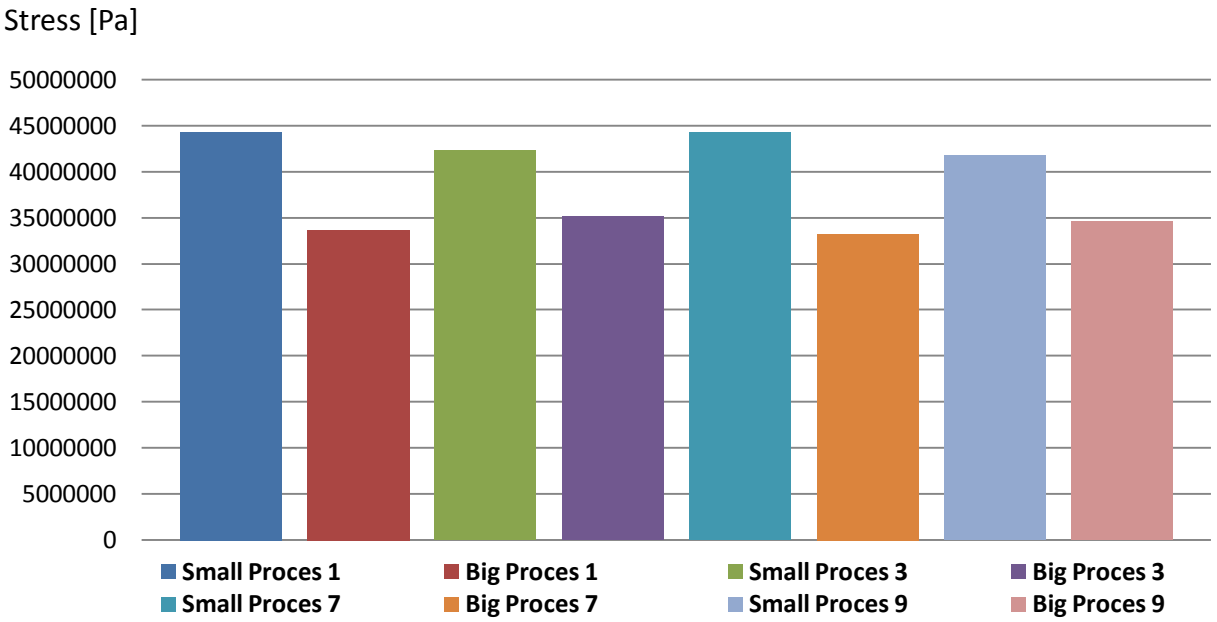
In relation to the maximum tensile strength provided by the manufacturer Borealis which in the representation below is shown as the 100 % line which corresponds to 36 MPa, it can be seen that both the small and big PP specimens are roughly about 15-20 % from the stated yield strength. This could have been caused by the fact that the granulate is rather old and have been stored in an open bag, but can also have been a result of the fact that our test procedure differs from the ISO standard, both regarding specimen geometry and more critically due to our use of a higher test speed.



Maximum tensile strength for a selection of small and big PP dog bone tests relative to the value stated by the manufacturer

7.3.2 ABS comparison

As opposed to what was the case with PP, the big and small ABS specimens definitely not follow the same tendencies. The maximum tensile strength for the big ABS specimens was generally increased with an increase in the injection speed and was at an optimum at the middle mold temperature. With the small specimens on the other hand the injection speed tendency was reversed and the mold temperature did not have much influence at all. In the representation below as with PP the maximum tensile strength of a selection of processes are illustrated for both the small and the big dogbone made from ABS.



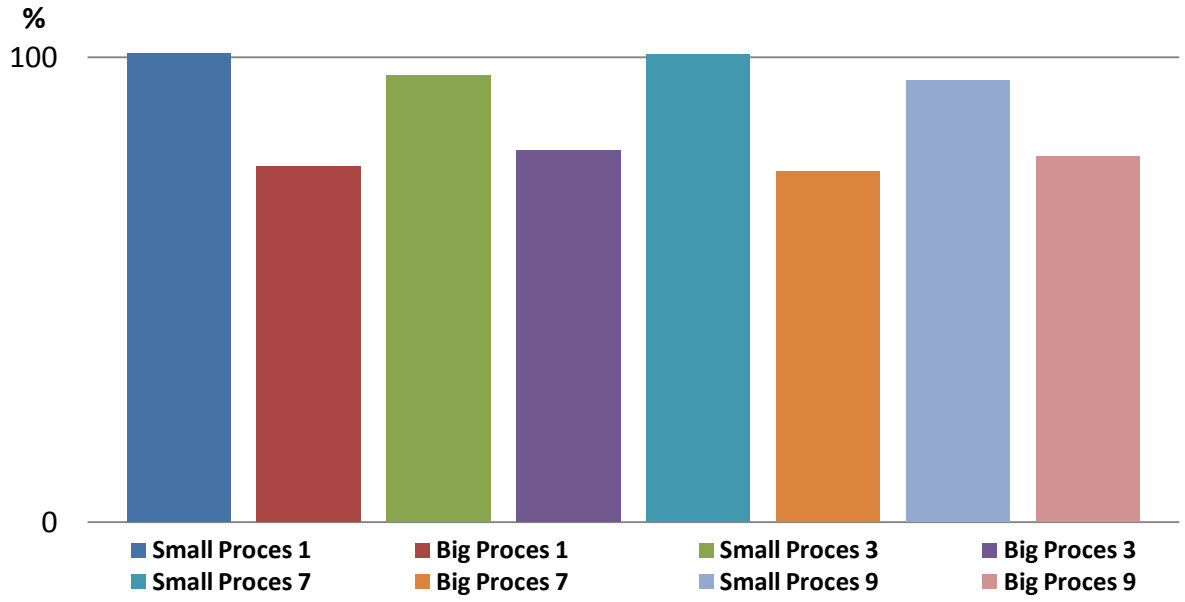
ABS maximum tensile strength comparison between small and big dog bone test for selected process parameters

In this representation it can be seen that the values of the maximum tensile strength of the small specimens are generally, not only slightly larger than for the big ABS specimens but about 20% larger. This result stands in contradiction to what was earlier seen for the big and small PP specimens and can in that relation not be explained by the earlier used arguments about less crystalinisation time for the small specimens which does not affect the strength of the amorphous ABS. The explanation for this remarkable test result is according to Professor Andy Horsewell to be found in the overall difference in composition of PP and ABS. Where Homo PP only consists of one type of polymeric chains it will always more or less have the same cooling characteristic even though it is semi-crystaline. ABS on the other hand consists of mixture of Acrylonitrile, butadiene and styrene, which means that the combined ABS have different phases through cooling in which the different polymeric-chains can be affected by sudden cooling from melt temperature. This phenomenon has according to Professor Horsewell induced that the extremely rapid cooling of the small specimens have brought the ABS through the cooling phases in another manner than it has been the case with the larger ABS specimens. Due to limitations in our project scope and a considerable time pressure we have unfortunately not been able to look into this subject more deeply, which suggested by Professor Horesewell could have been done by looking at the small ABS specimens in a electron microscope.

Another explanation for the relatively bad tensile performance of the large ABS specimens could be caused by the fact that the cooling time from specimen production to specimen testing was about the same for the big and the small specimens, which implies that the small specimens because of their low volume have cooled relatively more than the big specimens and were thus closer to room temperature.

7.3.2.1 Manufacturer data

In relation to the maximum tensile strength provided by the manufacturer of the used ABS copolymer BASF, which in the representation below is shown as the 100 % line corresponding to 44 MPa, it is evident that the small specimens generally achieve maximum tensile strength values very close to 44 MPa and that the large ABS specimens have values about 20 % lower than this.



Maximum tensile strength for a selection of small and big ABS dog bone tests relative to the value stated by the manufacturer

8 Conclusion

The investigational project had a difficult start were the supposed project definition; to investigate effects of injection molding process conditions on the mechanical properties of homo and block co-polymer micro molded plastic parts of Polypropylene, was changed several times due to difficulties related to accessing the necessary production and testing facilities. A new definition was completed by the start of the second week with which we had shifted the focus to examining the effects of injection molding process conditions on the mechanical properties of two different materials in two different specimen sizes. One of the selected materials was a semicrystaline PP homo polymer while the other was chosen to be an amorphous ABS block co-polymer. Each material was produced in two different sizes with varying injection speeds and mould temperatures, which resulted in a rather extensive production of more than 180 specimens that was later tensile tested and examined with a microscope.

In order to evaluate the test results a literature study was carried out on the different materials and their expected behavior related to varying sizes and process conditions. While producing and testing the different specimens we were aware that many sources of error could influence the findings, which we have kept in mind throughout the analysis of the results. We have however discovered some tendencies in the test results, which shortly will be summarized in the following:

- High injection speed tends to increase the tensile strength but decrease the ductility of the specimens, due to orientation of the polymer chains
- High mould temperatures will according to theory increase the tensile strength and decrease the ductility of the PP specimens due to longer cooling time where crystals can form and grow
    - This incident is hard unambiguously to demonstrate, which is assumed to be caused by a relatively large temperature difference between the melt and the mould
- Regarding the ABS specimens the mould temperature is of less significance due to the amorphous material structure
- The micro specimens behaved relatively much different from the large specimens, which might be due to rapid cooling.
    - We were unable to break the micro PP specimens because of a high degree of ductility presumably due to an almost complete amorphous structure
    - The ABS became relatively stronger and more ductile presumably due to a two phase nature, which has not been investigated further in this project
- By evaluating the fractured specimens indications of things like degree of crystallinity, size of skin layer, crack initiations etc can be identified.

Although the definition of the project has shifted during the process we think that it has been an interesting project from which our understanding and awareness of the effects of injection molding process conditions on the mechanical properties of polymers has grown substantially.

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Illustration of structural formula of polypropylene
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Description of Rheology
http://www.tangram.co.uk/TI-Polymer-PP_Controlled-Rheology.html

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APPENDIX

Page

1.1 Intro – process definitions

In this Appendix the data collected from the Instron Tensile pull testing machince is presented.
The test was performed in four sets each with 9 different settings of process parameters, which was conducted with five specimens of each parameter setting. This sums up to a total of 180 tests. Plus numerous of experimental and flawed test in order to calibrate and get familiar with the testing equipment. The different test sets had all the same fixed and variable parameters. The mold temperature and the injection speed was variable while all other parameters were fixed. A scheme of the test plan can be seen below.

Set 1 PP Big dogbone specimens			
	Mt = 30 C	**Mt = 45 C**	**Mt = 60 C**
Vi = 100 mm/s	Proces 1	Proces 4	Proces 7
Vi = 250 mm/s	Proces 2	Proces 5	Proces 8
Vi = 400 mm/s	Proces 3	Proces 6	Proces 9

Set 2 ABS Big dogbone specimens			
	Mt = 40 C	**Mt = 60 C**	**Mt = 80 C**
Vi = 25 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 400 mm/s	Proces 3	Proces 6	Proces 9

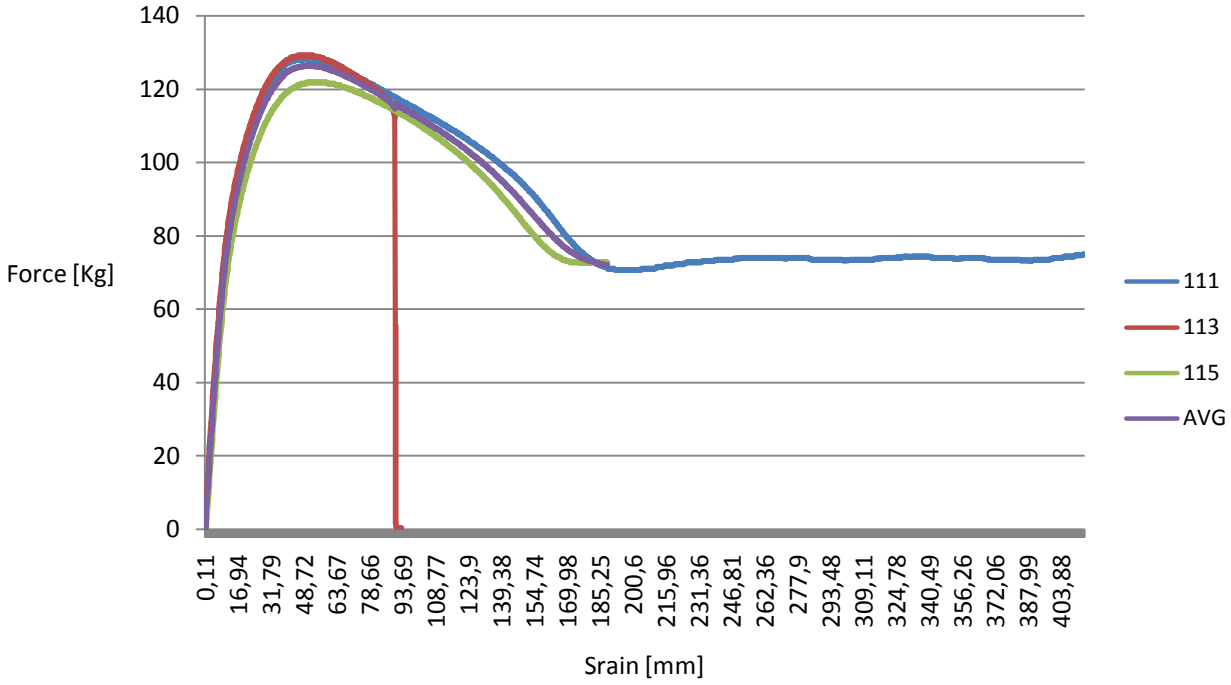
Set 3 PP Small dogbone specimens			
	Mt = 30 C	**Mt = 45 C**	**Mt = 60 C**
Vi = 50 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 250 mm/s	Proces 3	Proces 6	Proces 9

Set 4 ABS Small dogbone specimens			
	Mt = 45 C	**Mt = 60 C**	**Mt = 75 C**
Vi = 50 mm/s	Proces 1	Proces 4	Proces 7
Vi = 100 mm/s	Proces 2	Proces 5	Proces 8
Vi = 250 mm/s	Proces 3	Proces 6	Proces 9

The variable process conditions were chosen so that they represent low, mid and high in relation to the manufacturers intended process conditions.
To keep track of every dogbone before and after the testing they were all given a sequential three digit identifying number that made every dogbone within a set unique. The first number identifies the process number 1 -9 the second number identifies the material 1 – 3 and the final number is unique to the dogbone normally 1 – 5, but in some cases when it due to test failure was necessary to produce and test more specimens. During this appendix there will be refered to the above process numbers and to specific dogbone samples from the different sets.

1.2 Tensile test - big dog bone specimen of HH 315 M0 (PP)

Process 1

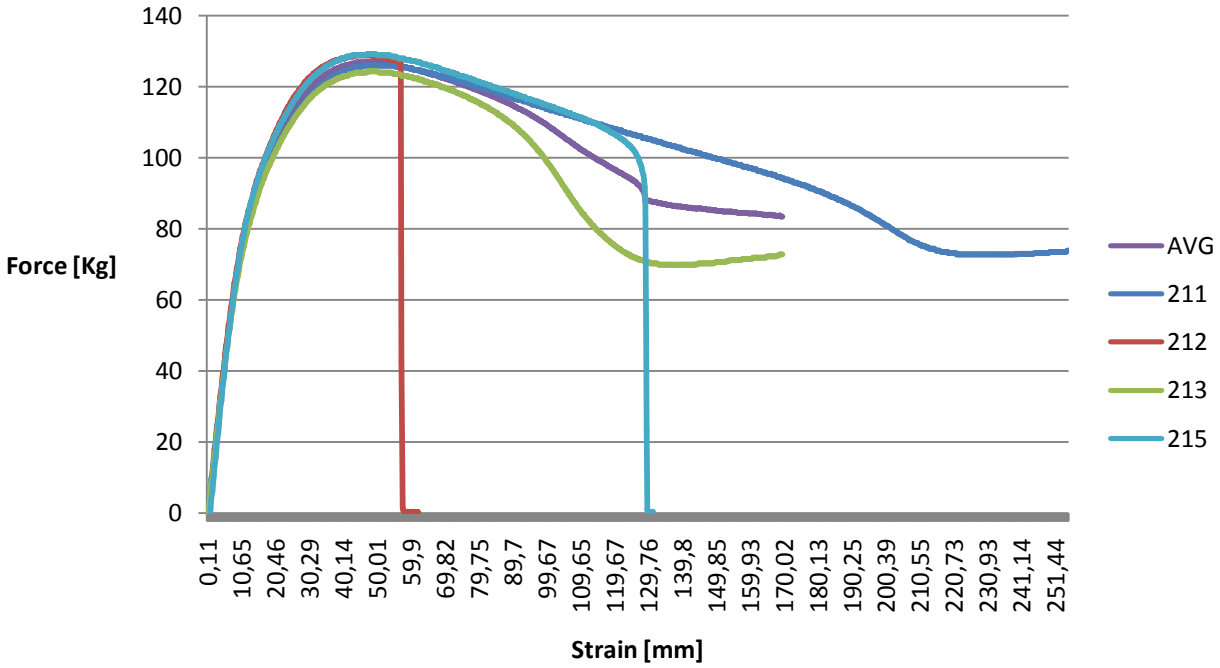


It was assessed that test 112 and 114 was to unreliable to include in the presentation of the behavior, the clamping jaws had been tightened too much which meant that the force started on much too high values. The maximum tensile values of these flawed test where though used, they were just not included in the calculation of the average force strain curve.

The maximum tensile values for the tests of process 1 are [Kg]

	123,3
	127,81
	127,19
	127,13
	126,8
avg	126,446
Std.D	1,796143

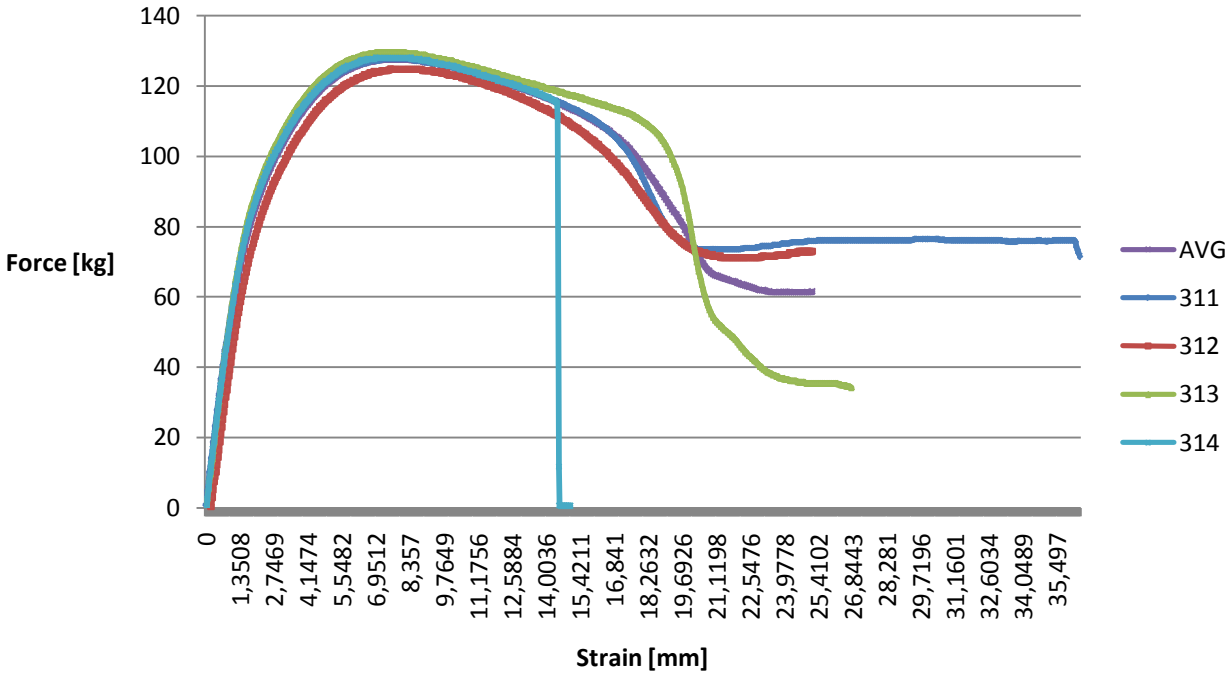
Process 2



It was assessed that test 214 was to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 2 are [Kg]

	127,16
	126,3
	128,78
	125,94
avg	127,045
Std.D	1,264845

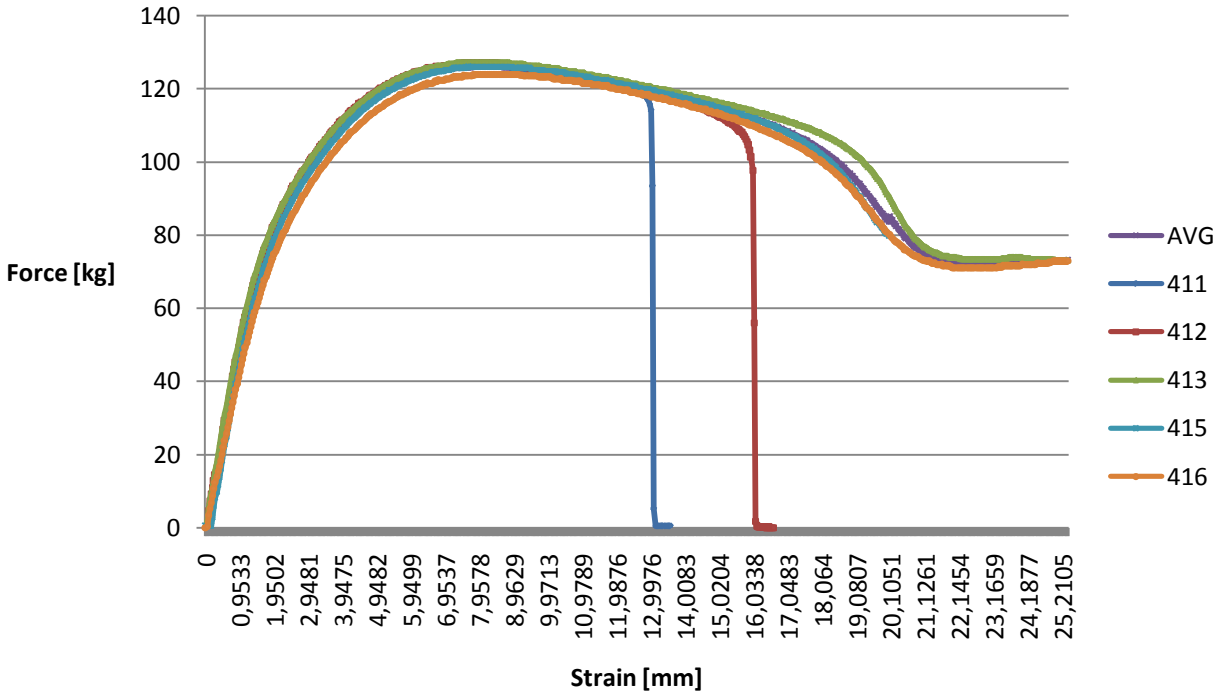
Process 3



It was assessed that test 315 was to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 3 are [Kg]

	127,97
	129,59
	124,72
	127,56
avg	127,46
Std.D	2,026047

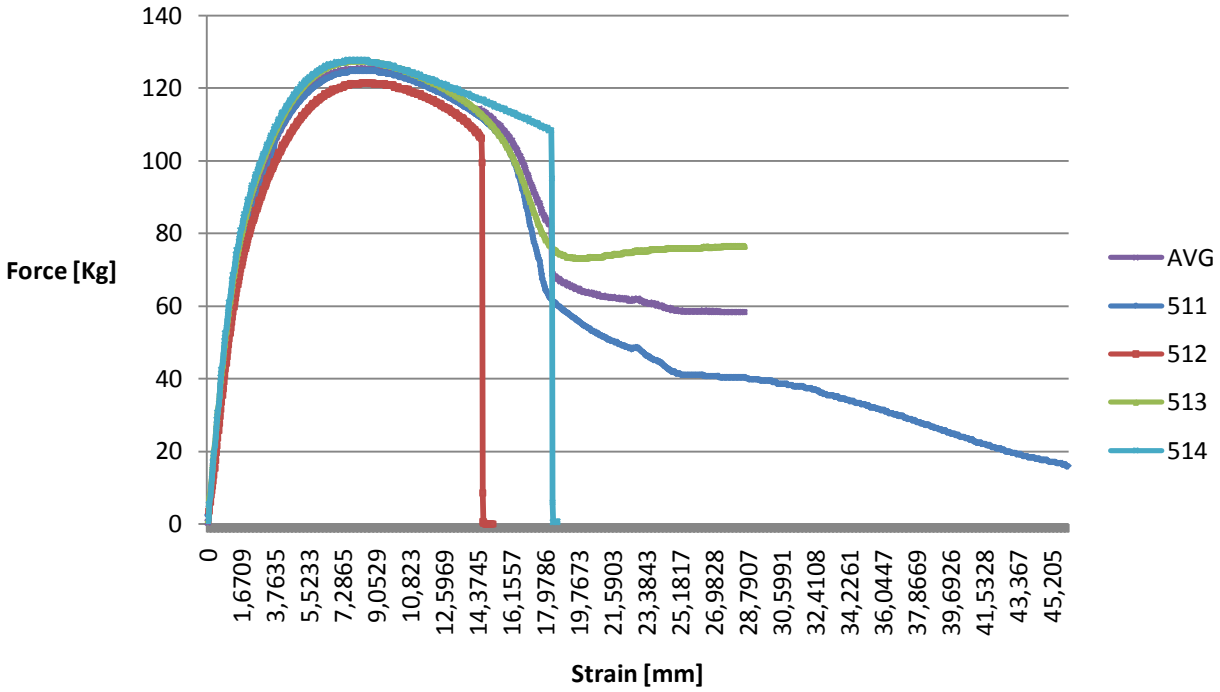
Process 4



It was assessed that test 414 was to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing. Luckely an extra specimen 416 was produced which brings the amount of test up to five.
The maximum tensile values for the tests of process 4 are [Kg]

	123,91
	125,94
	127,16
	126,75
	125,94
avg	125,94
Std.D	1,251539

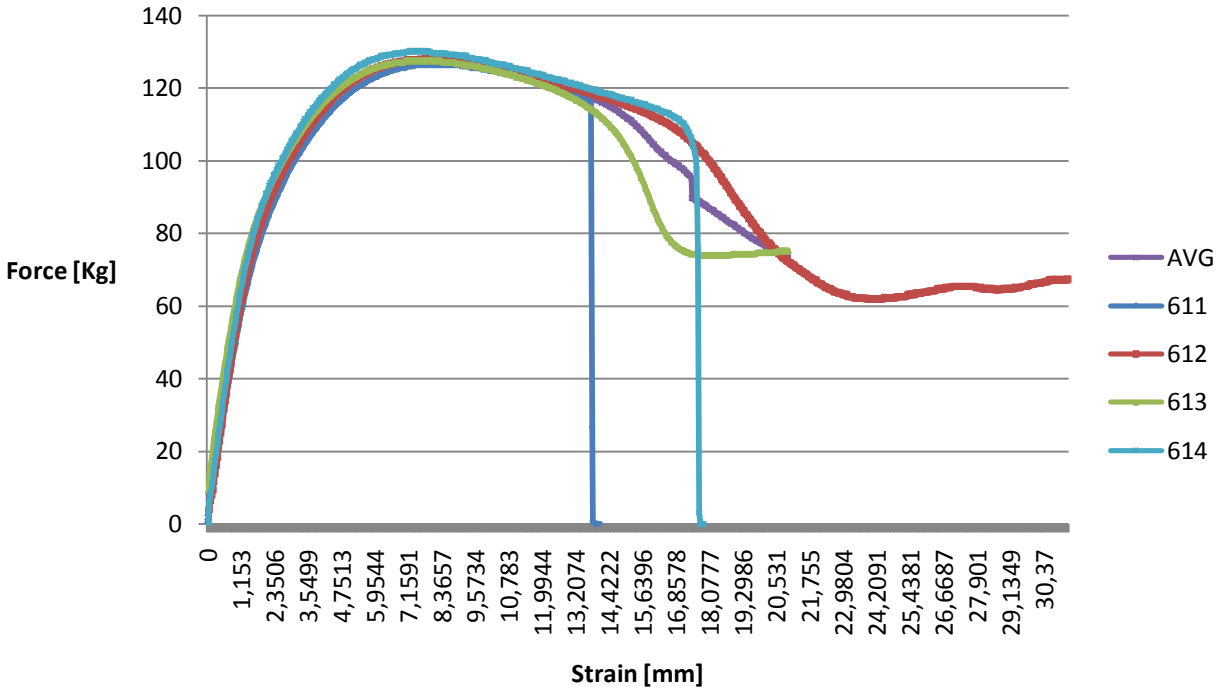
Process 5



It was assessed that test 515 was to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 5 are [Kg]

	126,7
	127,56
	127,56
	125,46
avg	126,82
Std.D	0,993177

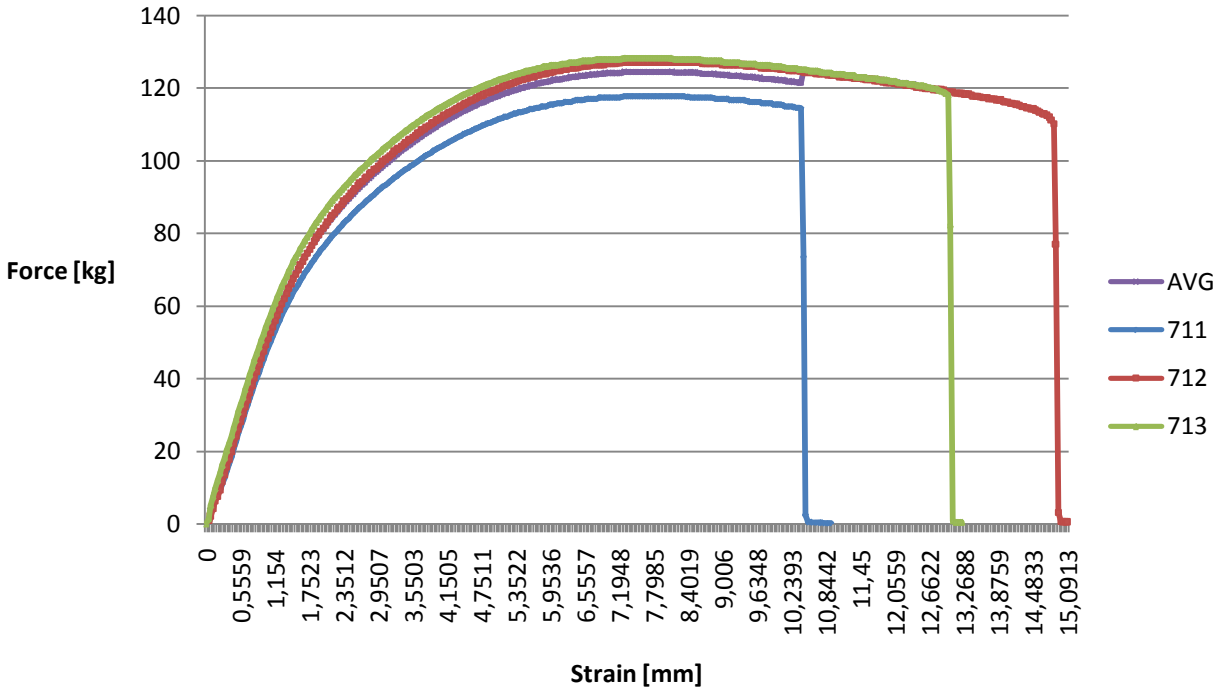
Process 6



It was assessed that test 615 was to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 6 are [Kg]

	129,59
	127,16
	127,16
	125,13
avg	127,26
Std.D	1,824445

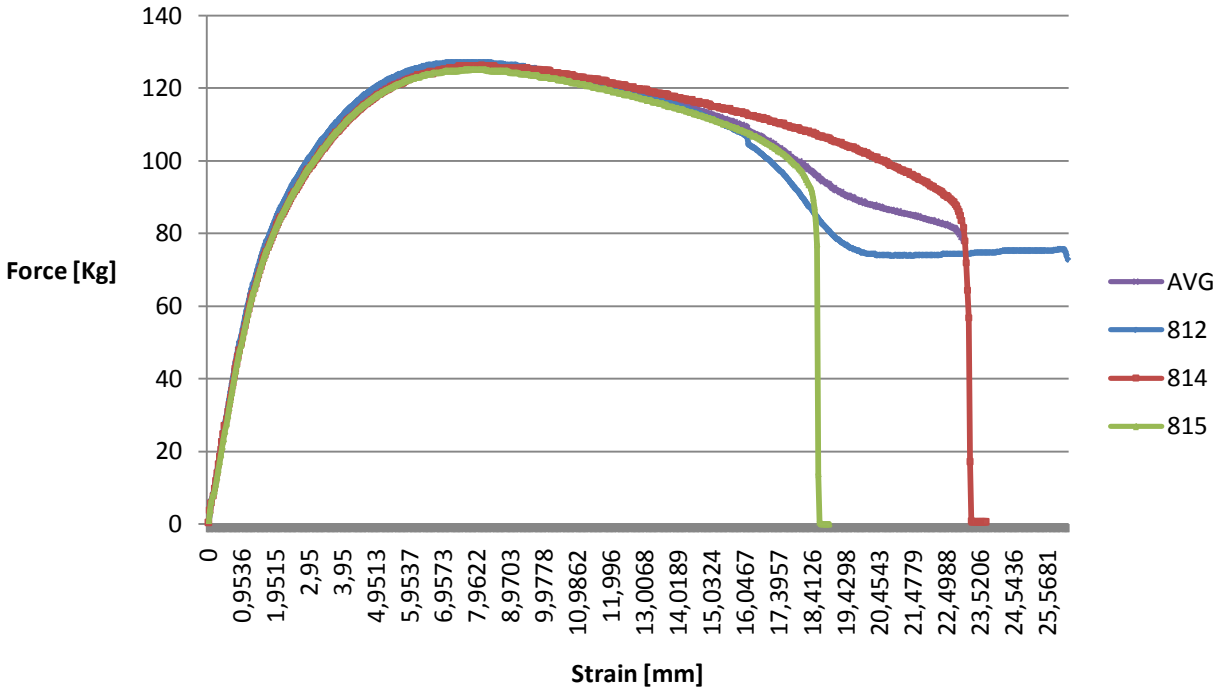
Process 7



It was assessed that test 714 and 715 were to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 8 are [Kg]

	119,38
	127,16
	126,81
avg	124,45
Std.D	0,677717

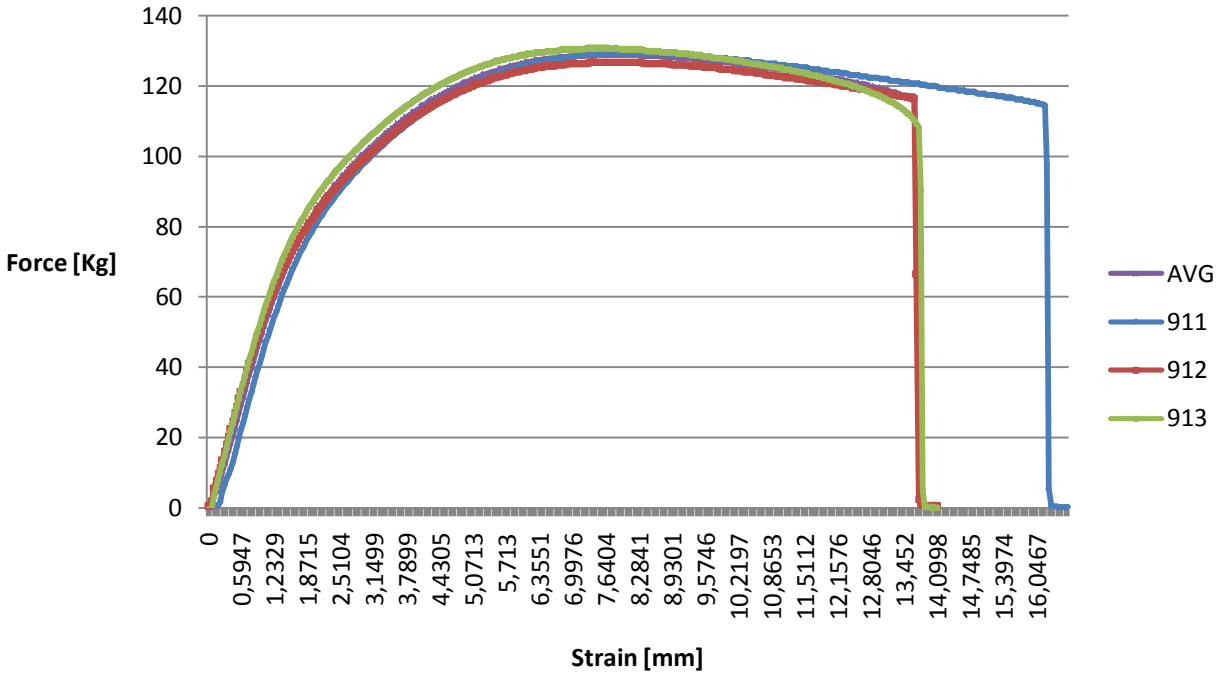
Process 8



It was assessed that test 814 and 815 were to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 8 are [Kg]

	125,12
	126,1
	127,16
avg	126,1267
Std.D	1,020261

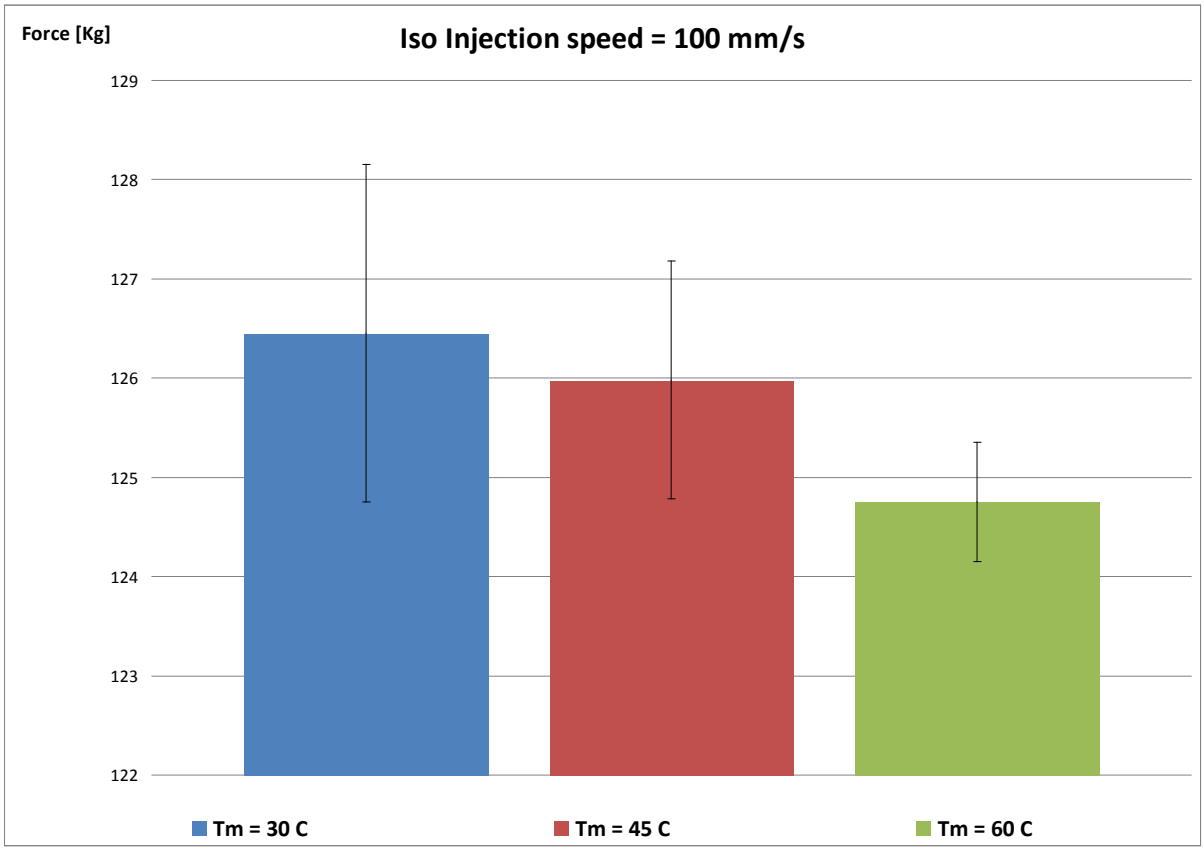
Process 9

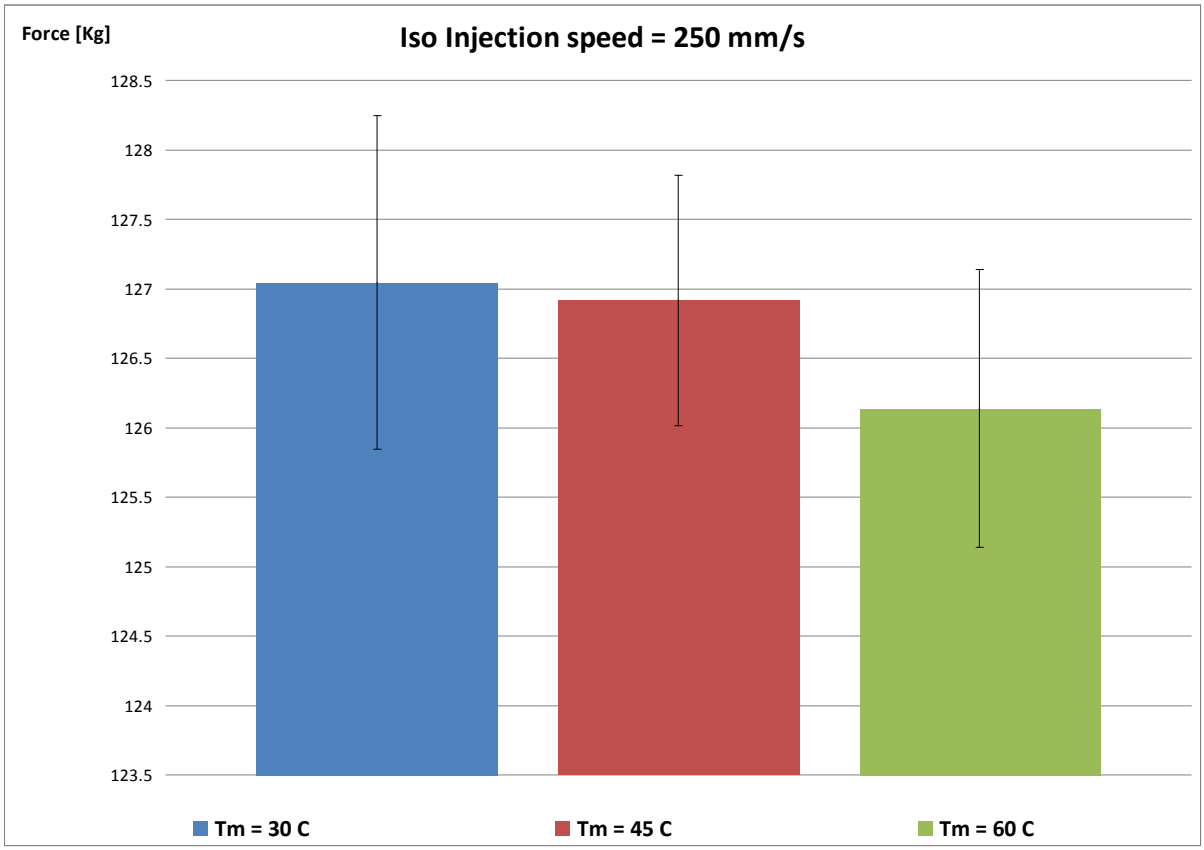


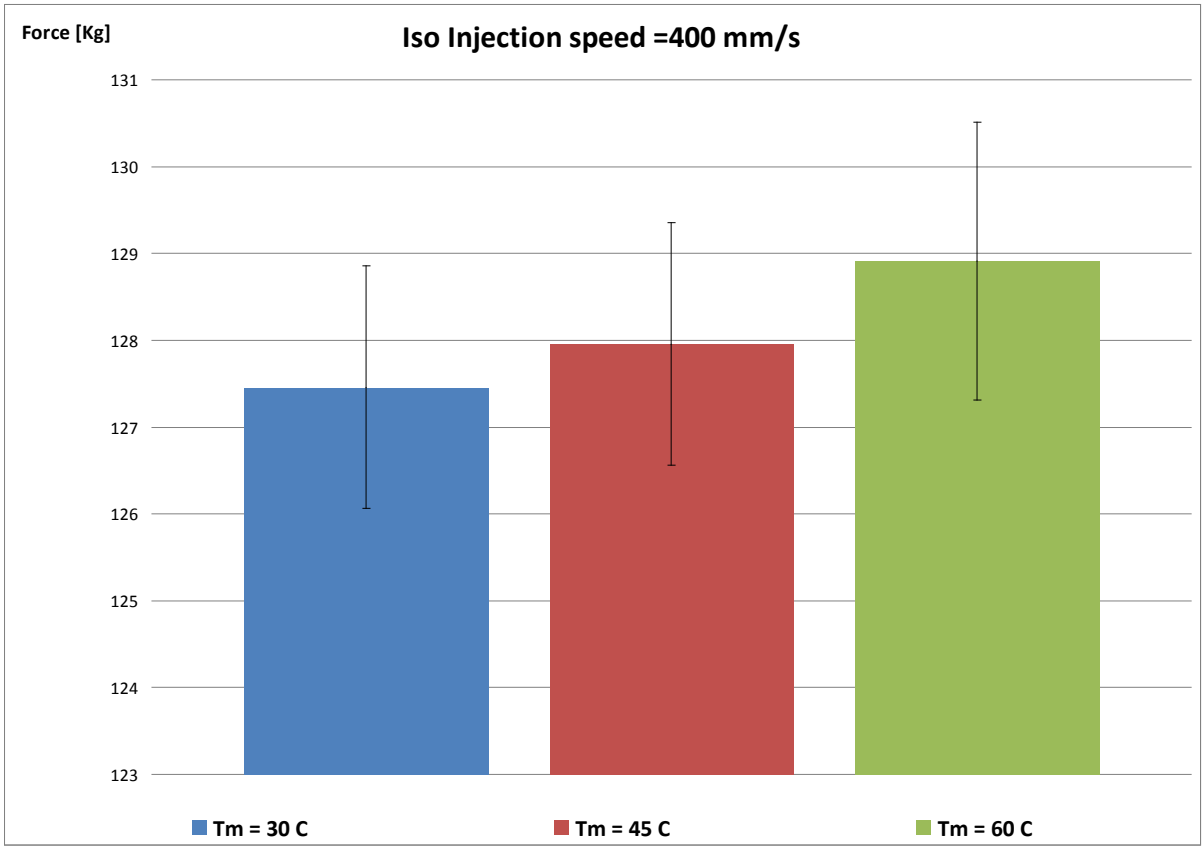
It was assessed that test 914 and 915 were to unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 9 are [Kg]

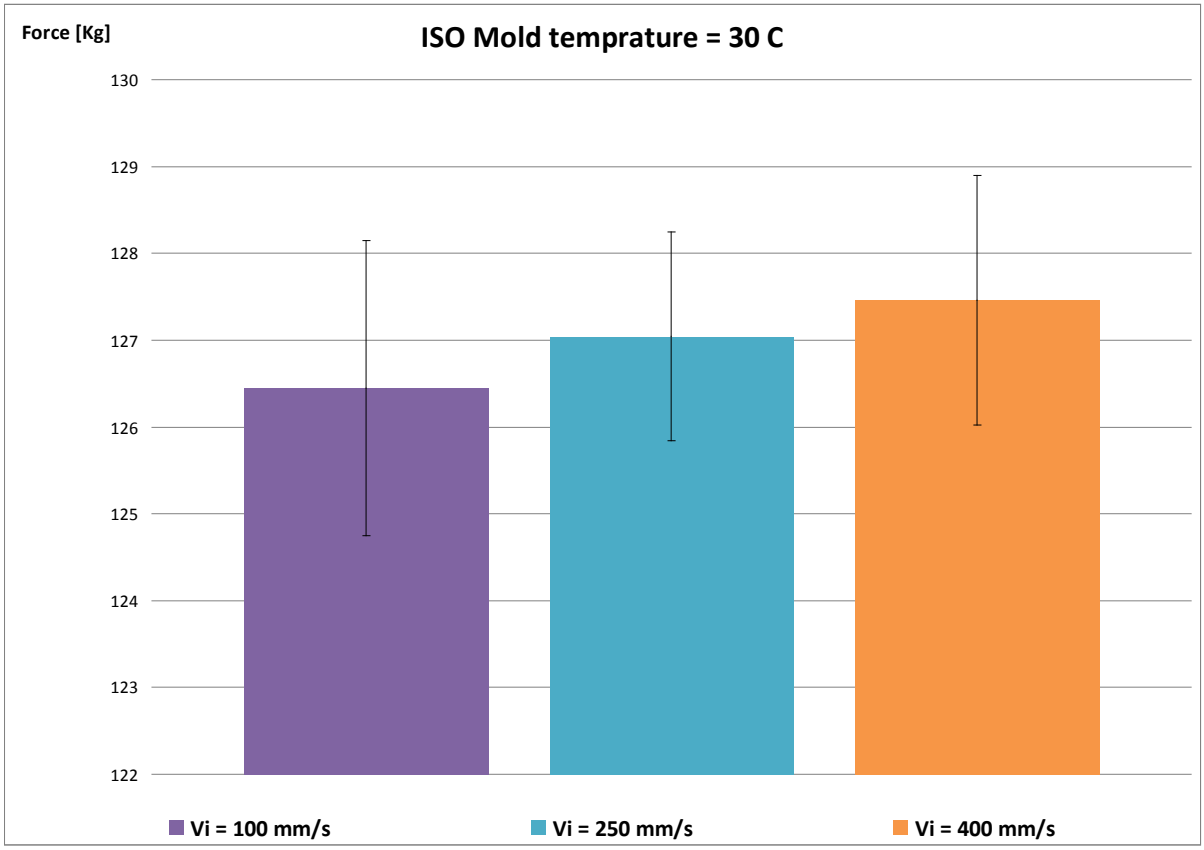
	130,8
	127,1
	128,9
avg	128,9333
Std.D	1,850225

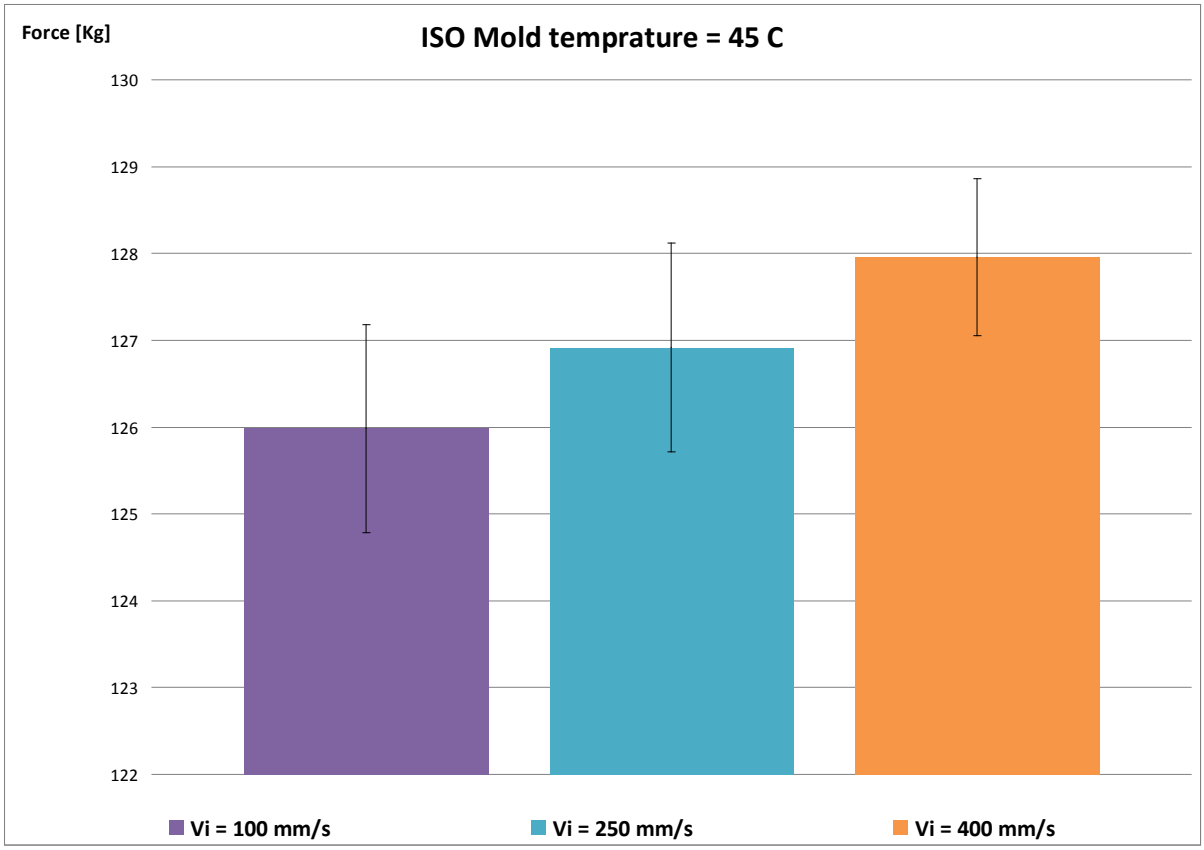
1.3 Systematic comparison maximum tensile test big PP

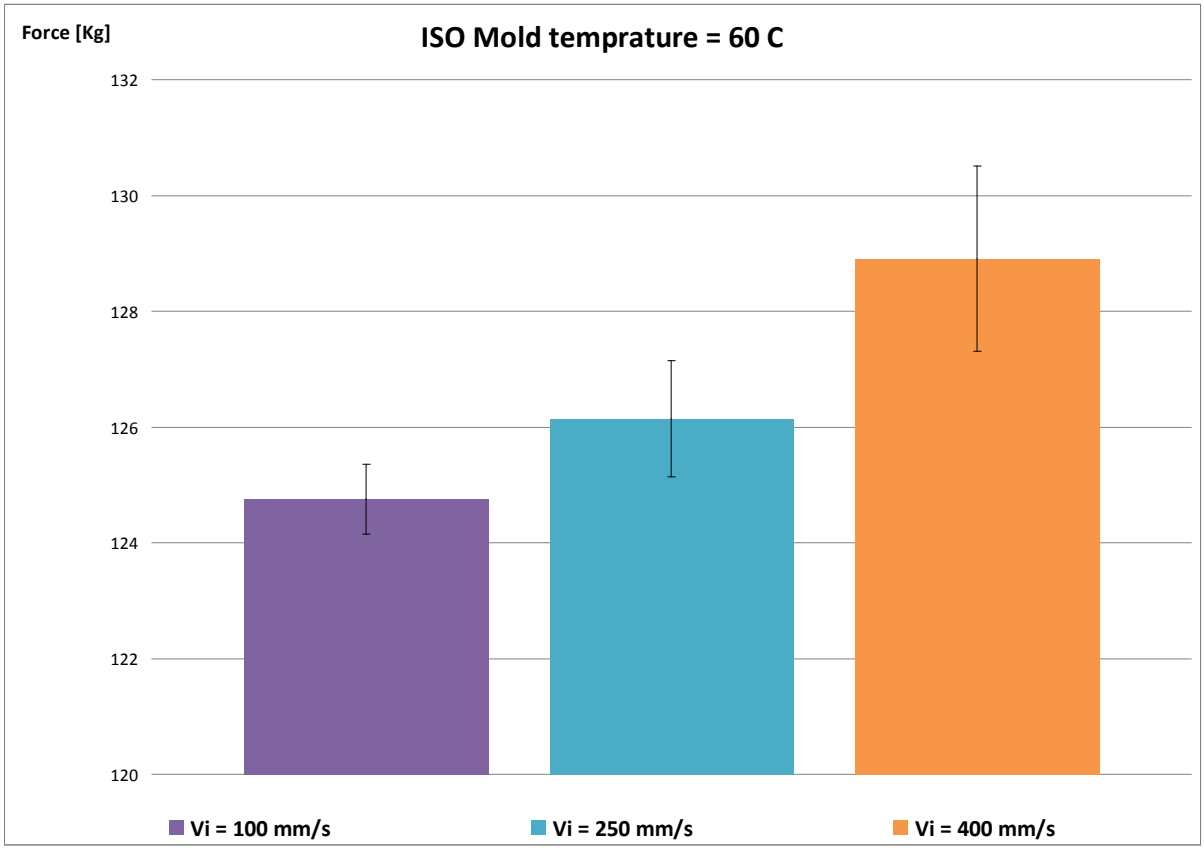





Force [Kg]
Iso Injection speed =400 mm/s
131
130
129
128
127
126
125
124
123
Tm = 30 C
Tm = 45 C
Tm = 60 C

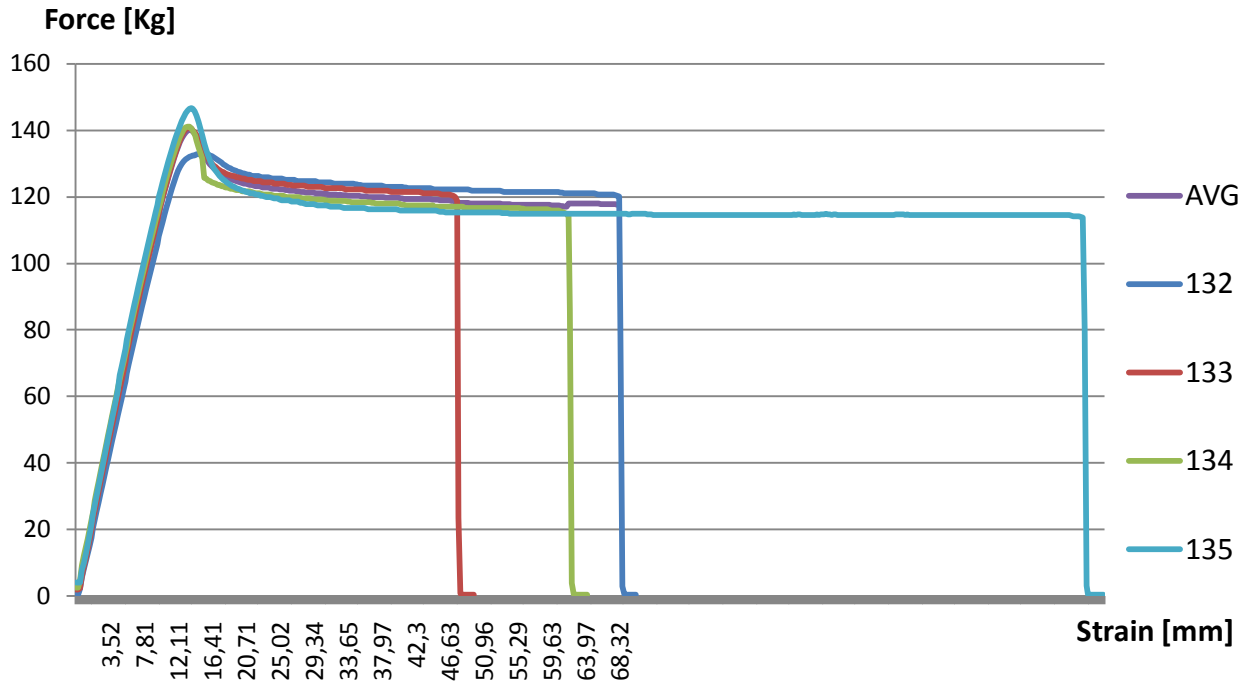

Force [Kg]
ISO Mold temprature = 30 C
130
129
128
127
126
125
124
123
122
Vi = 100 mm/s
Vi = 250 mm/s
Vi = 400 mm/s


Force [Kg]
ISO Mold temprature = 45 C
130
129
128
127
126
125
124
123
122
Vi = 100 mm/s
Vi = 250 mm/s
Vi = 400 mm/s


Force [Kg]
ISO Mold temprature = 60 C
132
130
128
126
124
122
120
Vi = 100 mm/s
Vi = 250 mm/s
Vi = 400 mm/s

1.4 Tensile test - big dog bone specimen of Terluran 35GP (ABS)

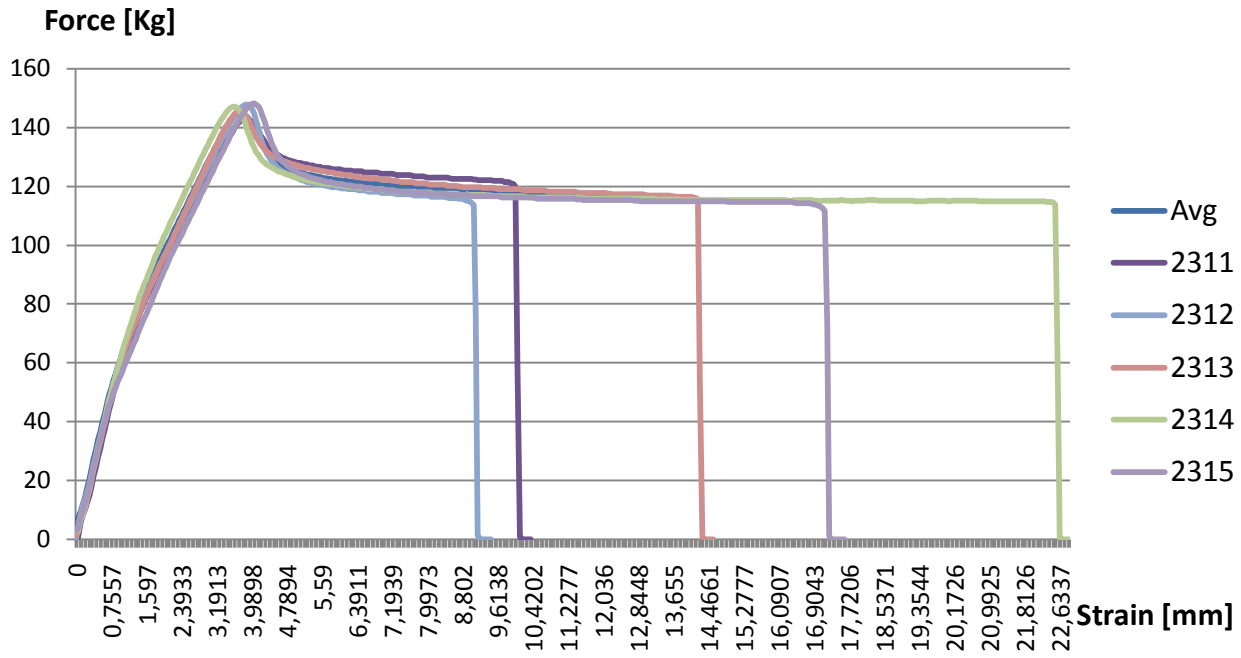
Process 1



It was assessed that test 131 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 1 are [Kg]

	132,45
	138,43
	140,97
	137,28
Avg	137,2825
Std. D	3,57153

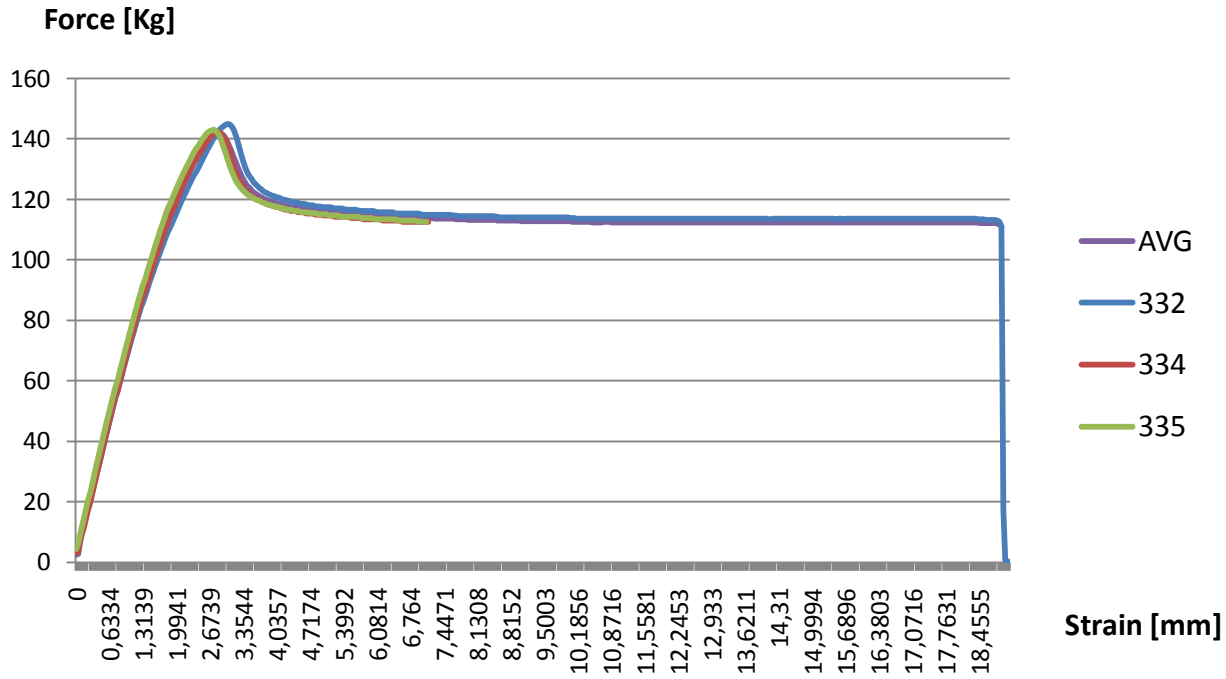
Process 2



It was assessed that test 2314 was too unreliable to include in the presentation of the maximum tensile testing.
The maximum tensile values for the tests of process 2 are [Kg]

	140,12
	139,63
	138,94
	140,16
Avg	139,7125
Std. D	0,568587

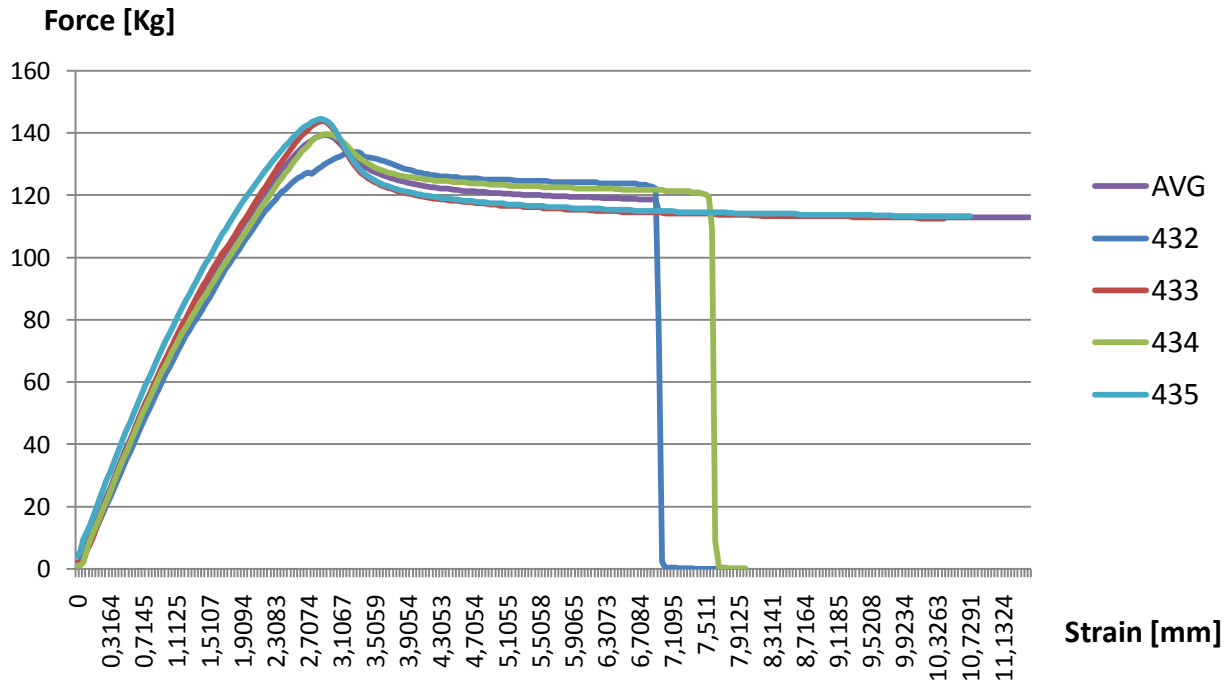
Process 3



It was assessed that test 331 and 333 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 3 are [Kg]

	145,03
	142,19
	142,96
Avg	143,3933
Std. D	1,468752

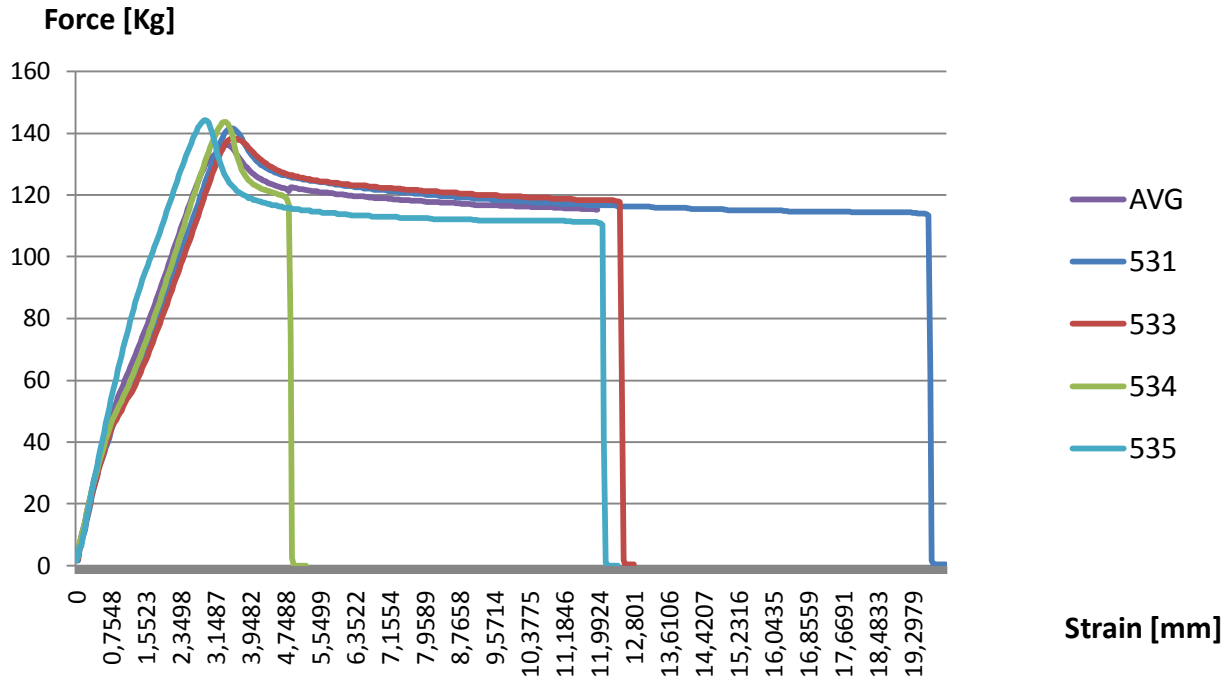
Process 4



It was assessed that test 431 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 4 are [Kg]

	134,06
	143,81
	139,82
	144,62
Avg	140,5775
Std. D	4,825021

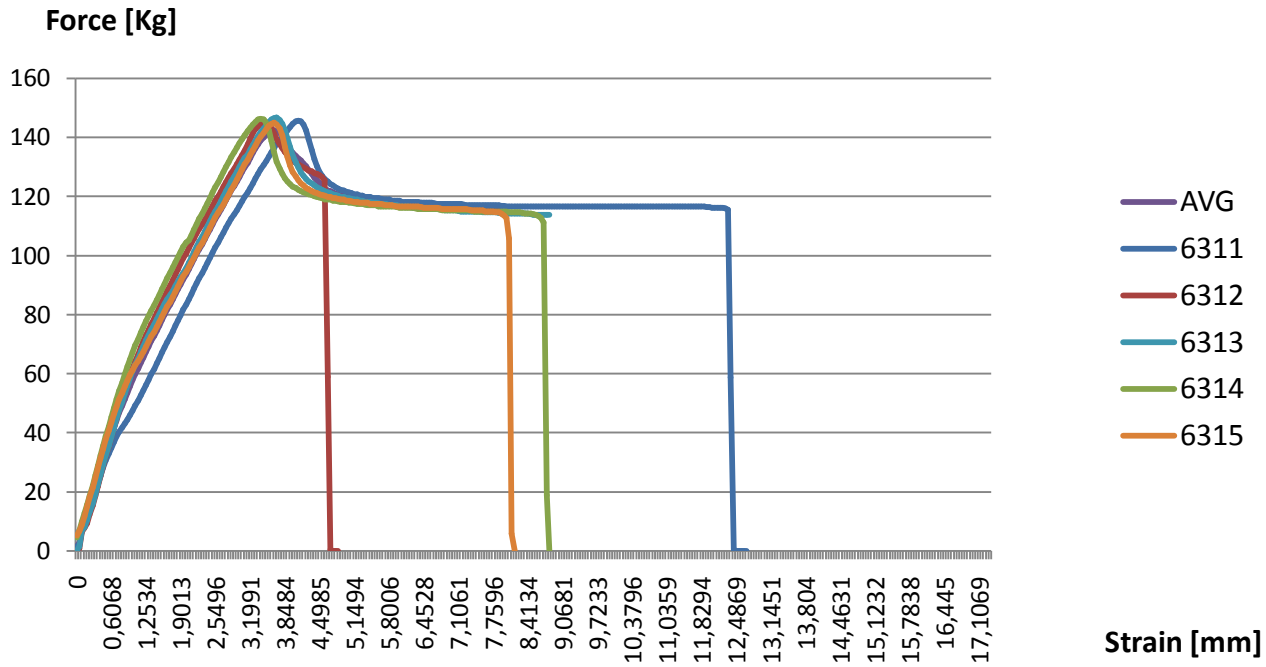
Process 5



It was assessed that test 532 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 5 are [Kg]

	141,38
	138,13
	143,5
	144,22
Avg	141,8075
Std. D	2,732

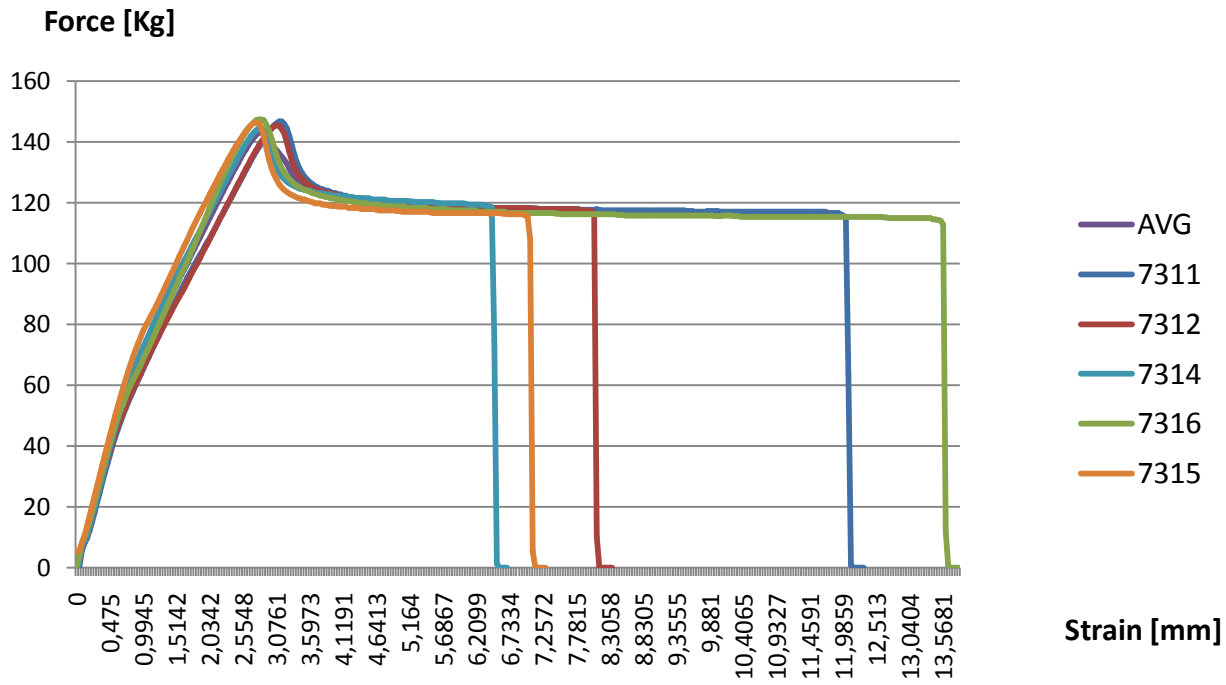
Process 6



The maximum tensile test of process 6 failed altogether because of over tightened camps, which is why a new production of these was made. It turned out that the new production had much different tensile properties and was then only used for showing the curvature of the Force strain graph, for that reason the values from the failed tests was used for maximum tensile strength comparison.
The tensile values for the tests of process 6 are [Kg]

	142,59
	137,72
	139,75
Avg	140,02
Std. D	2,446201

Process 7

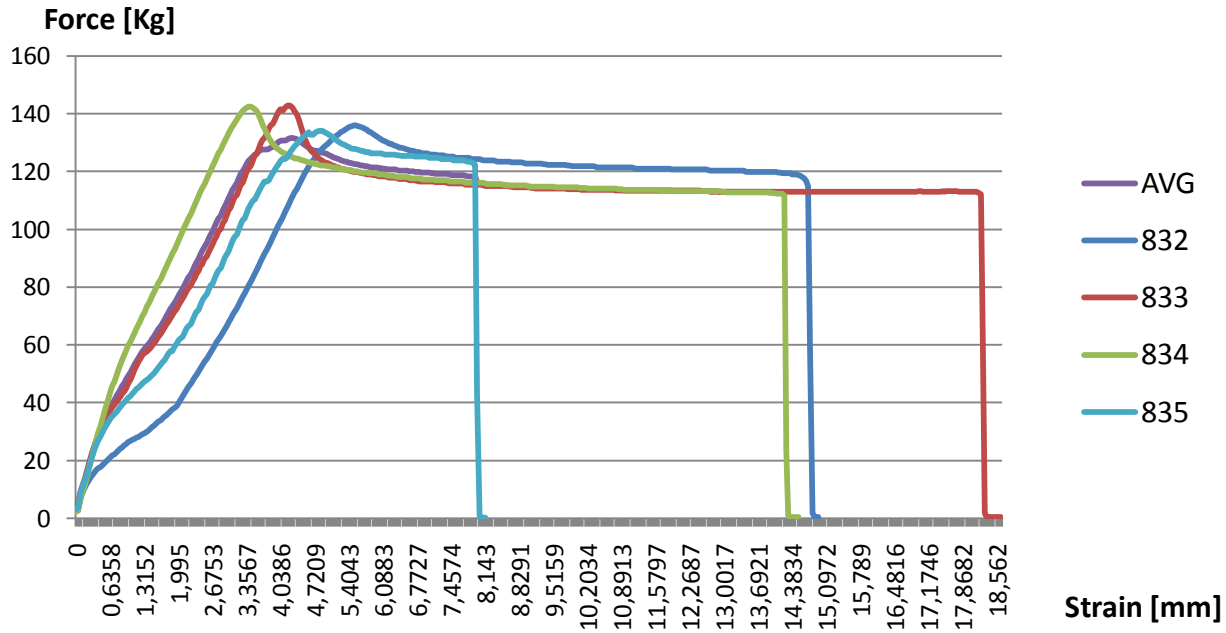


The tensile test of process 7 failed altogether because of over tightened camps, which is why a new production of these was made. It turned out that the new production had much different tensile properties and was then only used for showing the curvature of the Force strain graph, for that reason the values from the failed tests was used for maximum tensile strength comparison.
The maximum tensile values for the tests of process 7 are [Kg]

133,68
136,91
135,29

Avg	135,2933
Std. D	1,615003

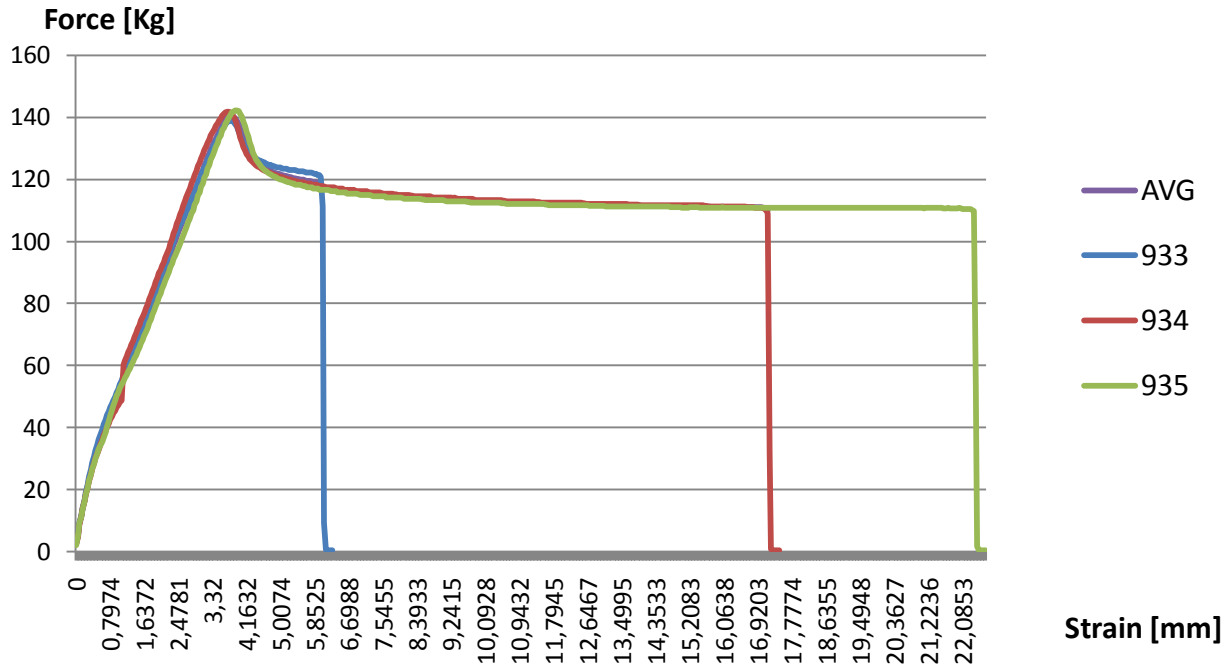
Process 8



It was assessed that test 831 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 8 are [Kg]

	136,05
	142,89
	142,59
	134,06
Avg	138,8975
Std. D	4,512364

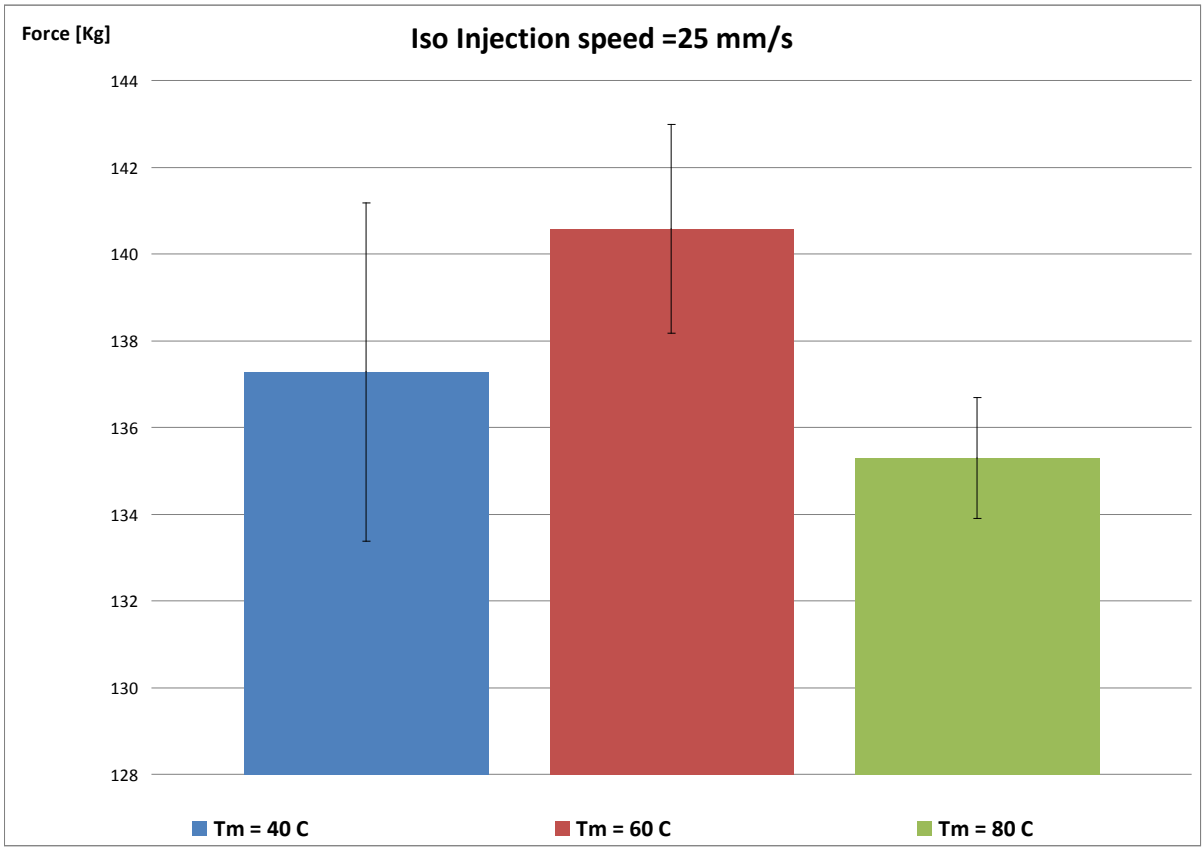
Process 9

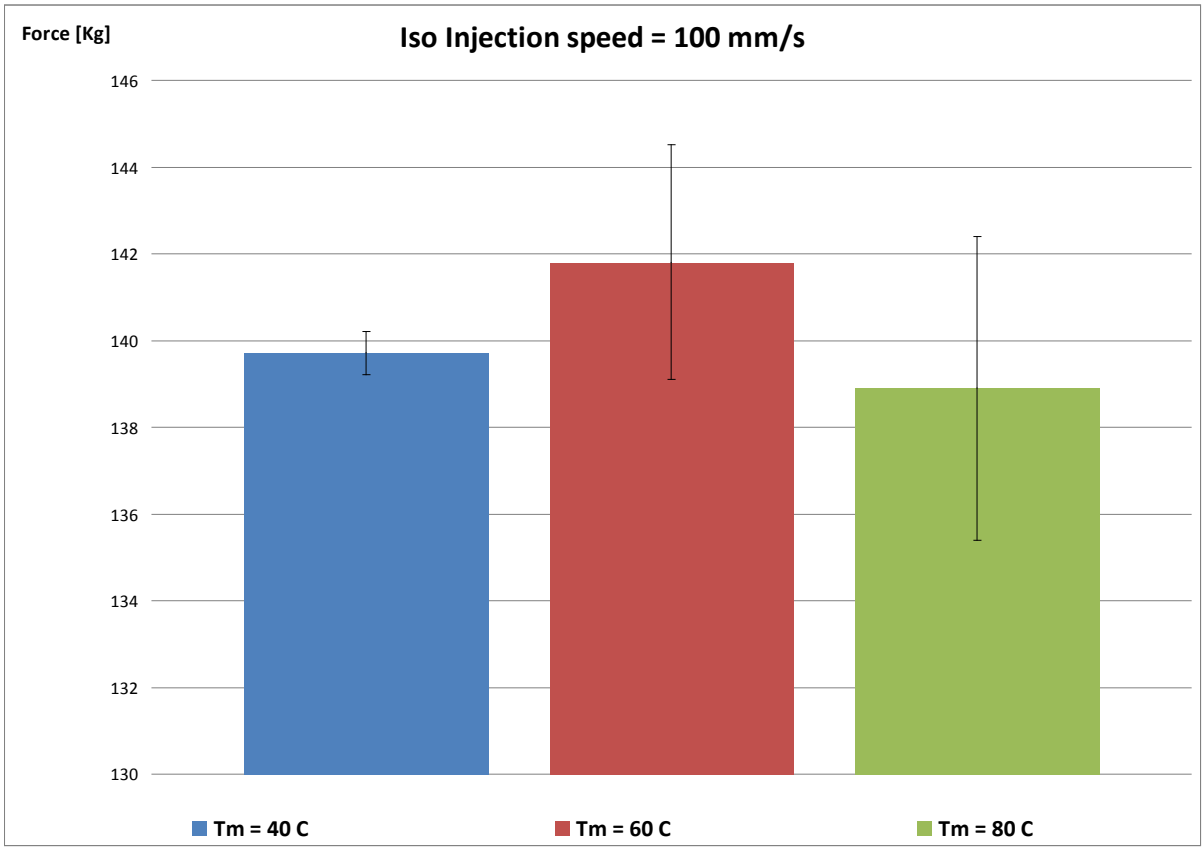


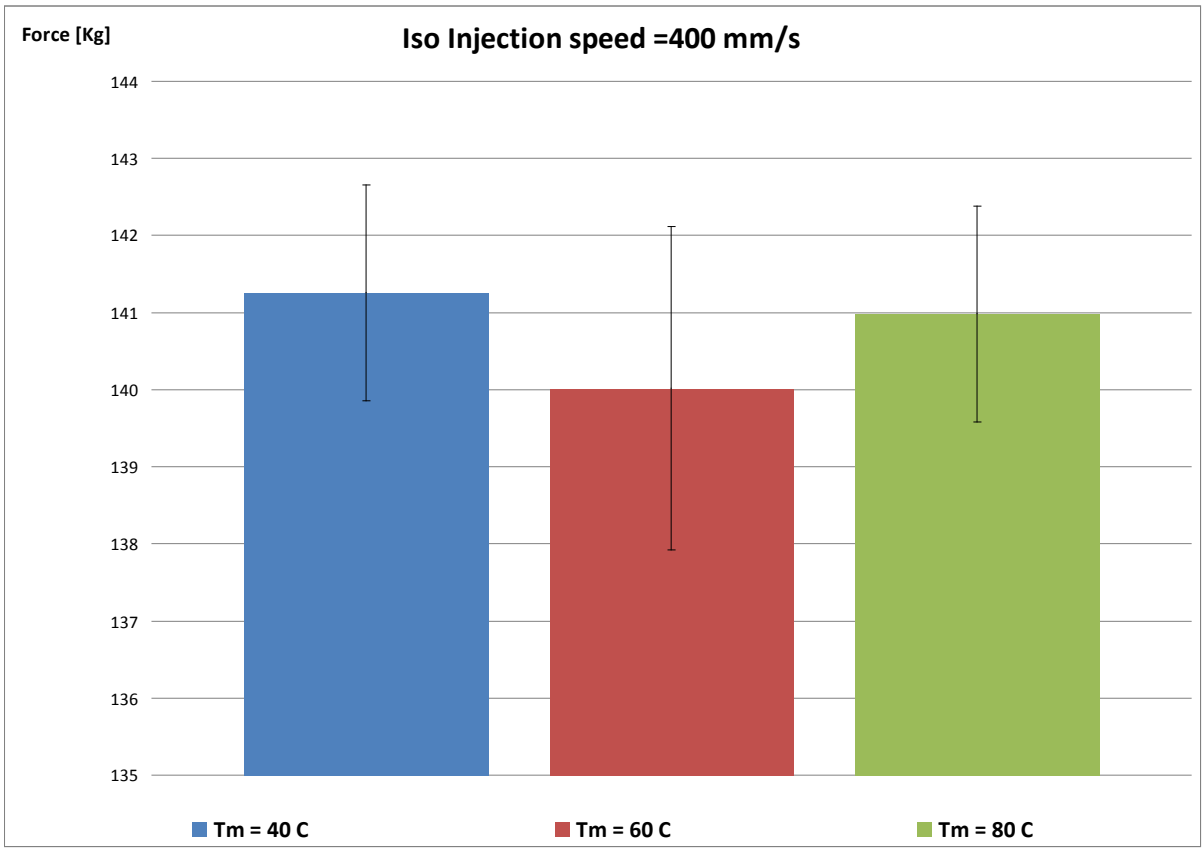
It was assessed that test 931 and 932 was too unreliable to include in the presentation of the Force-Strain behavior and that 932also was too unreliable to used regarding maximum tensile strength.
The maximum tensile values for the tests of process 9 are [Kg]

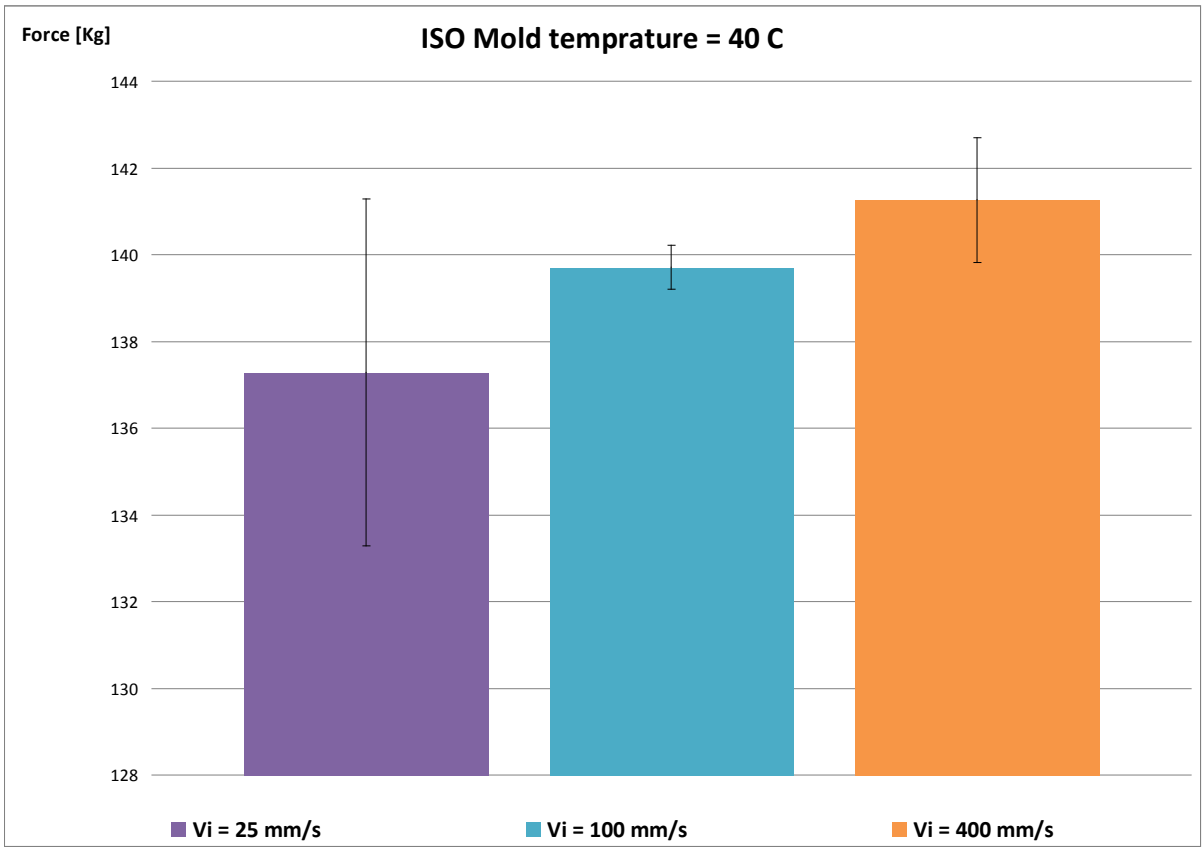
	141,03
	138,94
	141,78
	142,19
Avg	140,985
Std. D	1,445464

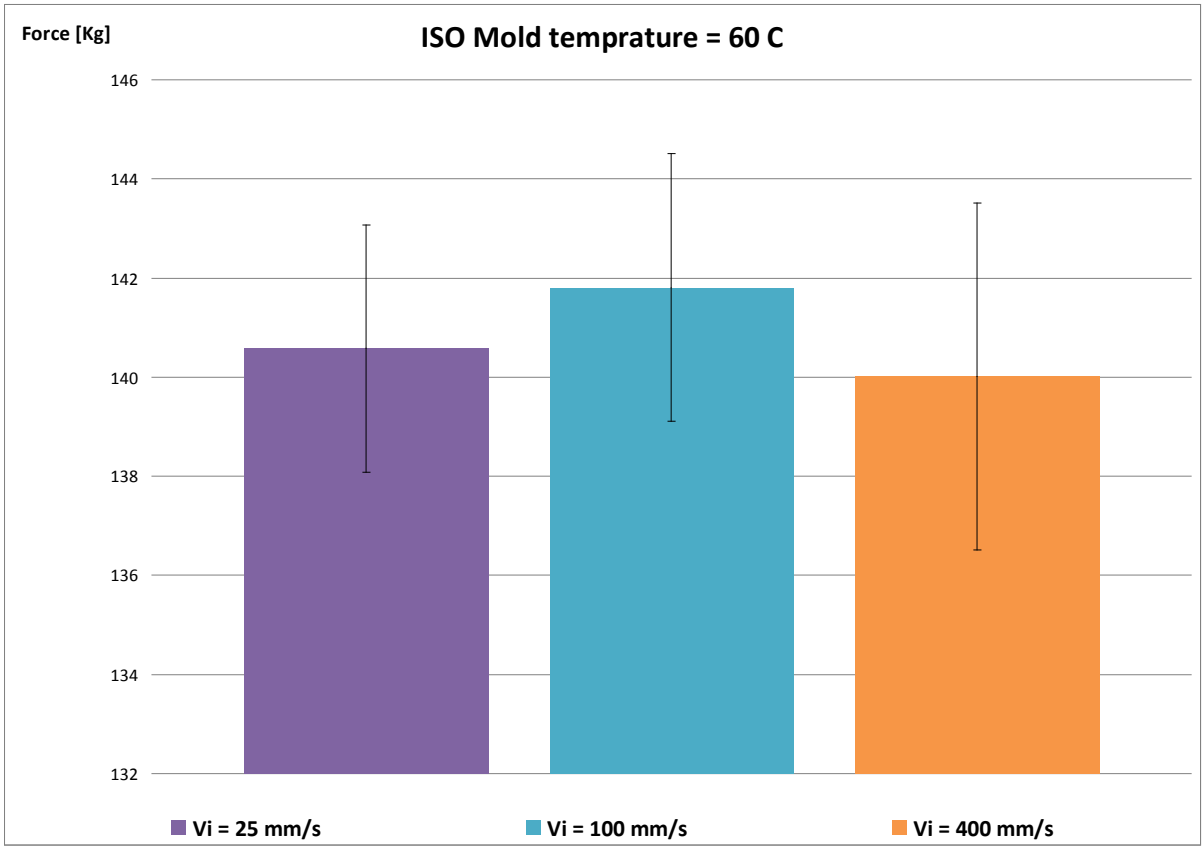
1.5 Systematic comparison maximum tensile test ABS big

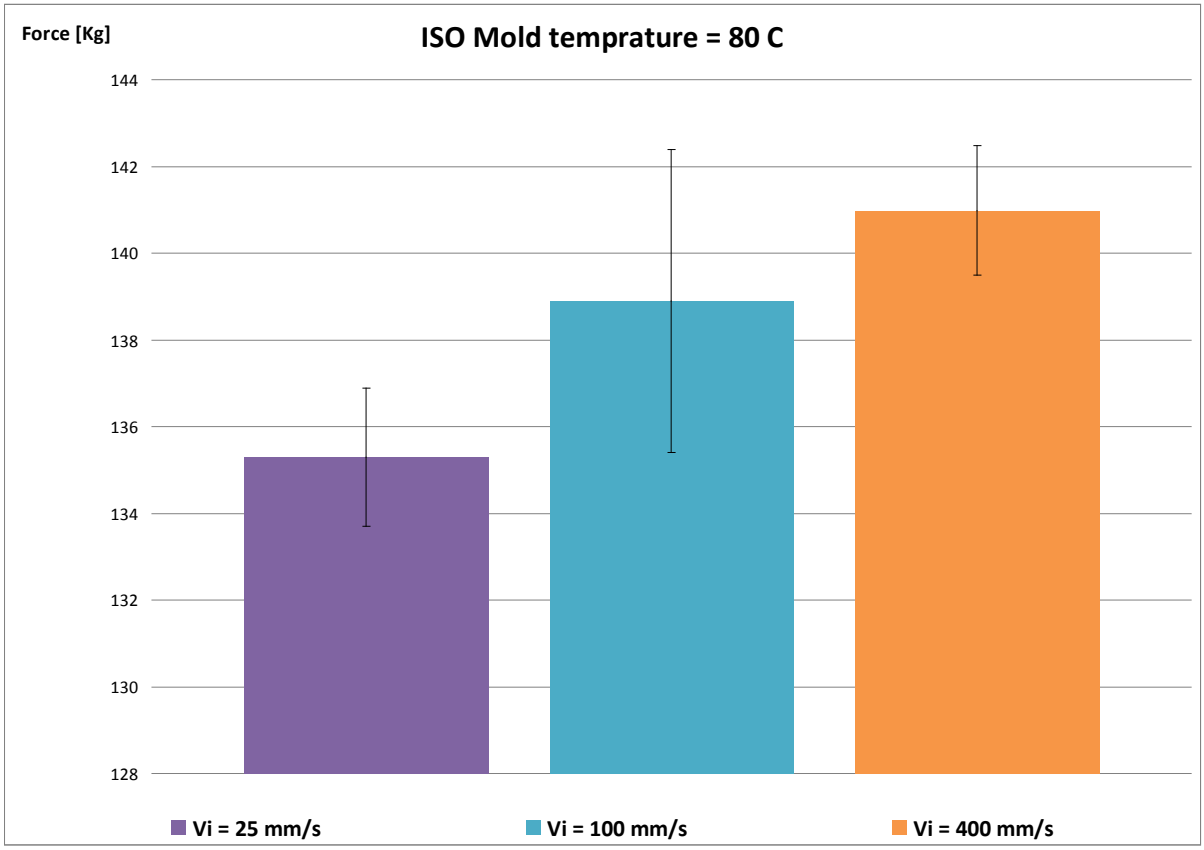





Force [Kg]
Iso Injection speed =400 mm/s
144
143
142
141
140
139
138
137
136
135
Tm = 40 C
Tm = 60 C
Tm = 80 C

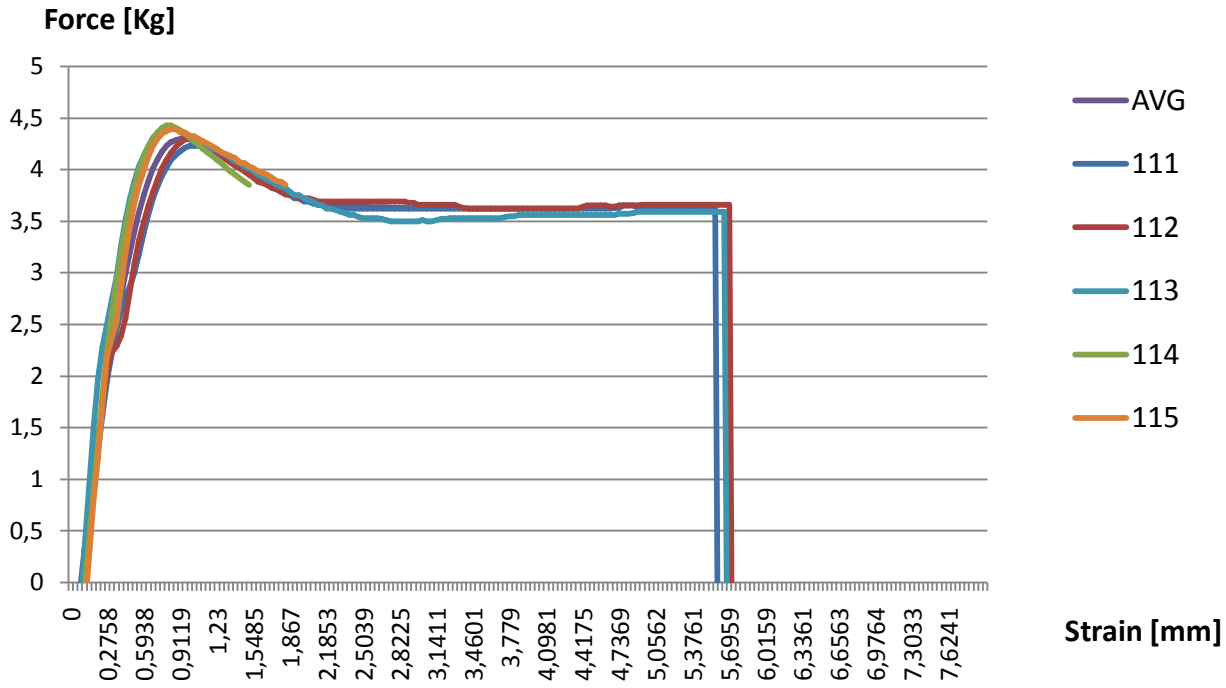

Force [Kg]
ISO Mold temprature = 40 C
144
142
140
138
136
134
132
130
128
Vi = 25 mm/s
Vi = 100 mm/s
Vi = 400 mm/s


Force [Kg]
ISO Mold temprature = 60 C
146
144
142
140
138
136
134
132
Vi = 25 mm/s
Vi = 100 mm/s
Vi = 400 mm/s


Force [Kg]
ISO Mold temprature = 80 C
144
142
140
138
136
134
132
130
128
Vi = 25 mm/s
Vi = 100 mm/s
Vi = 400 mm/s

1.6 Tensile test - small dog bone specimen of HH 315 M0 (PP)

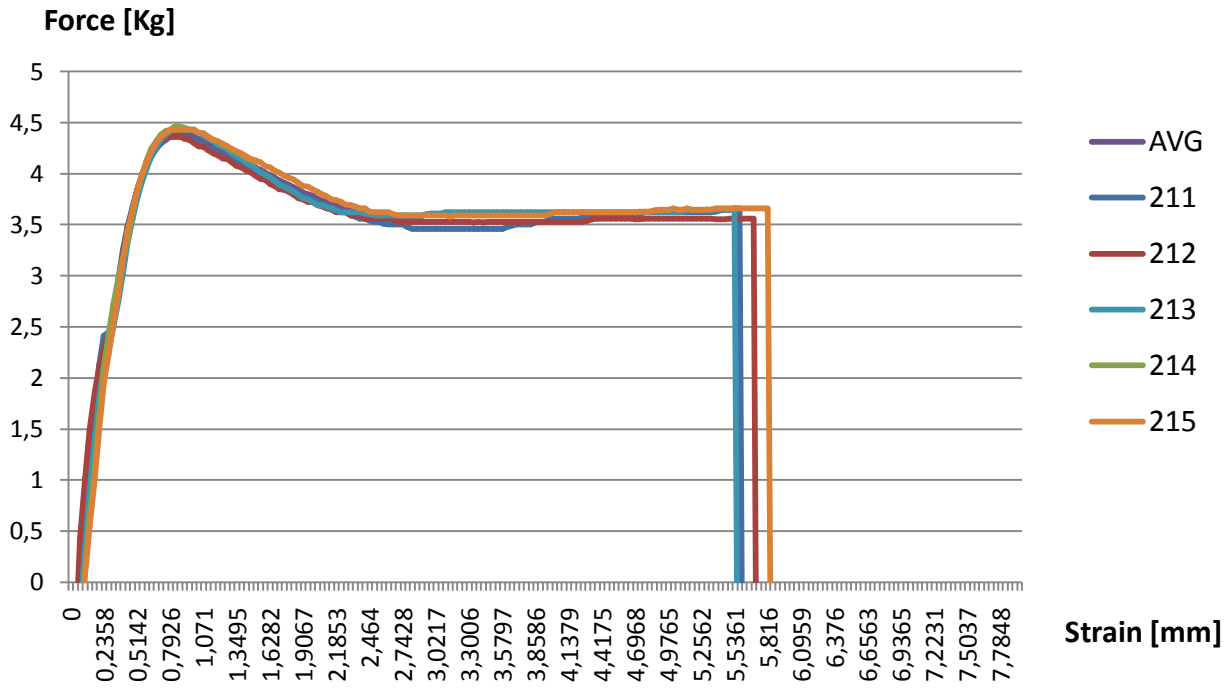
Process 1



The maximum tensile values for the tests of process 1 are [Kg]

	4,23
	4,3
	4,4
	4,43
	4,39
Avg	4,35
Std.D	0,082765

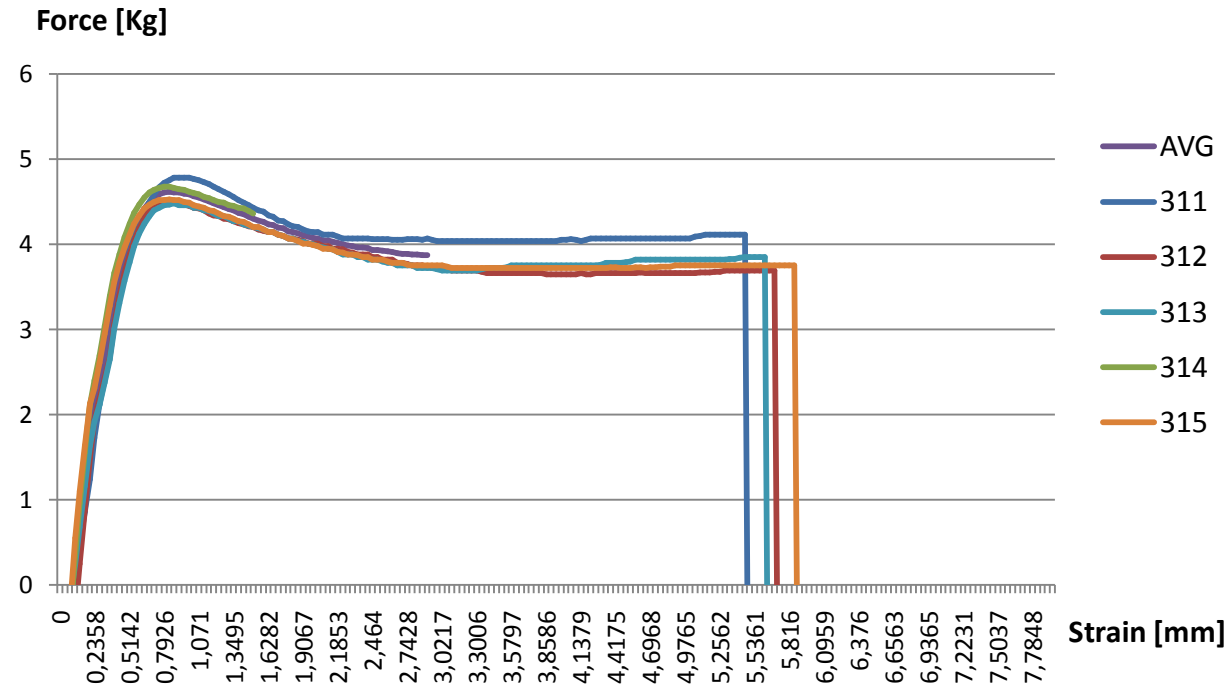
Process 2



The maximum tensile values for the tests of process 2 are [Kg]

	4,36
	4,36
	4,43
	4,46
	4,43
Avg	4,408
Std.D	0,045497

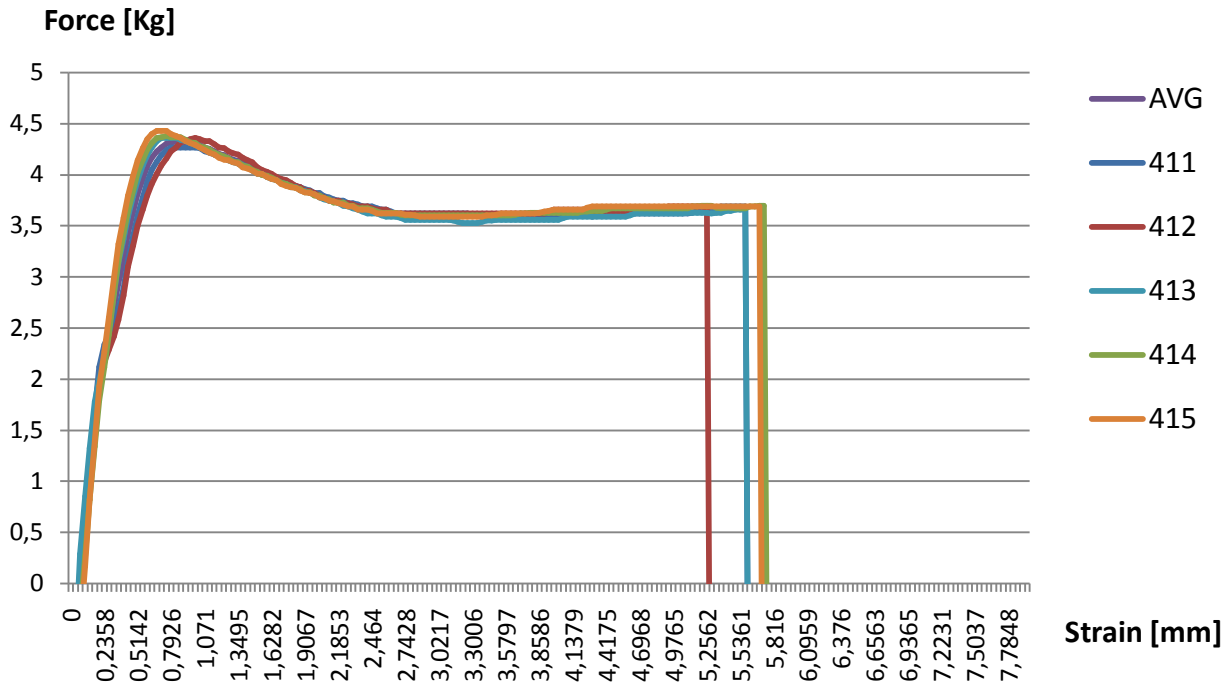
Process 3



The maximum tensile values for the tests of process 3 are [Kg]

	4,78
	4,52
	4,48
	4,68
	4,53
Avg	4,598
Std.D	0,126965

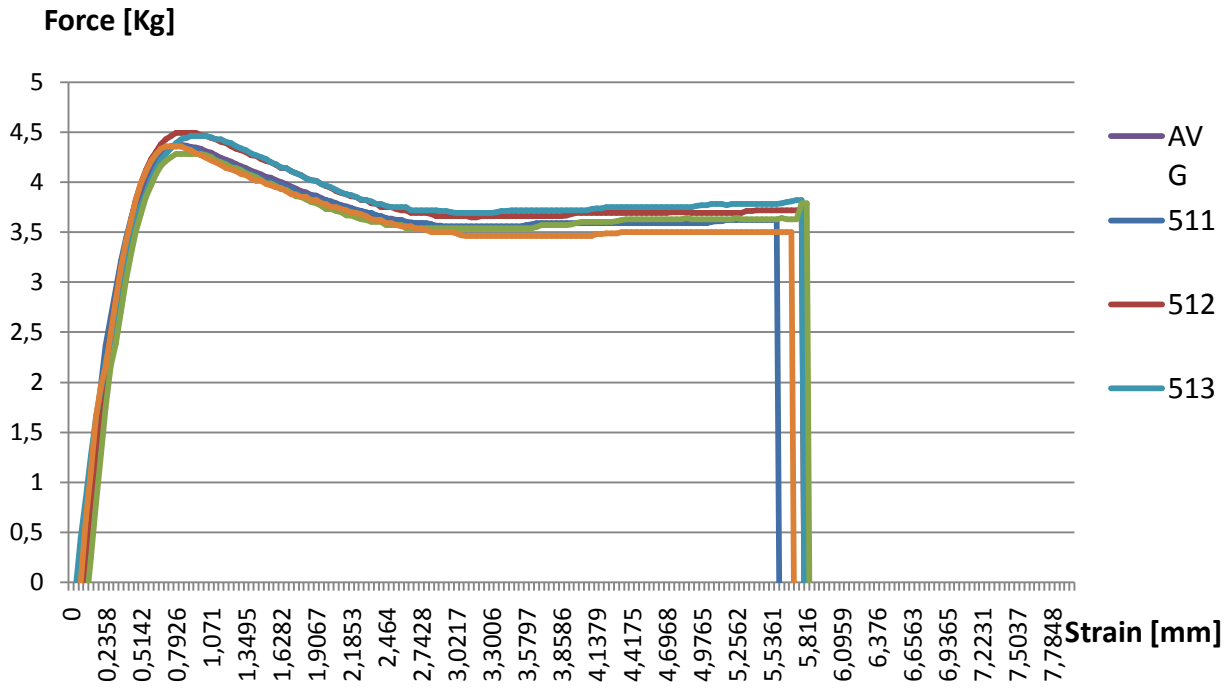
Process 4



The maximum tensile values for the tests of process 4 are [Kg]

	4,27
	4,36
	4,36
	4,38
	4,43
Avg	4,36
Std.D	0,057879

Process 5

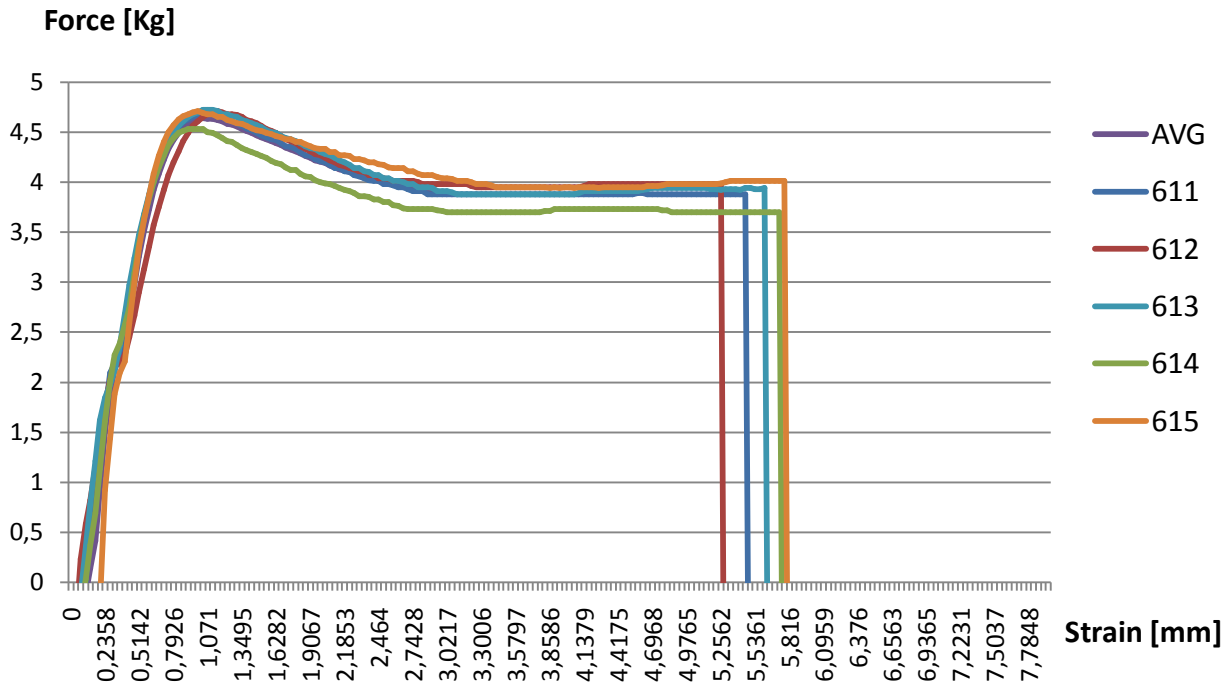


It was assessed that test 514was too unreliable to include in the presentation of the maximum tensile testing.

The maximum tensile values for the tests of process 5 are [Kg]

	4,36
	4,49
	4,46
	4,36
Avg	4,4175
Std.D	0,067515

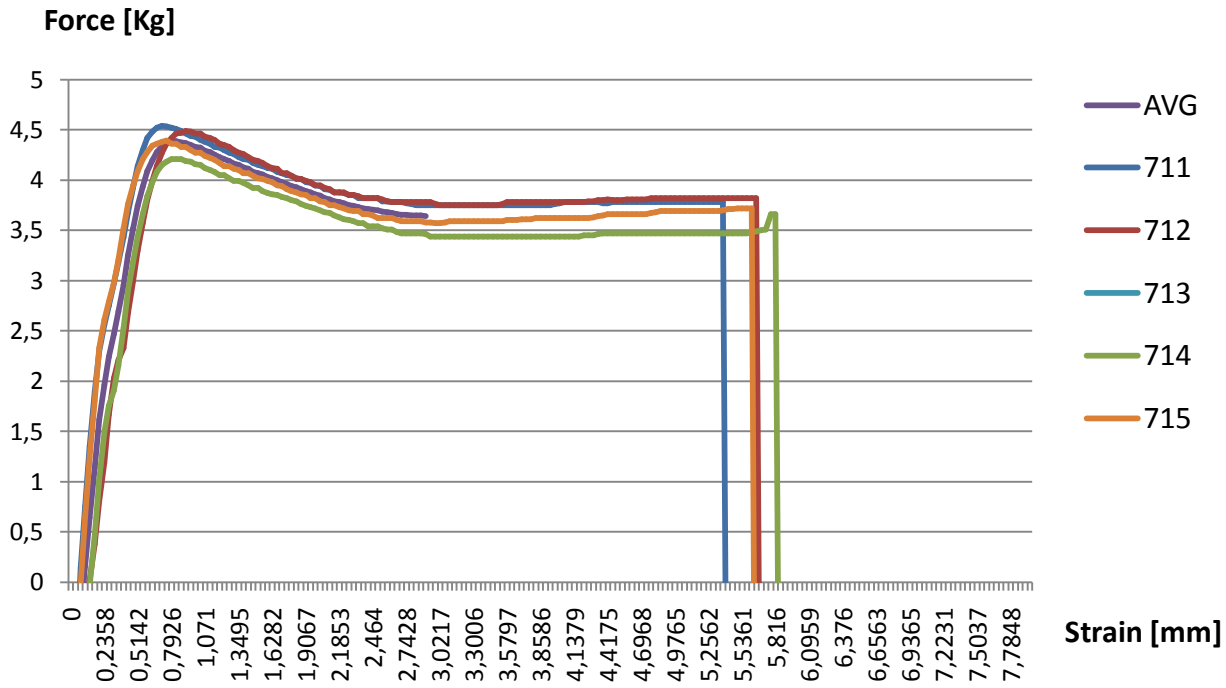
Process 6



The maximum tensile values for the tests of process 6 are [Kg]

	4,68
	4,71
	4,72
	4,53
	4,71
Avg	4,67
Std.D	0,079687

Process 7

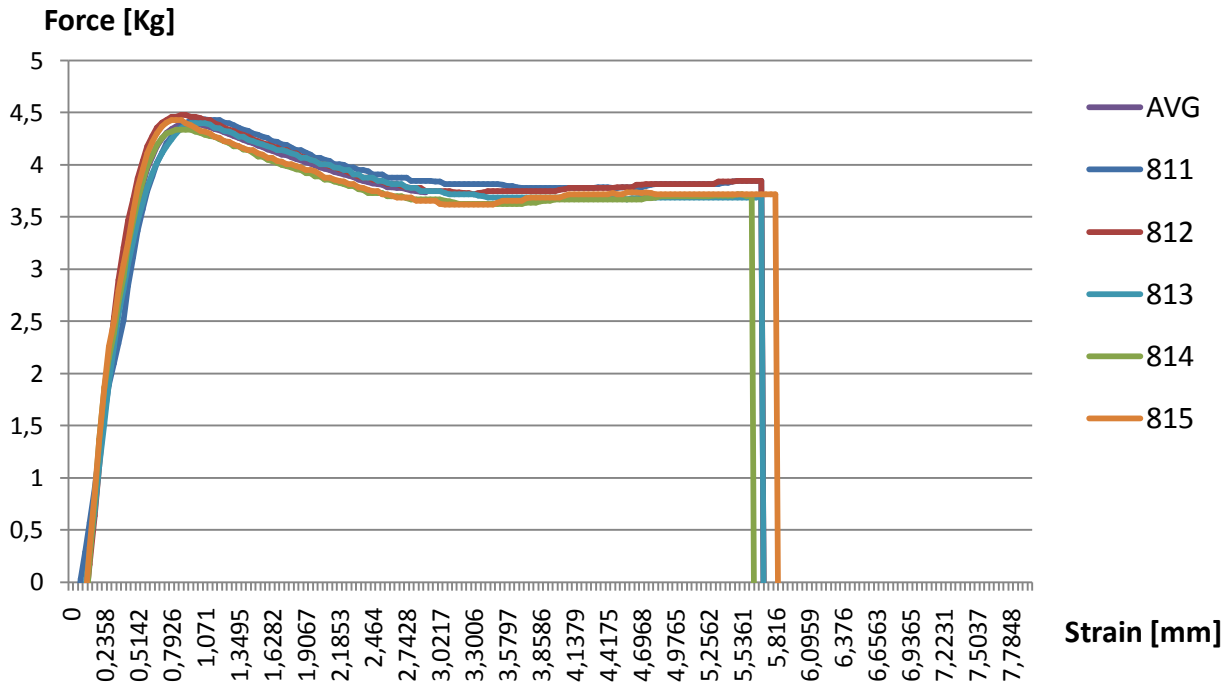


It was assessed that test 714was too unreliable to include in the presentation of the maximum tensile testing.

The maximum tensile values for the tests of process 7 are [Kg]

	4,54
	4,49
	4,21
	4,39
Avg	4,4075
Std.D	0,145688

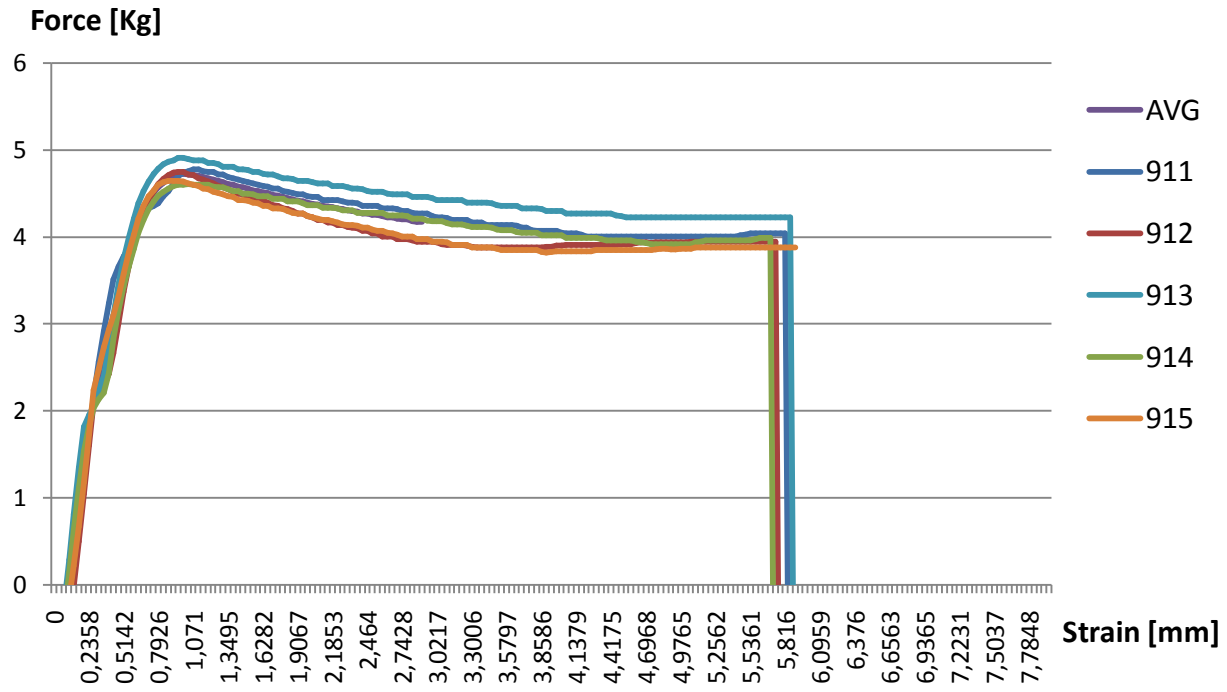
Process 8



It was assessed that test 814was too unreliable to include in the presentation of the maximum tensile testing.
The maximum tensile values for the tests of process 8 are [Kg]

	4,44
	4,48
	4,4
	4,43
Avg	4,4375
Std.D	0,03304

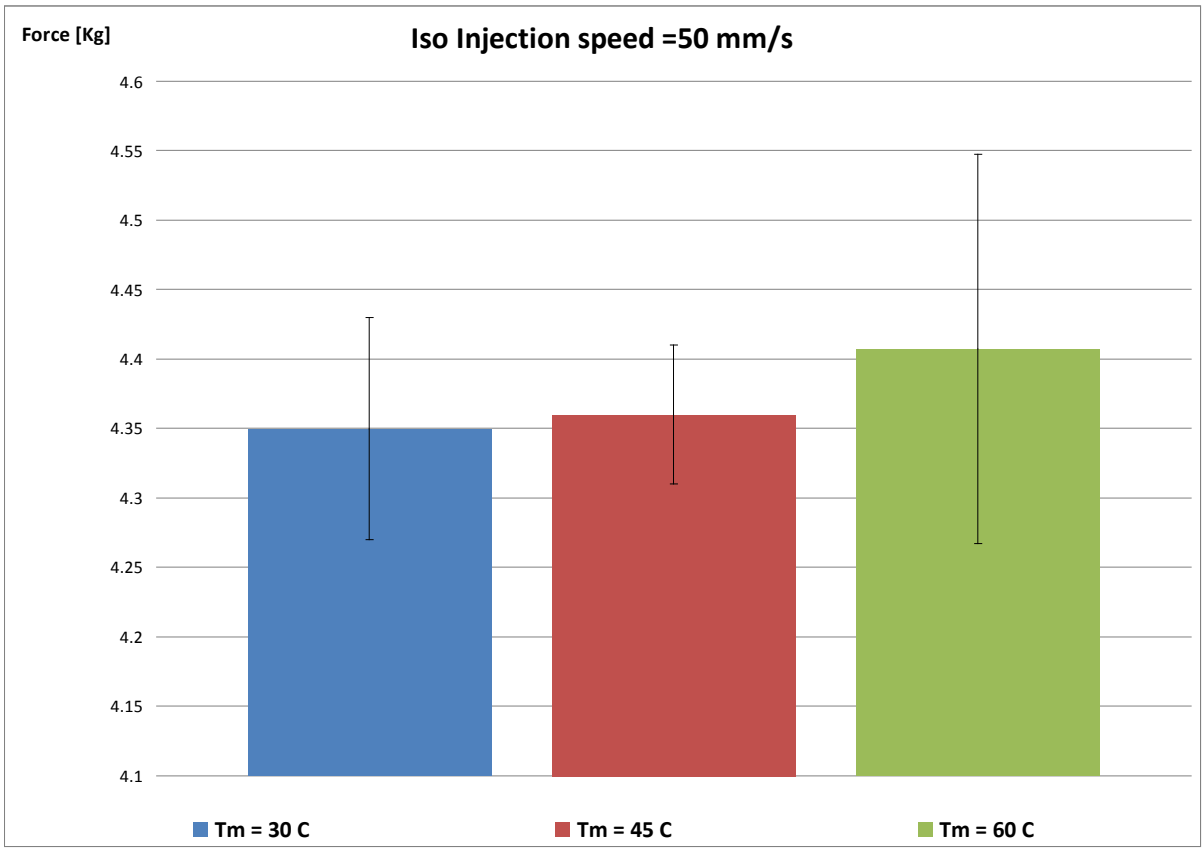
Process 9

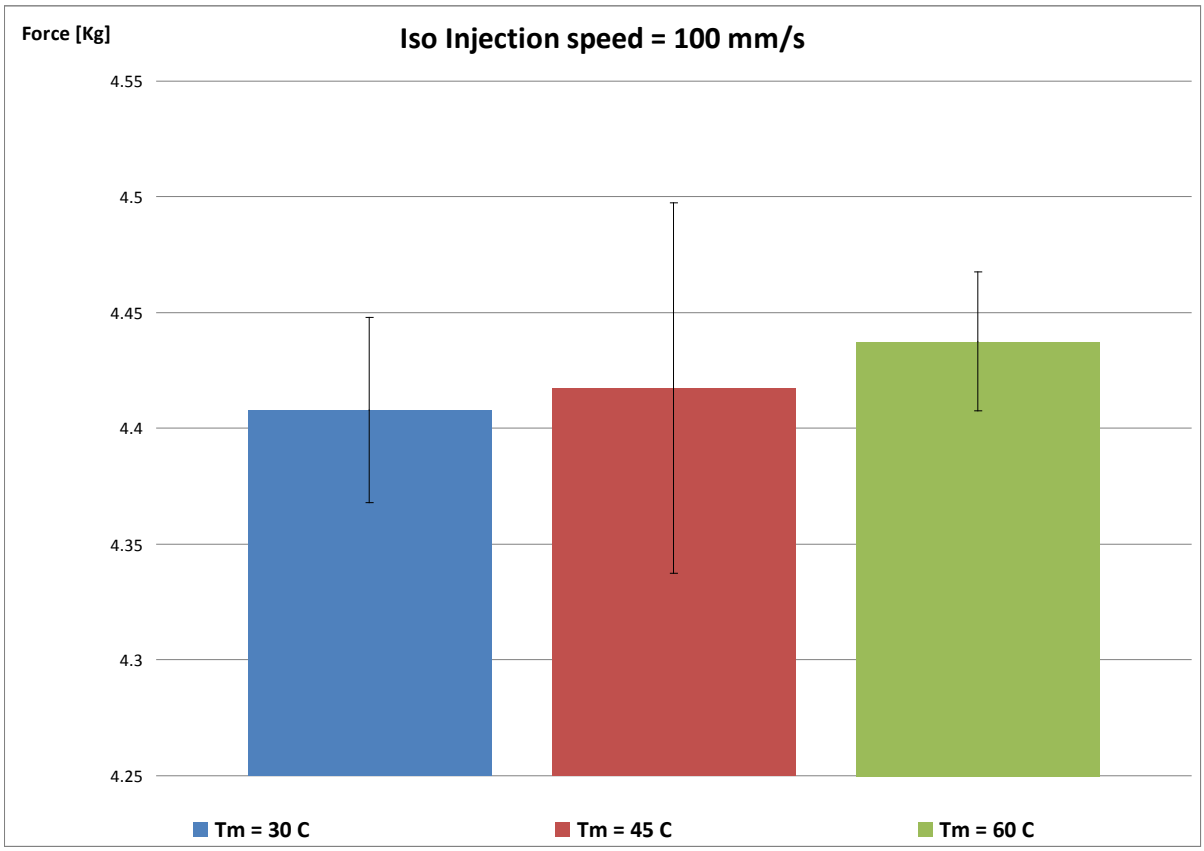


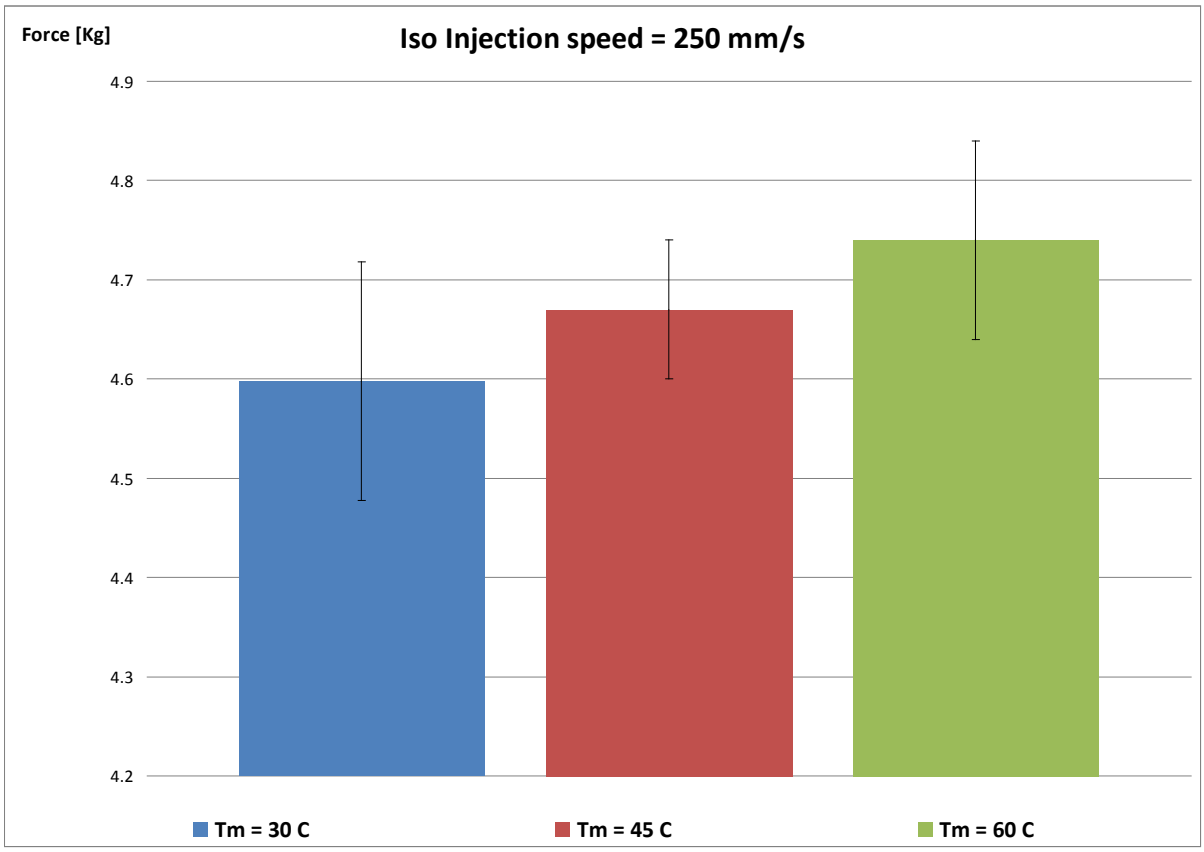
The maximum tensile values for the tests of process 9 are [Kg]

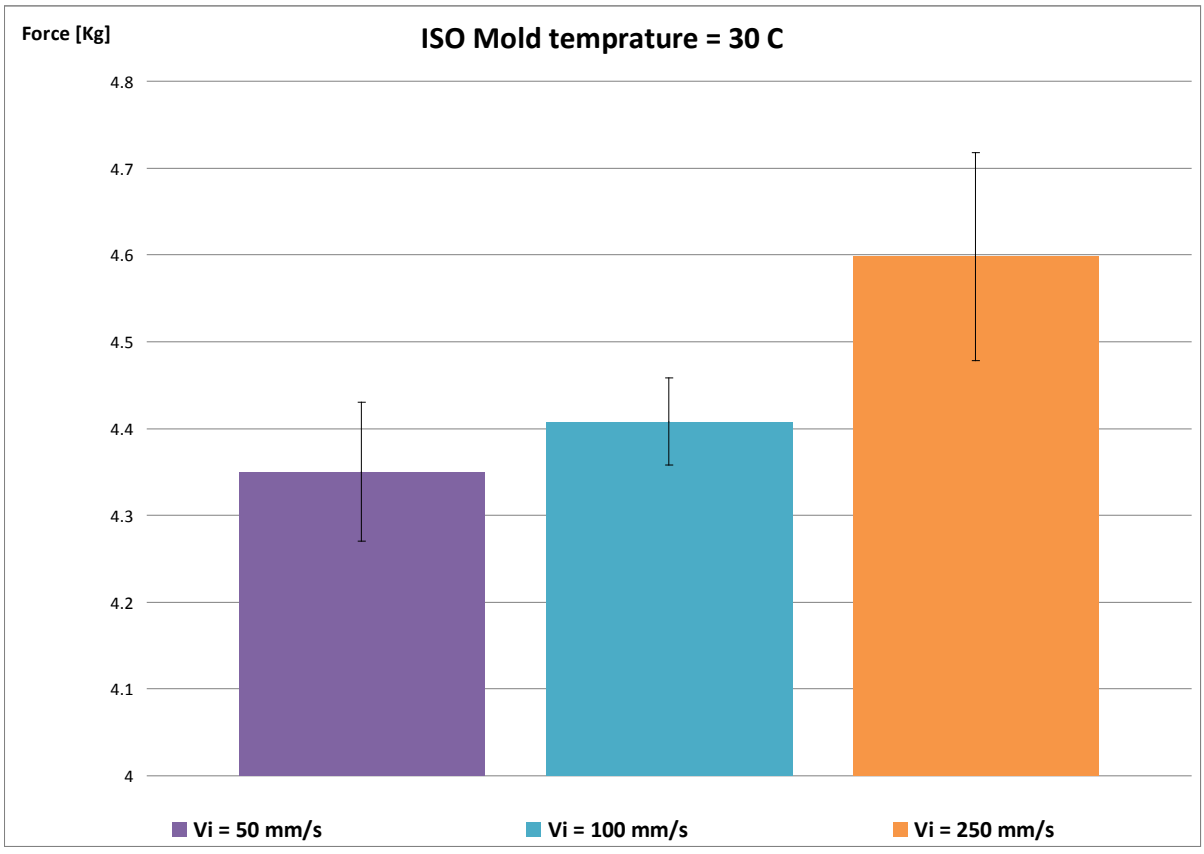
	4,78
	4,75
	4,91
	4,61
	4,65
Avg	4,74
Std.D	0,117898

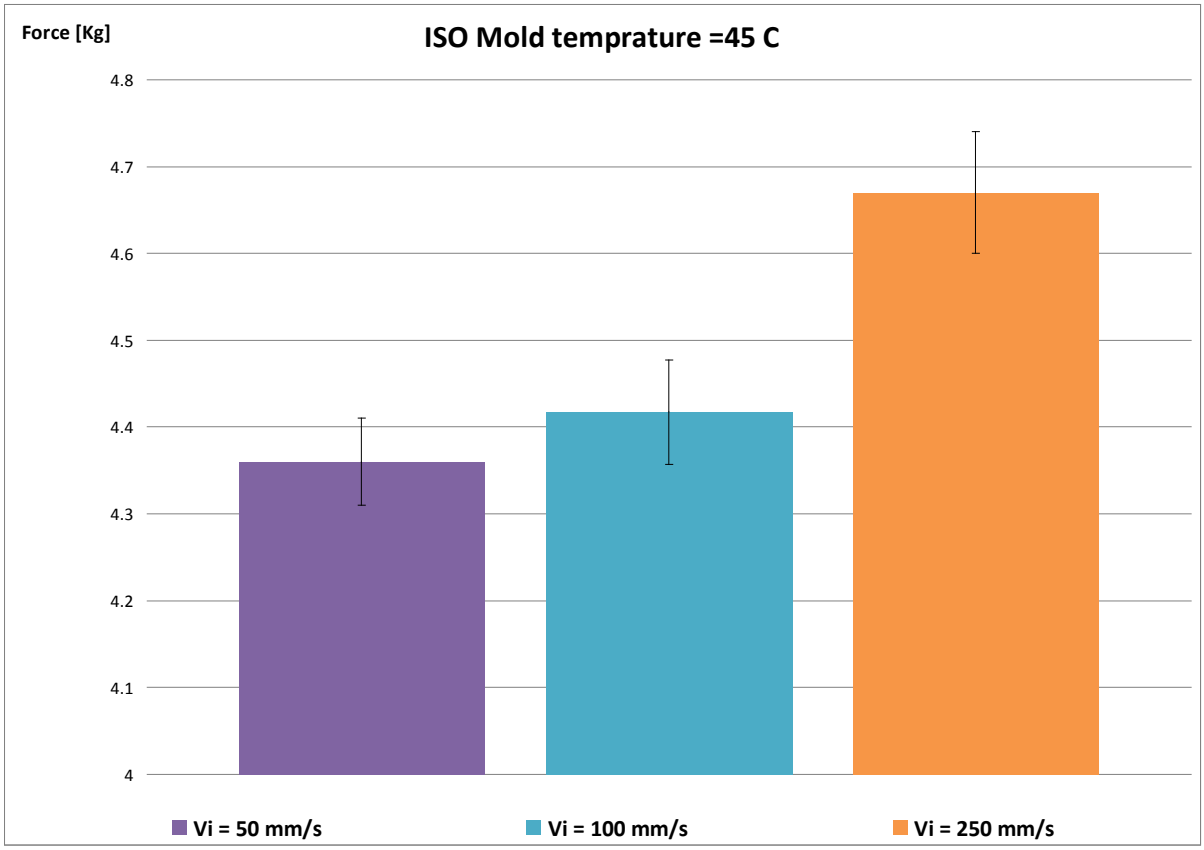
1.7 Systematic Comparison maximum tensile test Micro PP

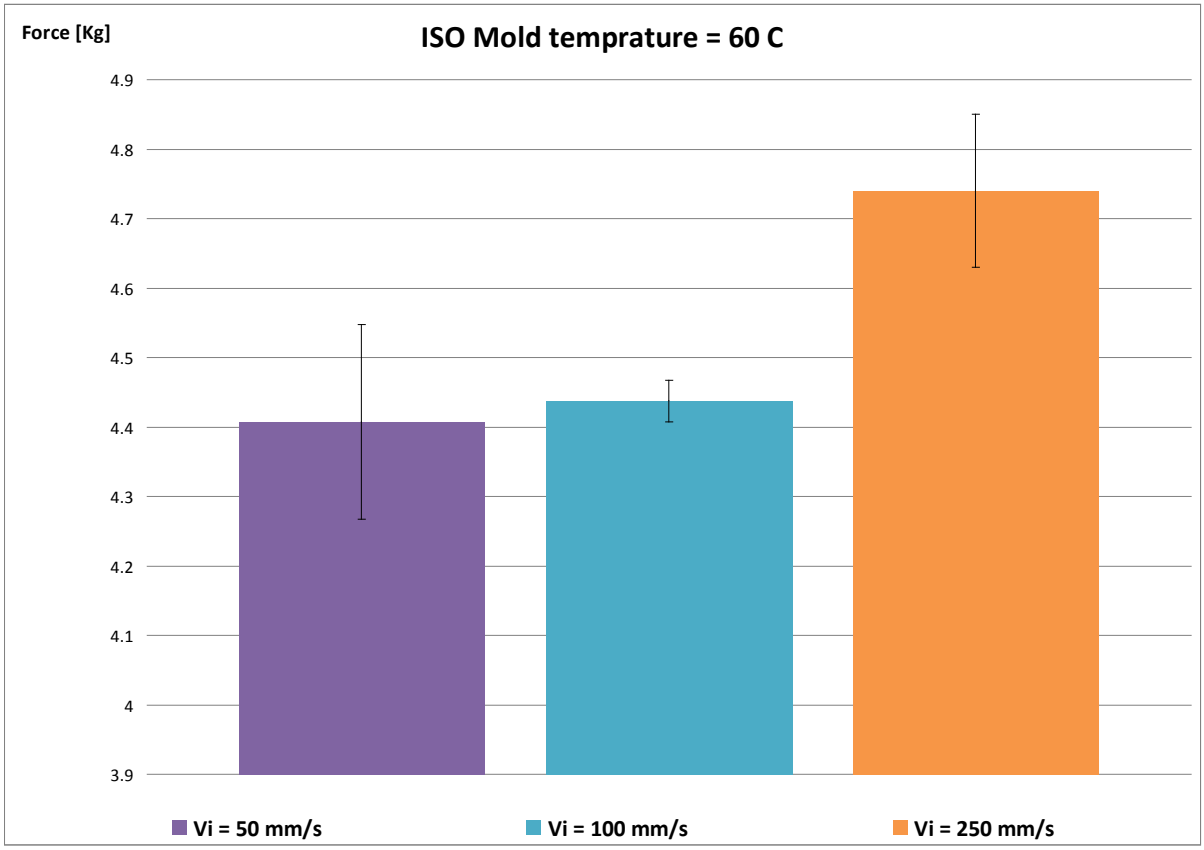





Force [Kg]
Iso Injection speed = 250 mm/s
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
Tm = 30 C
Tm = 45 C
Tm = 60 C

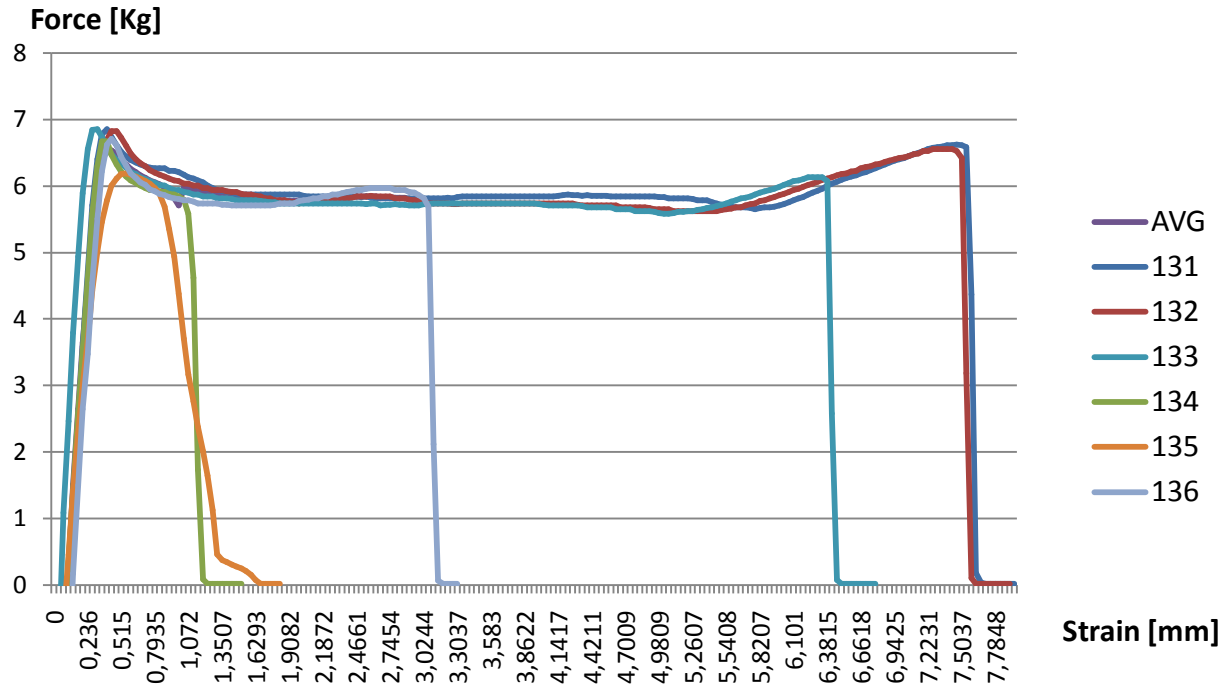

Force [Kg]
ISO Mold temprature = 30 C
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s


Force [Kg]
ISO Mold temprature =45 C
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s


Force [Kg]
ISO Mold temprature = 60 C
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s

1.8 Tensile test - small dog bone specimen of Terluran 35GP (ABS)

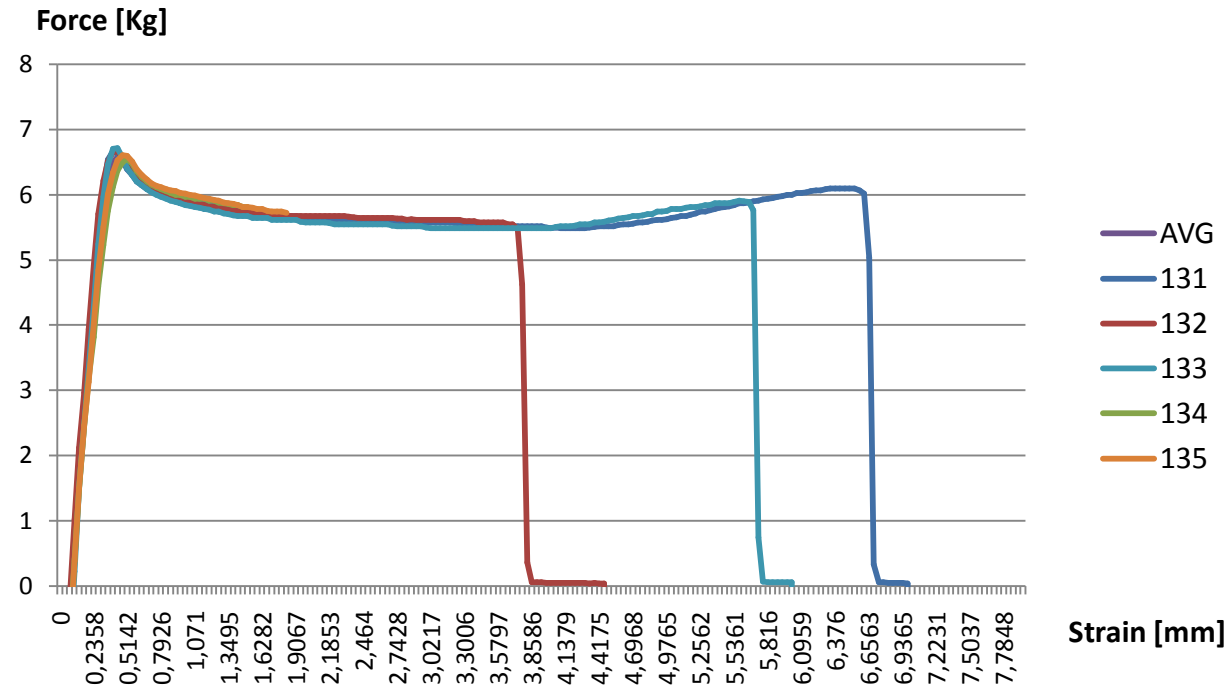
Process 1



It was assessed that test 135was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.
The maximum tensile values for the tests of process 1 are [Kg]

	6,85
	6,82
	6,85
	6,67
	6,71
Avg	6,78
Std. D	0,086168

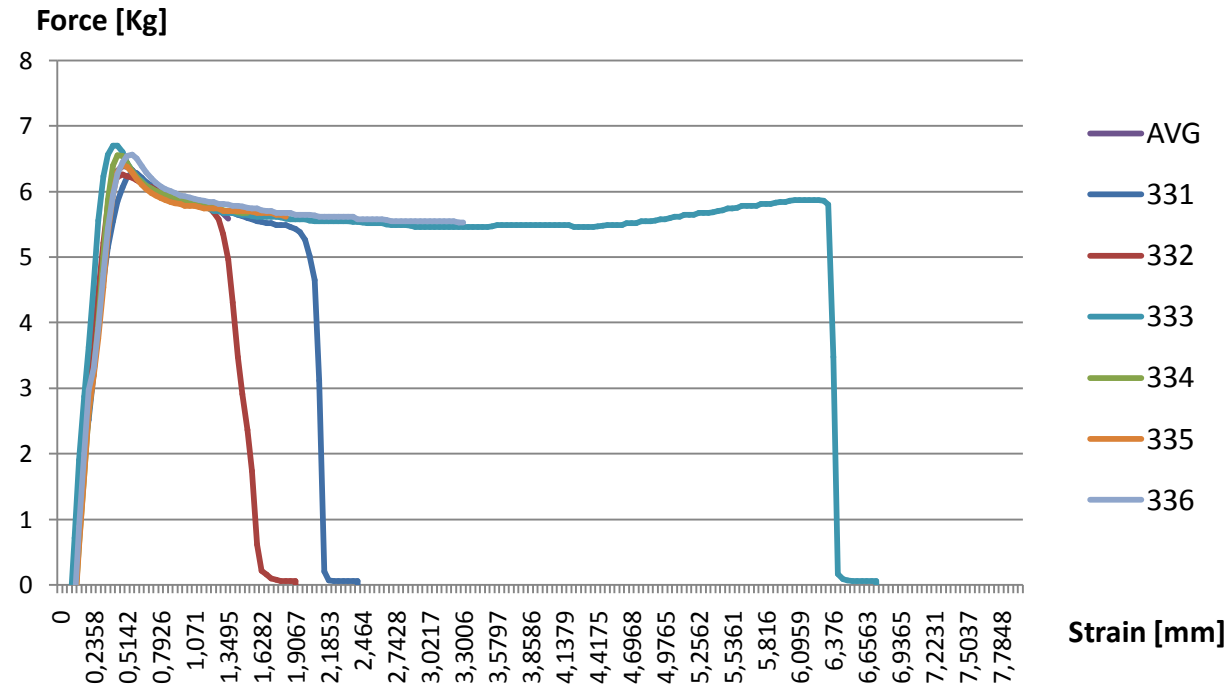
Process 2



The maximum tensile values for the tests of process 2 are [Kg]

	6,67
	6,67
	6,72
	6,55
	6,61
Avg	6,644
Std. D	0,065422

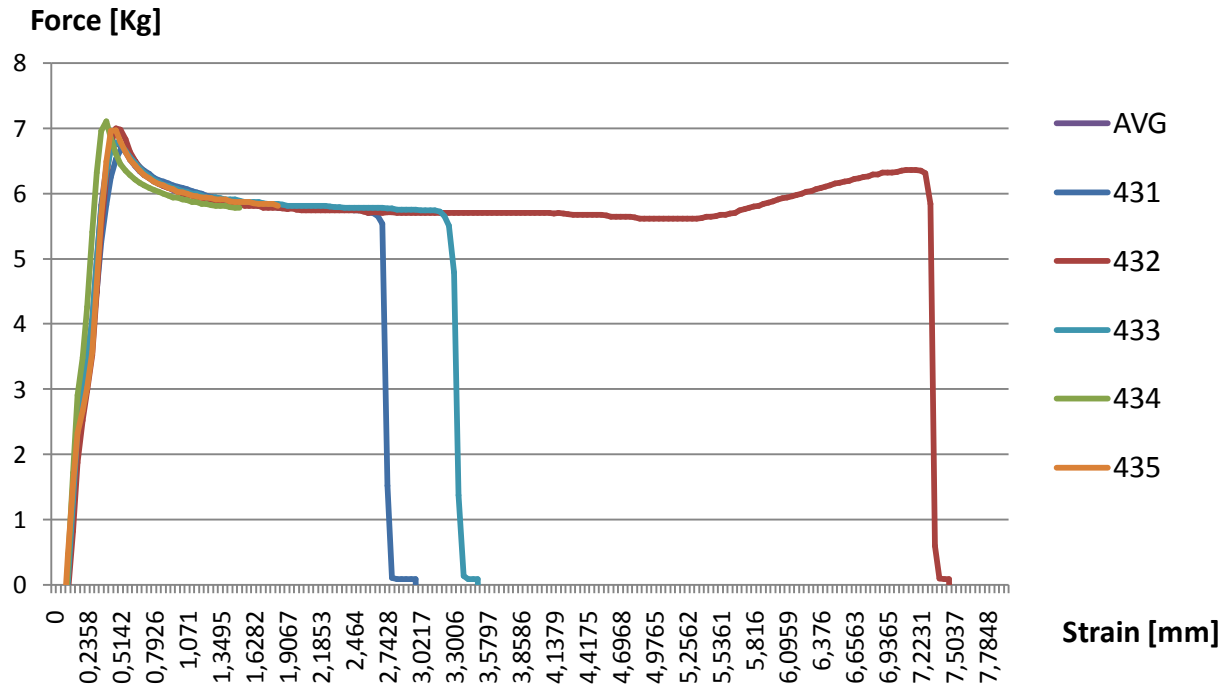
Process 3



The maximum tensile values for the tests of process 3 are [Kg]

	6,29
	6,26
	6,7
	6,56
	6,41
	6,57
Avg	6,465
Std. D	0,185553

Process 4

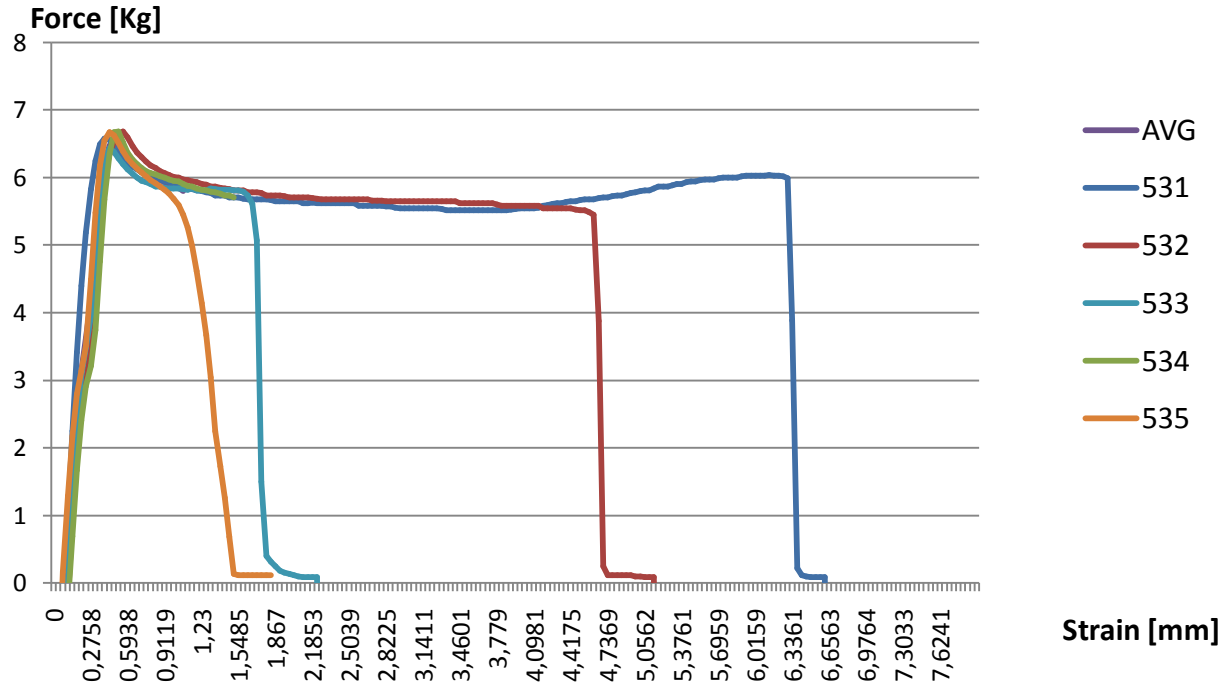


It was assessed that test 434 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.

The maximum tensile values for the tests of process 4 are [Kg]

	6,7
	7
	6,79
	6,97
Avg	6,865
Std. D	0,153948

Process 5

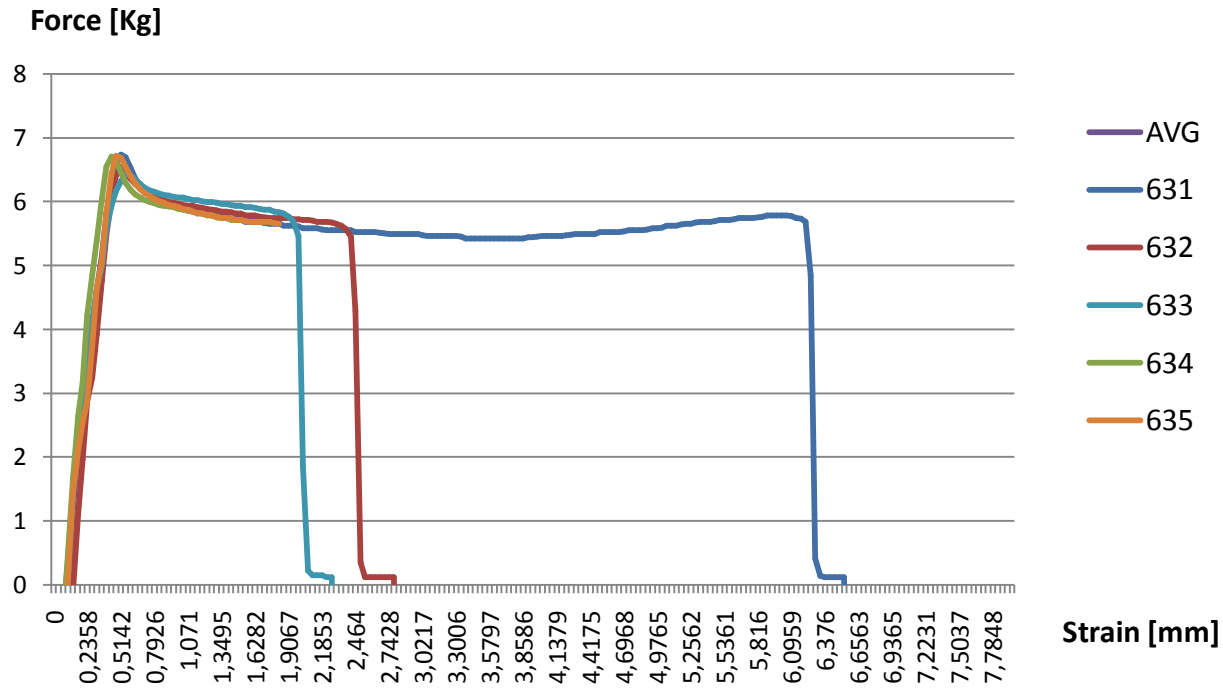


It was assessed that test 434 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.

The maximum tensile values for the tests of process 5 are [Kg]

	6,58
	6,68
	6,68
	6,67
Avg	6,6525
Std. D	0,057735

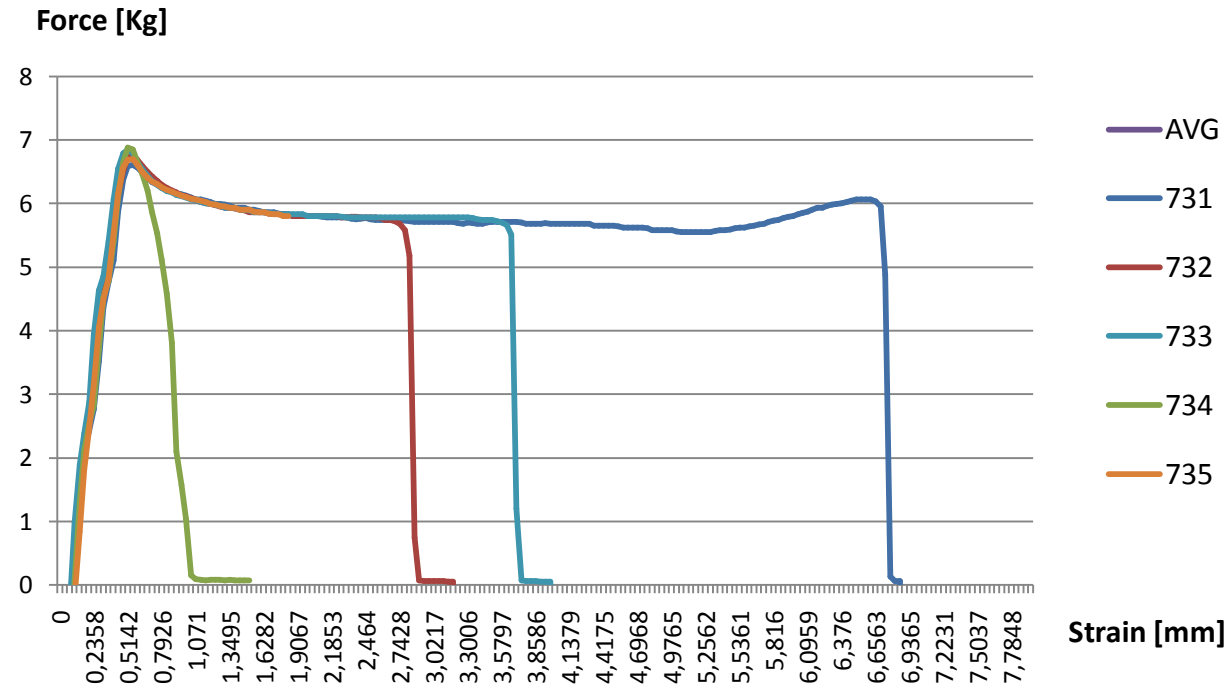
Process 6



The maximum tensile values for the tests of process 6 are [Kg]

	6,74
	6,5
	6,43
	6,71
	6,72
Avg	6,62
Std. D	0,153297

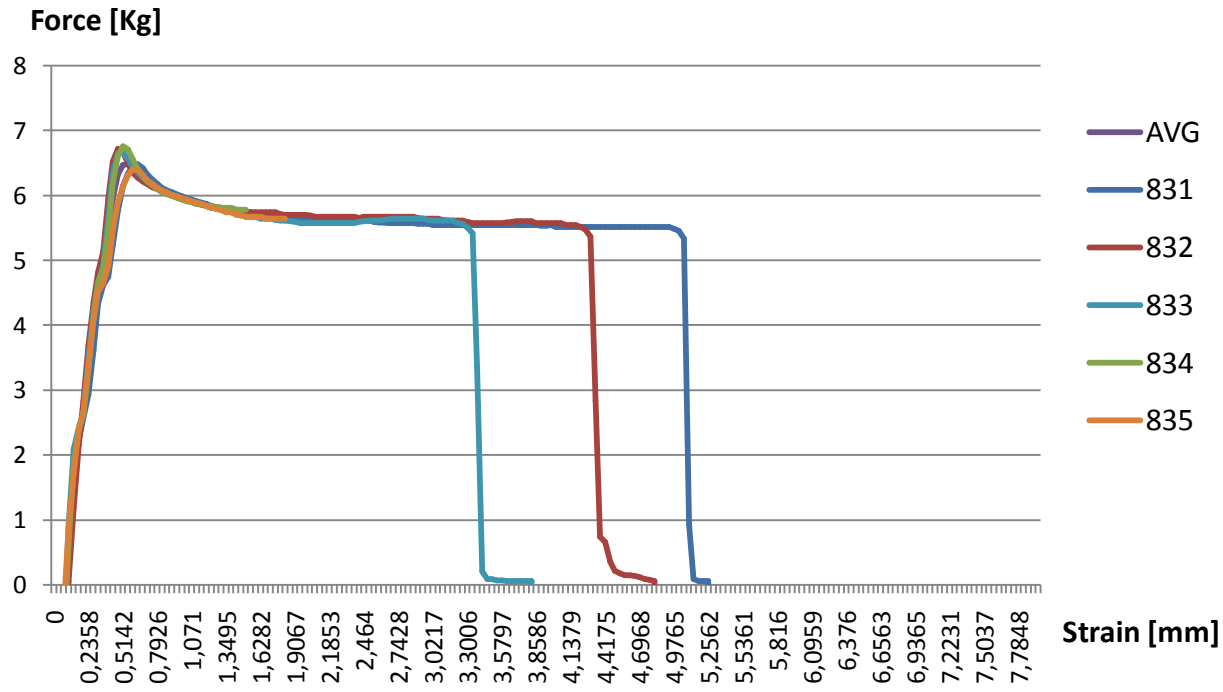
Process 7



The maximum tensile values for the tests of process 7 are [Kg]

	6,61
	6,77
	6,85
	6,88
	6,7
Avg	6,762
Std. D	0,110318

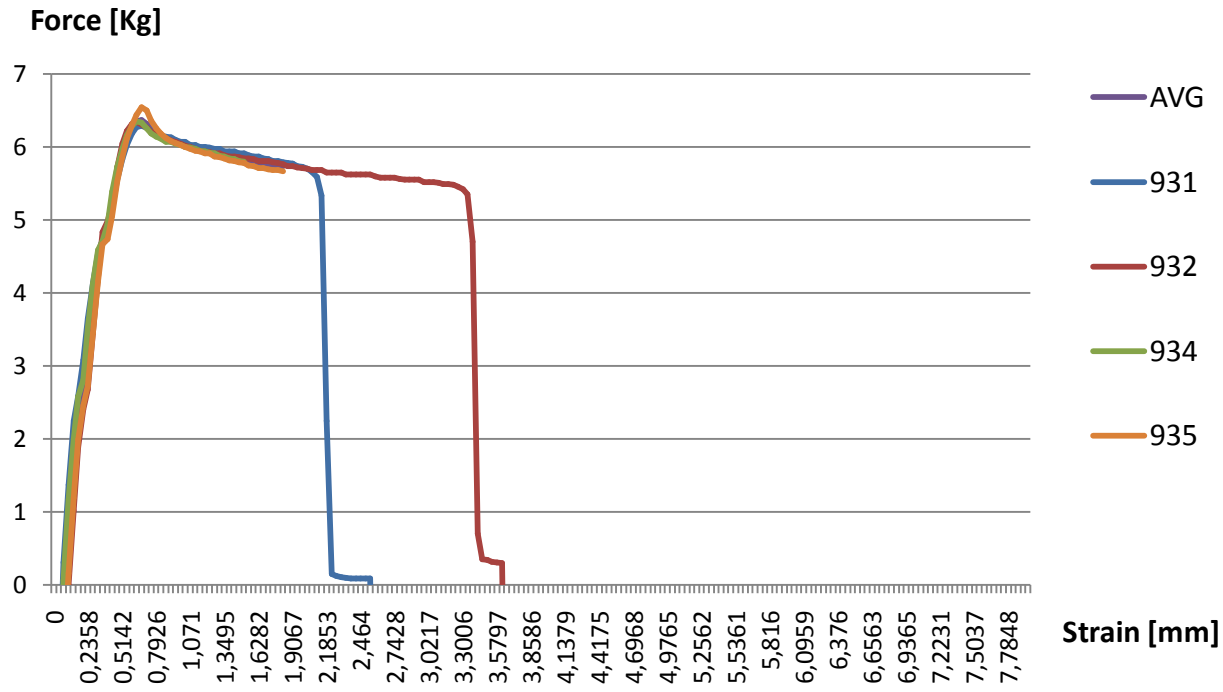
Process 8



The maximum tensile values for the tests of process 8 are [Kg]

	6,48
	6,72
	6,66
	6,76
	6,41
Avg	6,606
Std. D	0,153232

Process 9

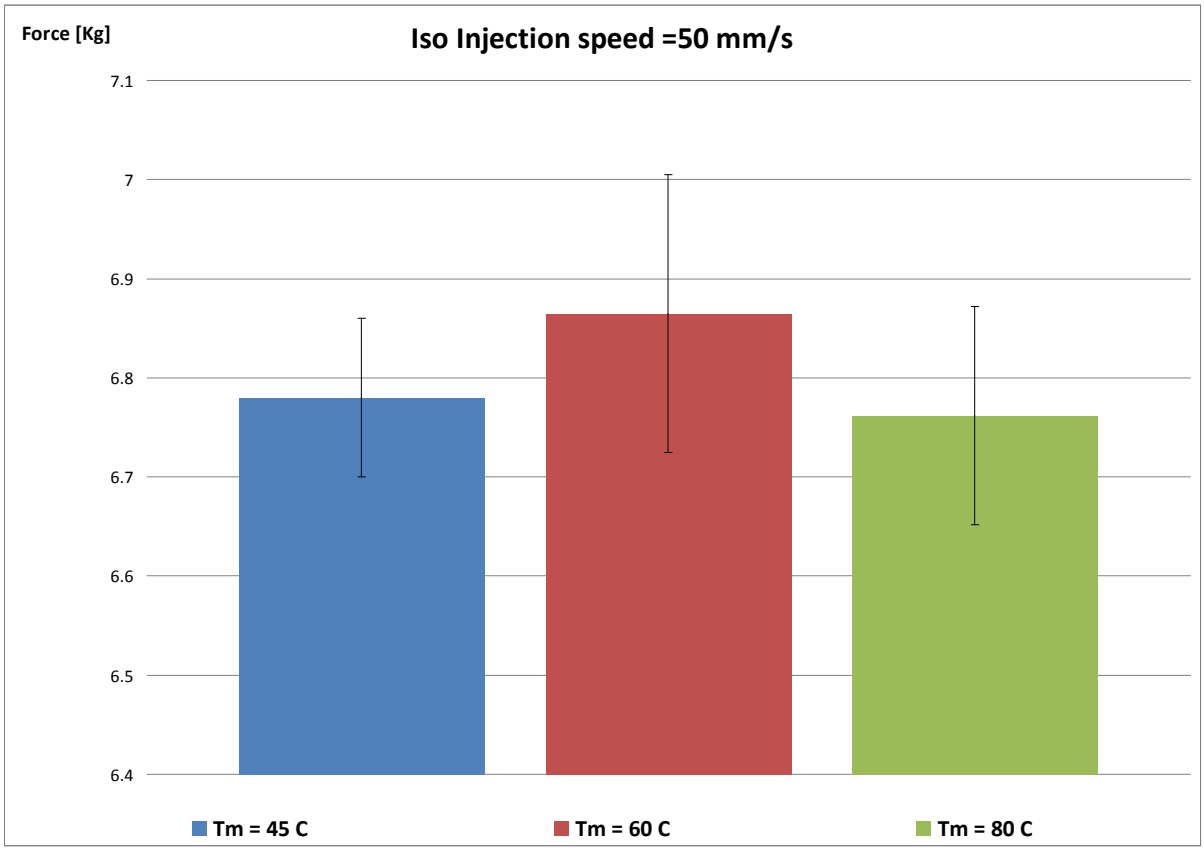


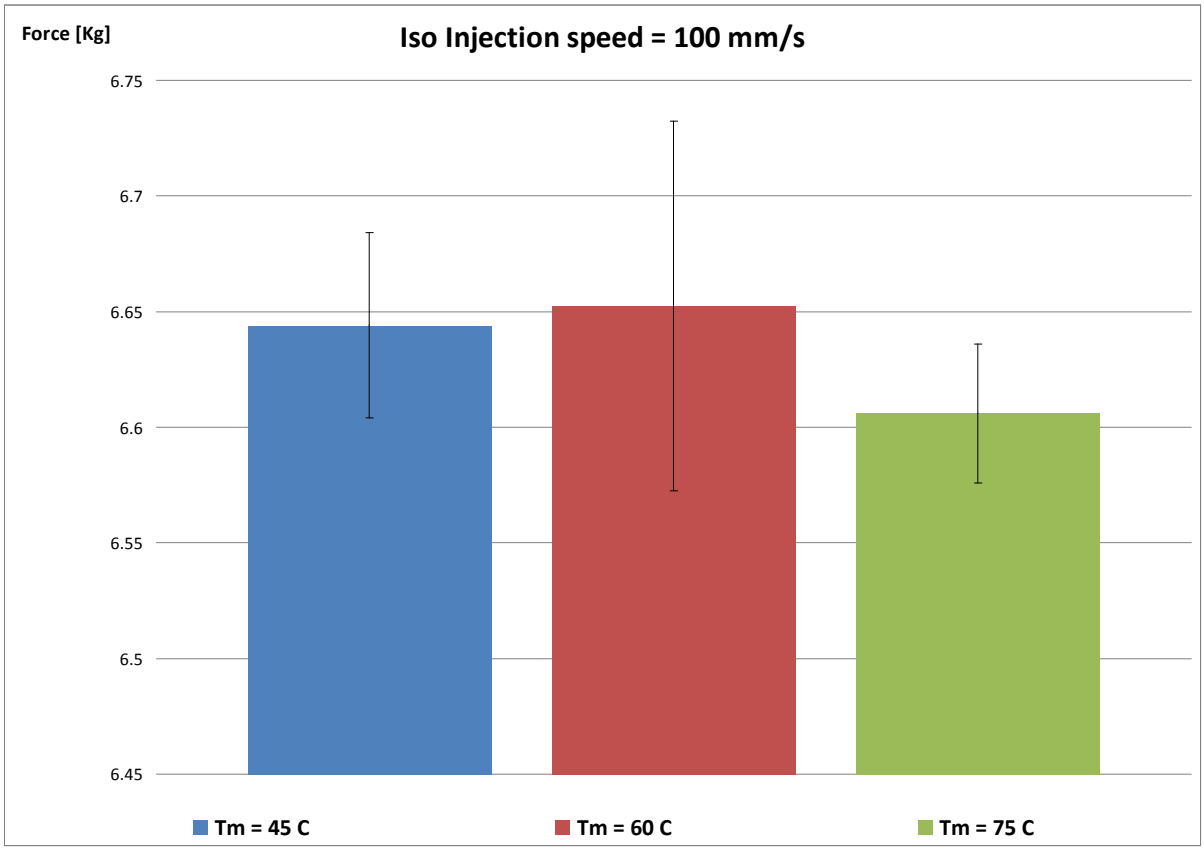
It was assessed that test 933 was too unreliable to include in the presentation of neither the Force-Strain behavior nor in the maximum tensile testing.

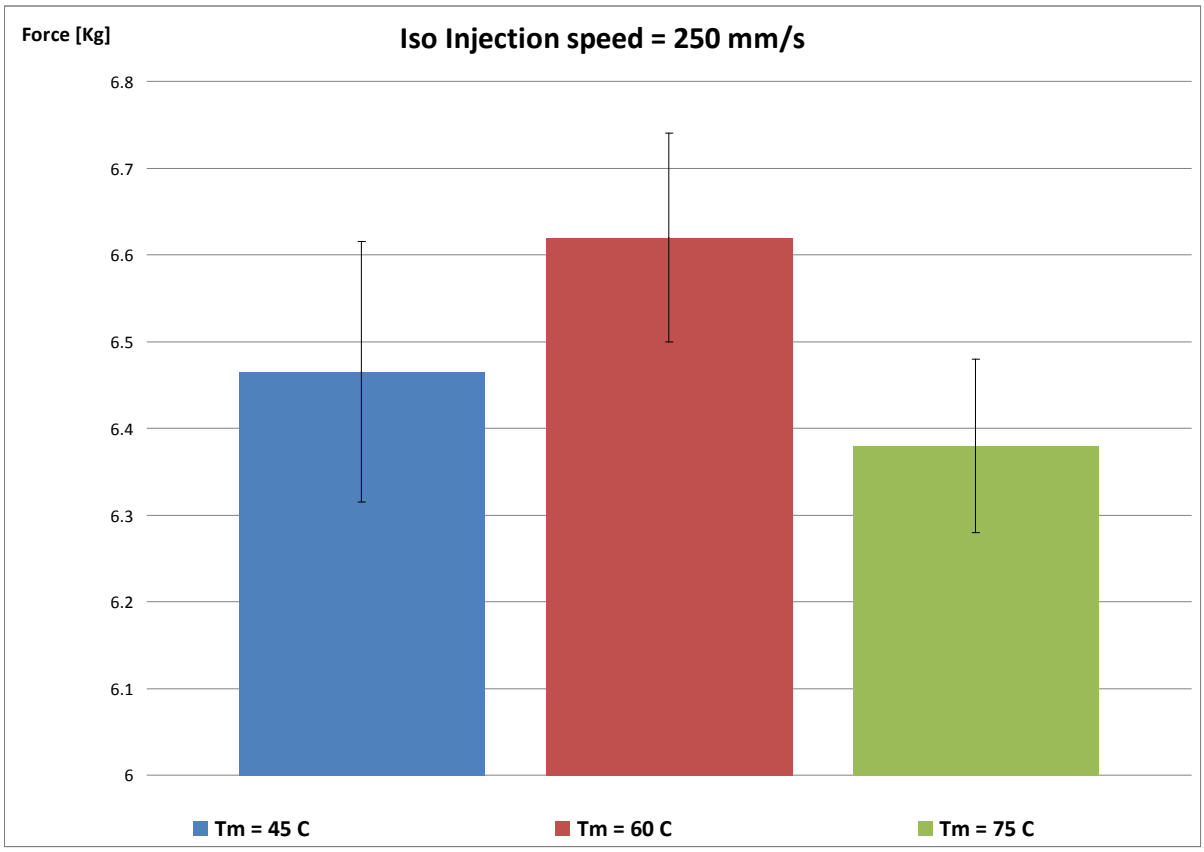
The maximum tensile values for the tests of process 9 are [Kg]

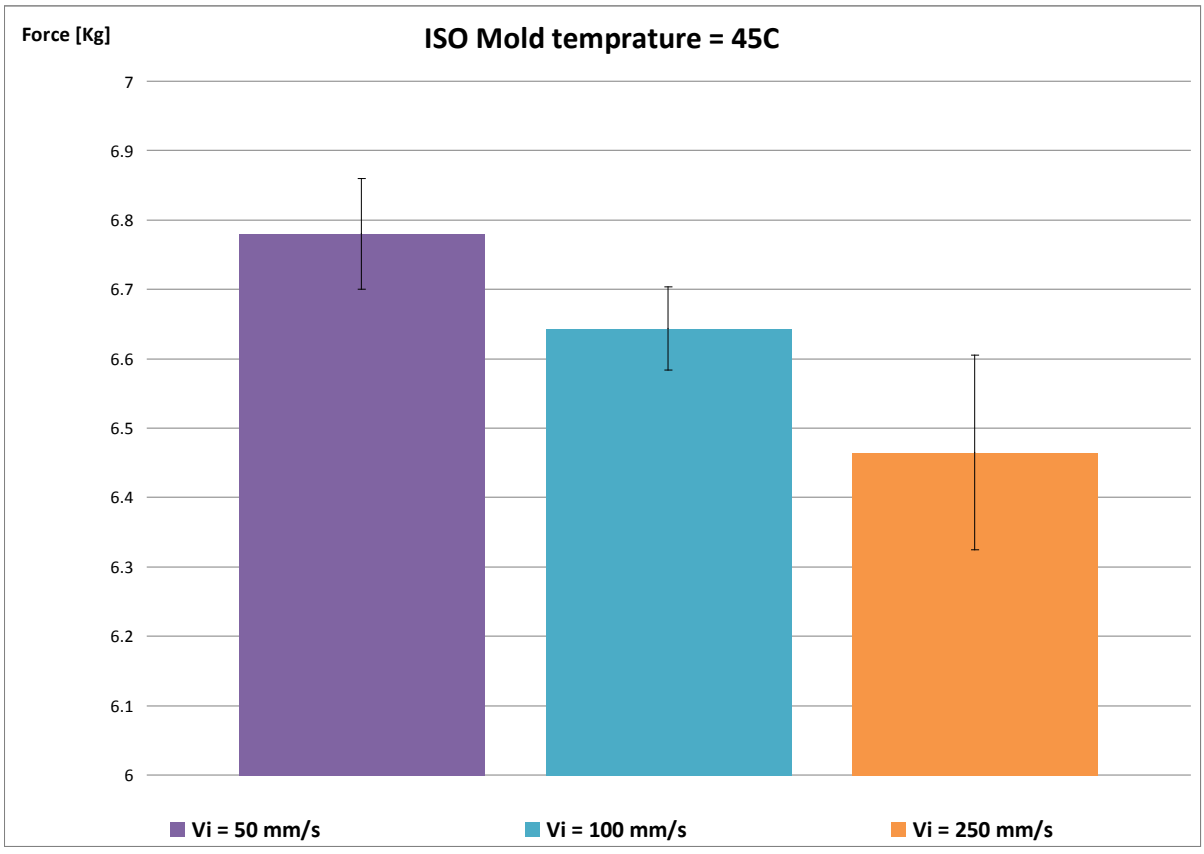
	6,29
	6,34
	6,35
	6,54
Avg	6,38
Std. D	0,109848

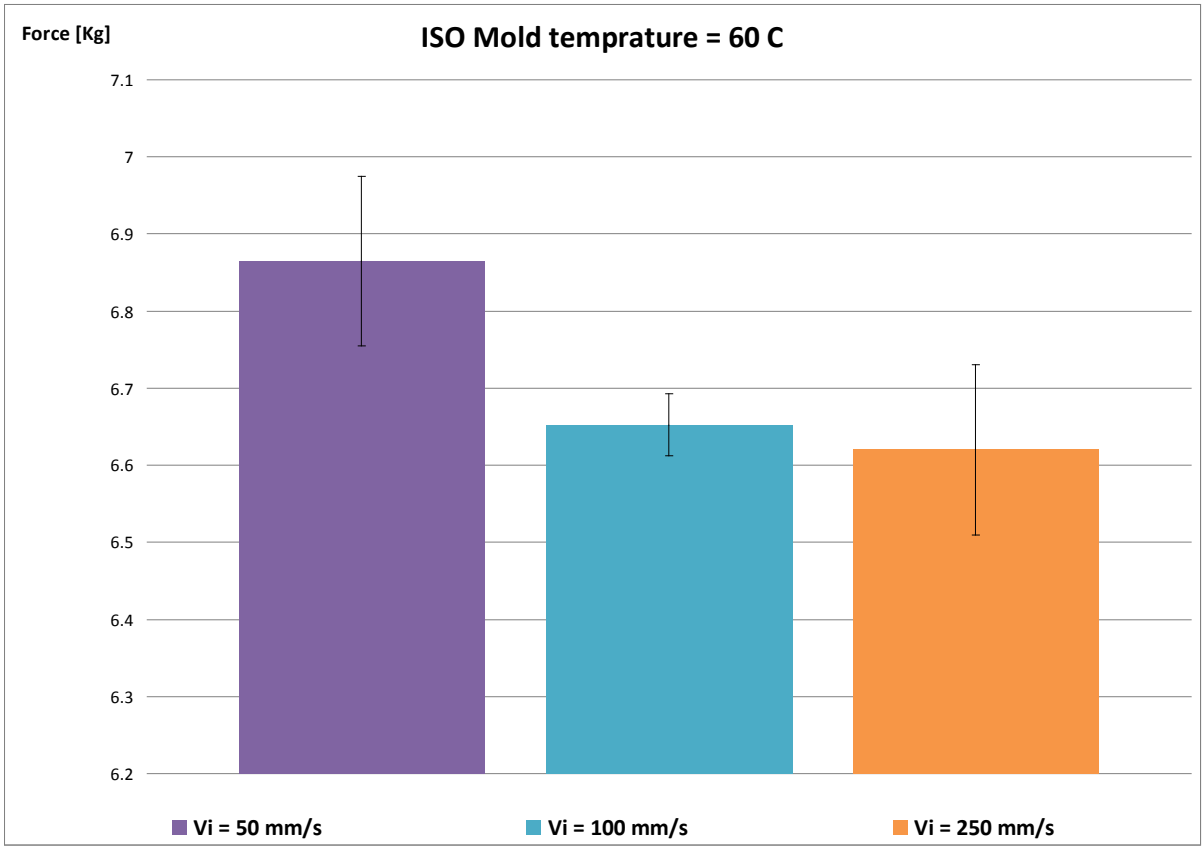
1.9 Comparison maximum tensile test micro ABS

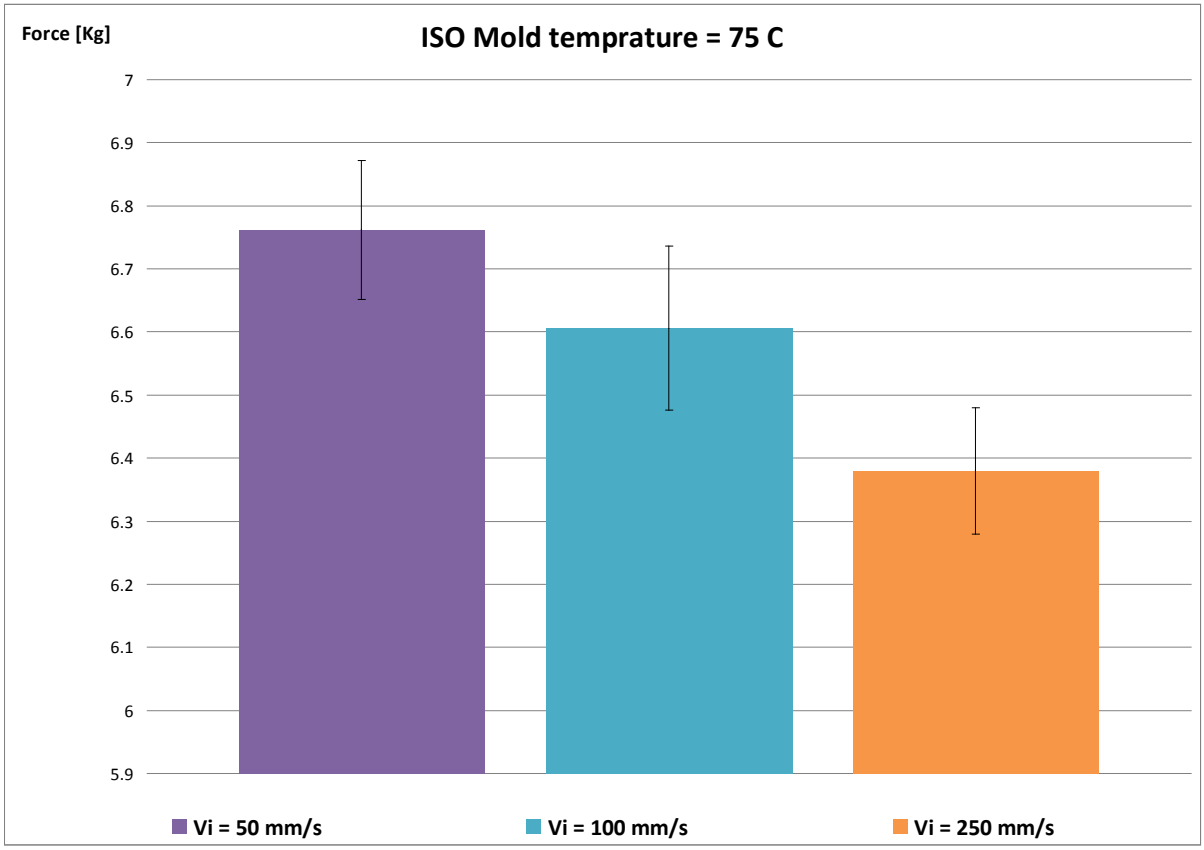





Force [Kg]
Iso Injection speed = 250 mm/s
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
Tm = 45 C
Tm = 60 C
Tm = 75 C


Force [Kg]
ISO Mold temprature = 45C
7
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s


Force [Kg]
ISO Mold temprature = 60 C
7.1
7
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s


Force [Kg]
ISO Mold temprature = 75 C
7
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
5.9
Vi = 50 mm/s
Vi = 100 mm/s
Vi = 250 mm/s

2.1 Data-sheet for PP HH 315 MO from the manufacturer

28.10.2007 Ed.8

Polypropylene
HH315MO

Description

HH315MO is a polypropylene homopolymer intended for injection moulding. Its high melt flow makes it especially suitable for products with long flow length. This grad is designed for high-speed injection moulding and contains nucleating, antistatic and slip additives.

This polymer is a CR (controlled rheology) grade with narrow molecular weight distribution giving low warpage. Products originating from this grade have excellent demoulding properties, very high stiffness, good transparency and gloss and good impact strength at ambient temperatures.

Applications

Thin wall containers
Square containers
Rectangular and flat products, like lids and trays
Caps and closures
Products with thicker wall sections requiring short cycle time

Special features

Shows excellent antistatic performance
Good stiffness
Good impact strength
Improved gloss and excellent transparency

Physical Properties

Property	Typical Value Data should not be used for specification work	Test Method
Density	910 kg/m3	ISO 1183
Melt Flow Rate (230 °C/2.16 kg)	35 g/10min	ISO 1133
Tensile Modulus (1 mm/min)	1,650 MPa	ISO 527-2
Tensile Strain at Yield (50 mm/min)	8 %	ISO 527-2
Tensile Stress at Yield (50 mm/min)	38 MPa	ISO 527-2
Heat Deflection Temperature (0.45 N/mm²) [1]	105 °C	ISO 75-2
Charpy Impact Strength, notched (23 °C)	2.0 kJ/m²	ISO 179/1eA
Hardness, Rockwell (R-scale)	102	ISO 2039-2

[1] Measured on injection moulded specimens acc. to ISO 1873-2

Processing Techniques

HH315MO is easy to process with standard injection moulding machines.

Following parameters should be used as guidelines:

Melt temperature	210 - 250 °C	
Holding pressure	200 - 500 bar	Minimum to avoid sink marks
Mould temperature	15 - 60 °C	
Injection speed	High	

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FN 259056 d | DVR: Commercial Court of Vienna | Website www.borealisgroup.com

BOREALIS

Polypropylene

HH315MO

Shrinkage 1 - 2 %, depending on wall thickness and moulding parameters

Storage

HH315MO should be stored in dry conditions at temperatures below 50°C and protected from UV-light. Improper storage can initiate degradation, which results in odour generation and colour changes and can have negative effects on the physical properties of this product.

Safety

The product is not classified as a dangerous preparation.

Recycling

The product is suitable for recycling using modern methods of shredding and cleaning. In-house production waste should be kept clean to facilitate direct recycling.

Please see our Safety Data Sheet for details on various aspects of safety, recovery and disposal of the product, for more information contact your Borealis representative.

Related Documents

The following related documents are available on request, and represent various aspects on the usability, safety, recovery and disposal of the product.

Recovery and disposal of polyolefins
Information on emissions from processing and fires
Safety Data Sheet
Statement on compliance to food contact regulations

Polypropylene
HH315MO

Disclaimer

The product(s) mentioned herein are not intended to be used for medical, pharmaceutical or healthcare applications and we do not support their use for such applications.

To the best of our knowledge, the information contained herein is accurate and reliable as of the date of publication, however we do not assume any liability whatsoever for the accuracy and completeness of such information.

Borealis makes no warranties which extend beyond the description contained herein. Nothing herein shall constitute any warranty of merchantability or fitness for a particular purpose.

It is the customer's responsibility to inspect and test our products in order to satisfy itself as to the suitability of the products for the customer's particular purpose. The customer is responsible for the appropriate, safe and legal use, processing and handling of our products.

No liability can be accepted in respect of the use of Borealis' products in conjunction with other materials. The information contained herein relates exclusively to our products when not used in conjunction with any third party materials.

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2.2 Data-Sheet for ABS Terluran GP-35

Rheological properties			
Melt volume-flow rate	**34**	cm³/10min	ISO 1133
Temperature	**220**	°C	ISO 1133
Load	**10**	kg	ISO 1133
Molding shrinkage (parallel)	**-**	%	ISO 294-4, 2577
Molding shrinkage (normal)	**-**	%	ISO 294-4, 2577

Mechanical properties			
Tensile modulus	**2300**	MPa	ISO 527-1/-2
Yield stress	**44**	MPa	ISO 527-1/-2
Yield strain	**2.4**	%	ISO 527-1/-2
Nominal strain at break	**12**	%	ISO 527-1/-2
Stress at 50% strain	*	MPa	ISO 527-1/-2
Stress at break	*	MPa	ISO 527-1/-2
Strain at break	*	%	ISO 527-1/-2
Tensile creep modulus (1h)	**-**	MPa	ISO 899-1
Tensile creep modulus (1000h)	**-**	MPa	ISO 899-1
Charpy impact strength (+23°C)	**130**	kJ/m²	ISO 179/1eU
Charpy impact strength (-30°C)	**90**	kJ/m²	ISO 179/1eU
Charpy notched impact strength (+23°C)	**19**	kJ/m²	ISO 179/1eA
Charpy notched impact strength (-30°C)	**7**	kJ/m²	ISO 179/1eA
Tensile notched impact strength (+23°C)	*	kJ/m²	ISO 8256/1
Puncture - maximum force (+23°C)	*	N	ISO 6603-2
Puncture - maximum force (-30°C)	*	N	ISO 6603-2
Puncture energy (+23°C)	*	J	ISO 6603-2
Puncture energy (-30°C)	*	J	ISO 6603-2

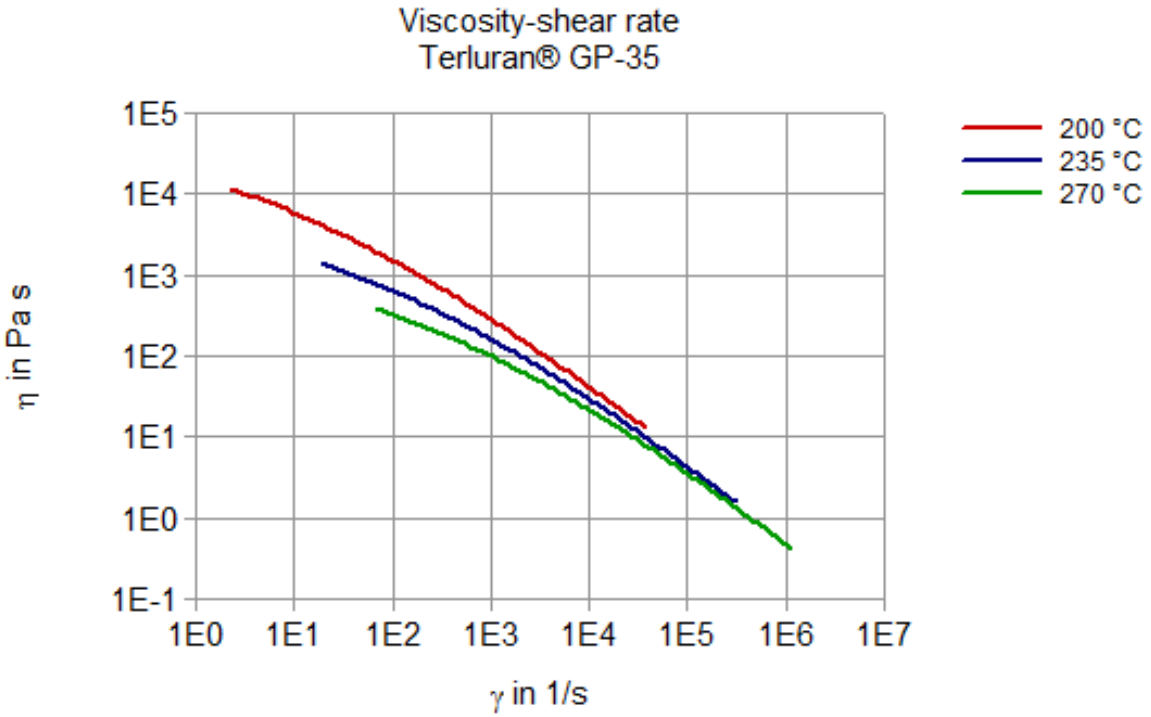
Electrical properties			
Relative permittivity (100 Hz)	**-**	-	IEC 60250
Relative permittivity (1 MHz)	**-**	-	IEC 60250
Dissipation factor (100 Hz)	**-**	E-4	IEC 60250
Dissipation factor (1 MHz)	**-**	E-4	IEC 60250
Volume resistivity	**1E13**	Ohm*m	IEC 60093
Surface resistivity	**-**	Ohm	IEC 60093
Electric strength	**41**	kV/mm	IEC 60243-1
Comparative tracking index	**-**	-	IEC 60112

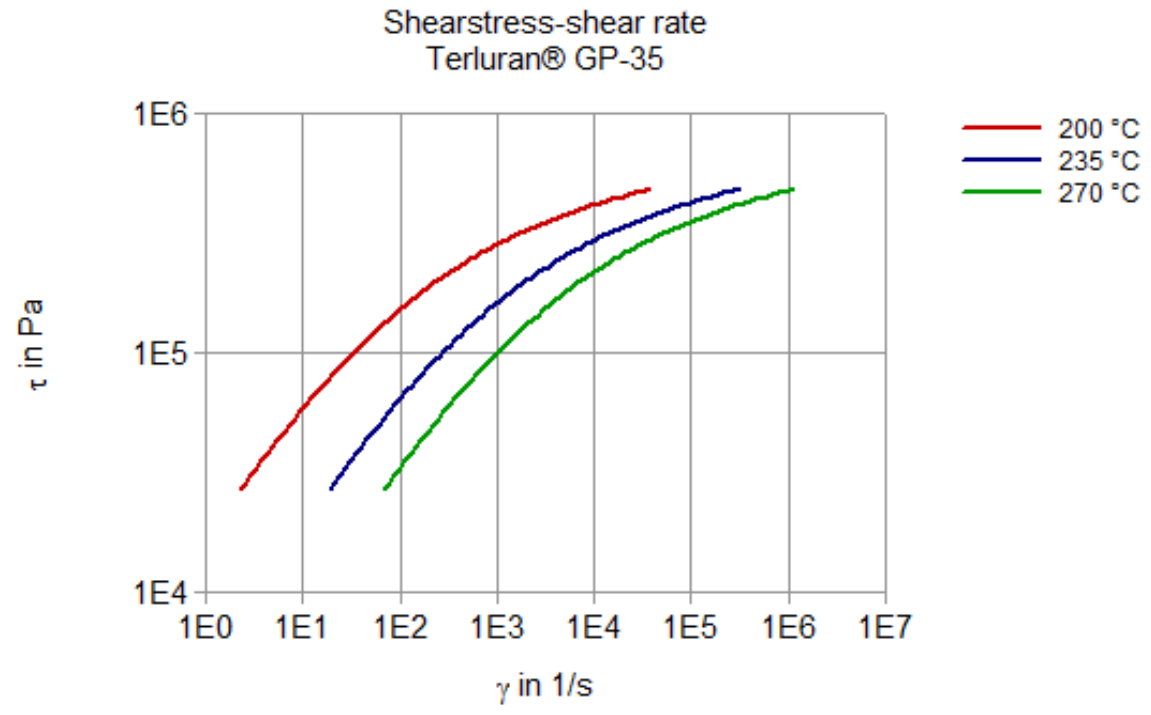
Thermal properties			
Melting temperature (10°C/min)	-	°C	ISO 11357-1/-3
Glass transition temperature (10°C/min)	-	°C	ISO 11357-1/-2
Temp. of deflection under load (1.80 MPa)	78	°C	ISO 75-1/-2
Temp. of deflection under load (0.45 MPa)	89	°C	ISO 75-1/-2
Temp. of deflection under load (8.00 MPa)	*	°C	ISO 75-1/-2
Vicat softening temperature (50°C/h 50N)	95	°C	ISO 306
Coeff.of linear therm. expansion (parallel)	0.95	E-4/°C	ISO 11359-1/-2
Coeff.of linear therm. expansion (normal)	*	E-4/°C	ISO 11359-1/-2
Burning Behav. at 1.5mm nom. thickn.	HB	class	IEC 60695-11-10
Thickness tested	1.5	mm	IEC 60695-11-10
UL recognition	UL	-	-
Burning Behav. at thickness h	HB	class	IEC 60695-11-10
Thickness tested	0.8	mm	IEC 60695-11-10
UL recognition	-	-	-
Burning Behav. 5V at thickn. h	-	class	IEC 60695-11-20
Thickness tested	-	mm	IEC 60695-11-20
UL recognition	-	-	-
Oxygen index	-	%	ISO 4589-1/-2

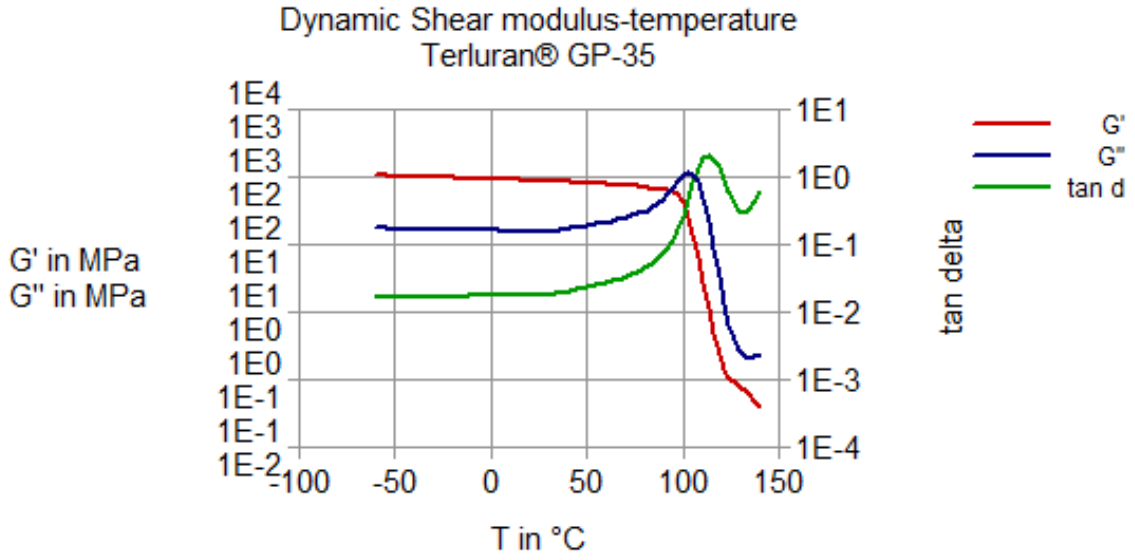
Other properties			
Water absorption	0.95	%	Similar to ISO 62
Humidity absorption	0.24	%	Similar to ISO 62
Density	1040	kg/m³	ISO 1183

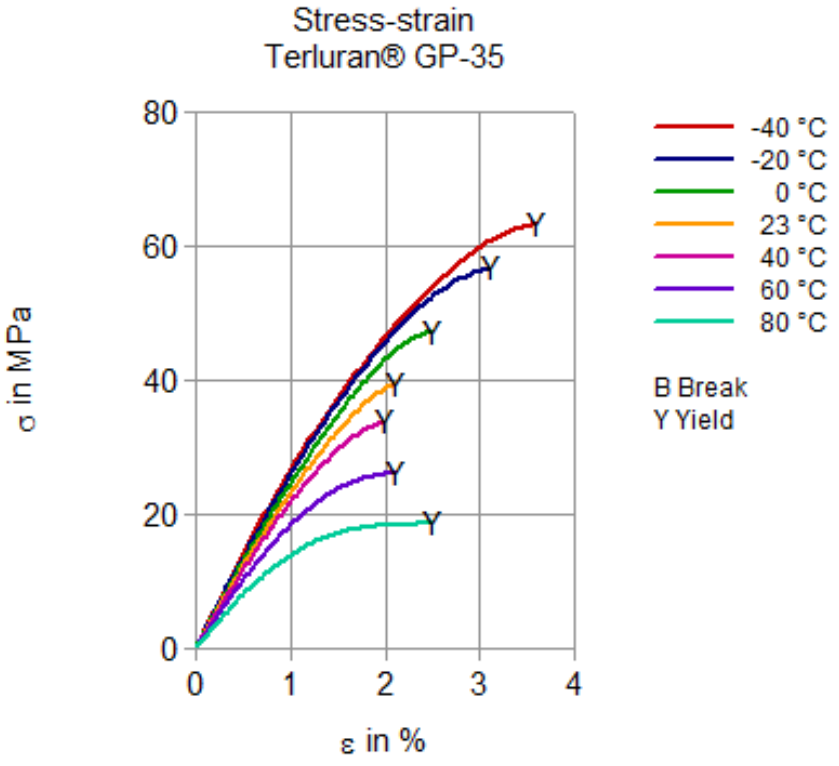
Material specific properties			
Viscosity number	-	cm³/g	ISO 307, 1157, 1628
Indicative density (PE only)	*	kg/m³	ISO 1872-1
Luminous transmittance	-	%	ISO 13468-1, -2

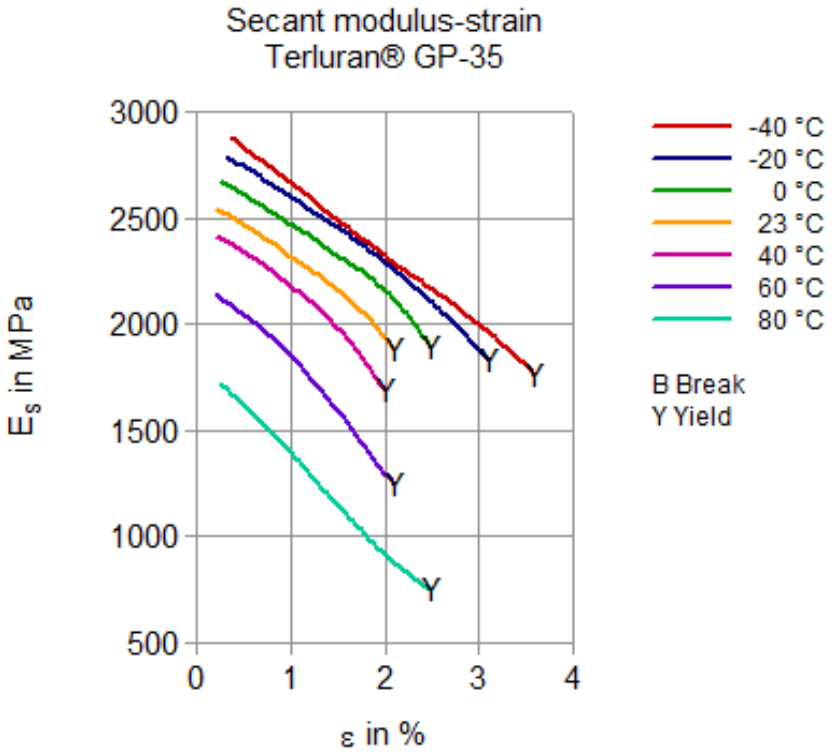
Test specimen production			
Processing conditions acc. ISO	-	-	ISO....-2
Injection Molding, melt temperature	250	°C	ISO 294
Injection Molding, mold temperature	60	°C	ISO 10724
injection velocity	100	mm/s	ISO 294
pressure at hold	-	MPa	ISO 294
Compression Molding, molding temperature	-	°C	ISO 293
cooling rate	-	K/min	ISO 293
molding time	-	min	ISO 293
demolding temperature	-	°C	ISO 293

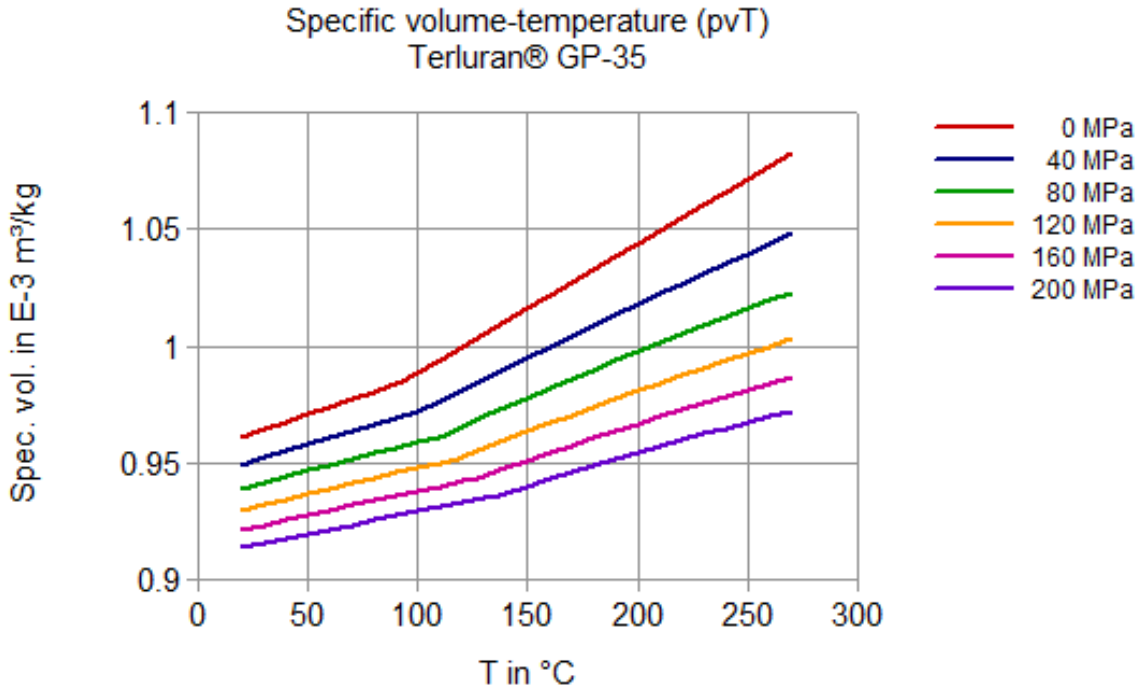

Viscosity-shear rate
Terluran® GP-35
1E5
1E4
1E3
1E2
1E1
1E0
1E-1
η in Pa s
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
γ in 1/s
200 °C
235 °C
270 °C

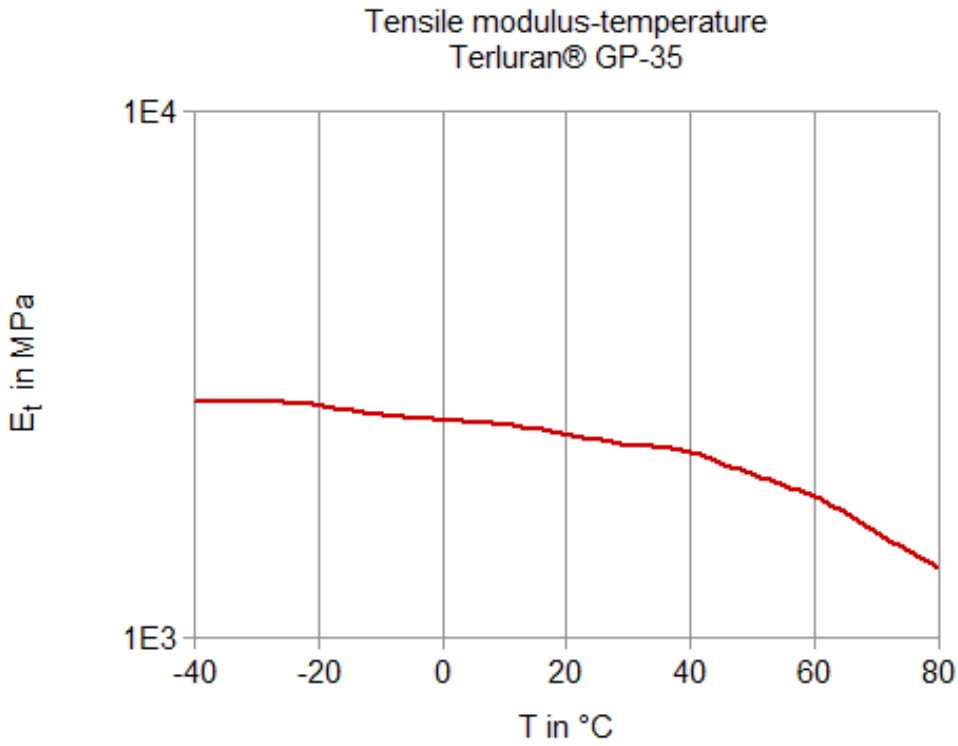

Shearstress-shear rate
Terluran® GP-35
1E6
1E5
1E4
τ in Pa
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
γ in 1/s
200 °C
235 °C
270 °C


Dynamic Shear modulus-temperature
Terluran® GP-35
G' in MPa
G'' in MPa
1E4
1E3
1E3
1E2
1E2
1E1
1E1
1E0
1E0
1E-1
1E-1
1E-2
1E1
1E0
1E-1
1E-2
1E-3
1E-4
-100
-50
0
50
100
150
T in °C
tan delta
G'
G''
tan d


Stress-strain
Terluran® GP-35
σ in MPa
80
60
40
20
0
0
1
2
3
4
ε in %
-40 °C
-20 °C
0 °C
23 °C
40 °C
60 °C
80 °C
B Break
Y Yield

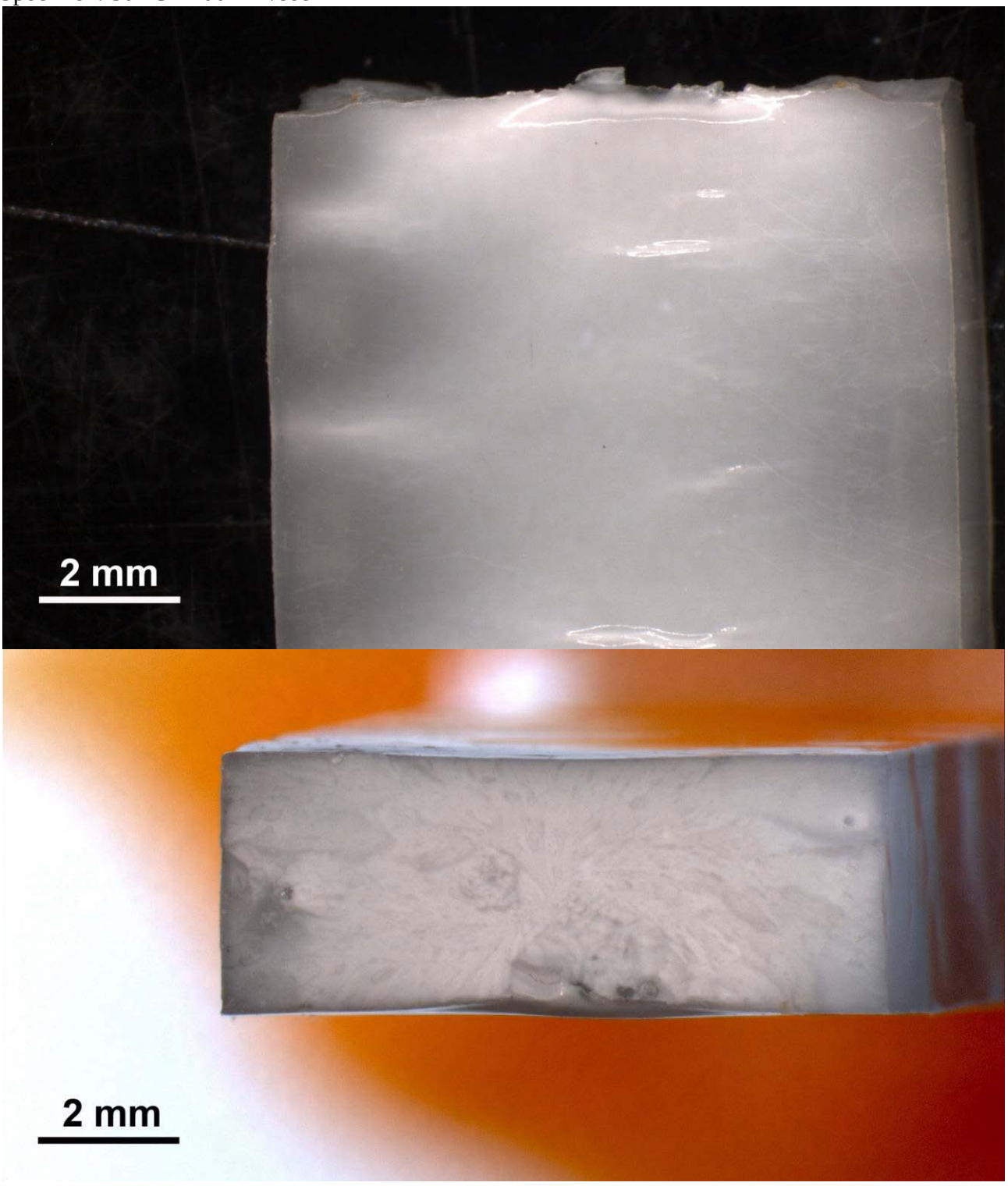

Secant modulus-strain
Terluran® GP-35
3000
2500
2000
1500
1000
500
0
1
2
3
4
E_s in MPa
ε in %
-40 °C
-20 °C
0 °C
23 °C
40 °C
60 °C
80 °C
B Break
Y Yield
Y


Specific volume-temperature (pvT)
Terluran® GP-35
1.1
1.05
1
0.95
0.9
0
50
100
150
200
250
300
Spec. vol. in E-3 m³/kg
T in °C
0 MPa
40 MPa
80 MPa
120 MPa
160 MPa
200 MPa

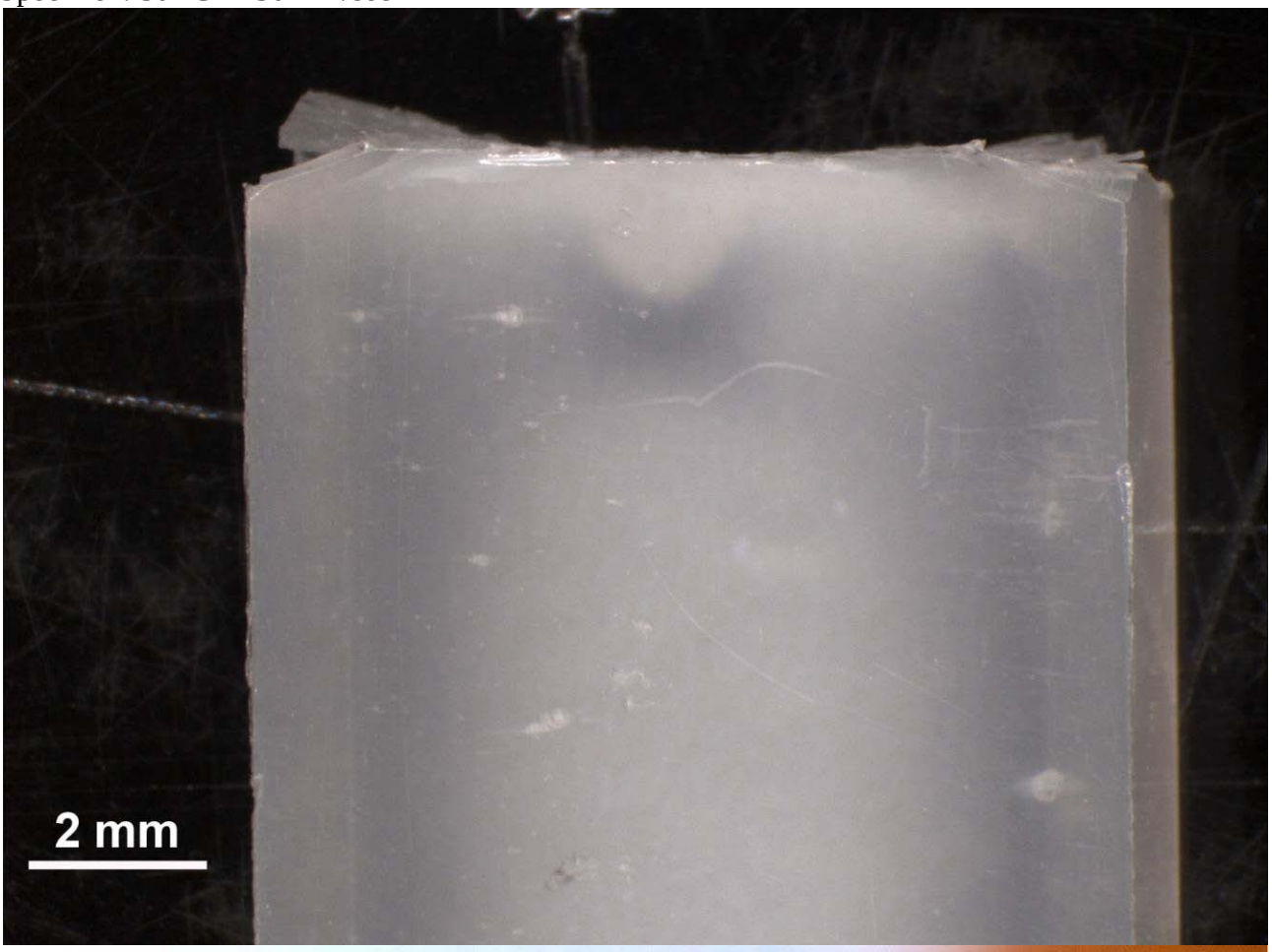

Tensile modulus-temperature
Terluran® GP-35
1E4
1E3
E_t in MPa
-40
-20
0
20
40
60
80
T in °C

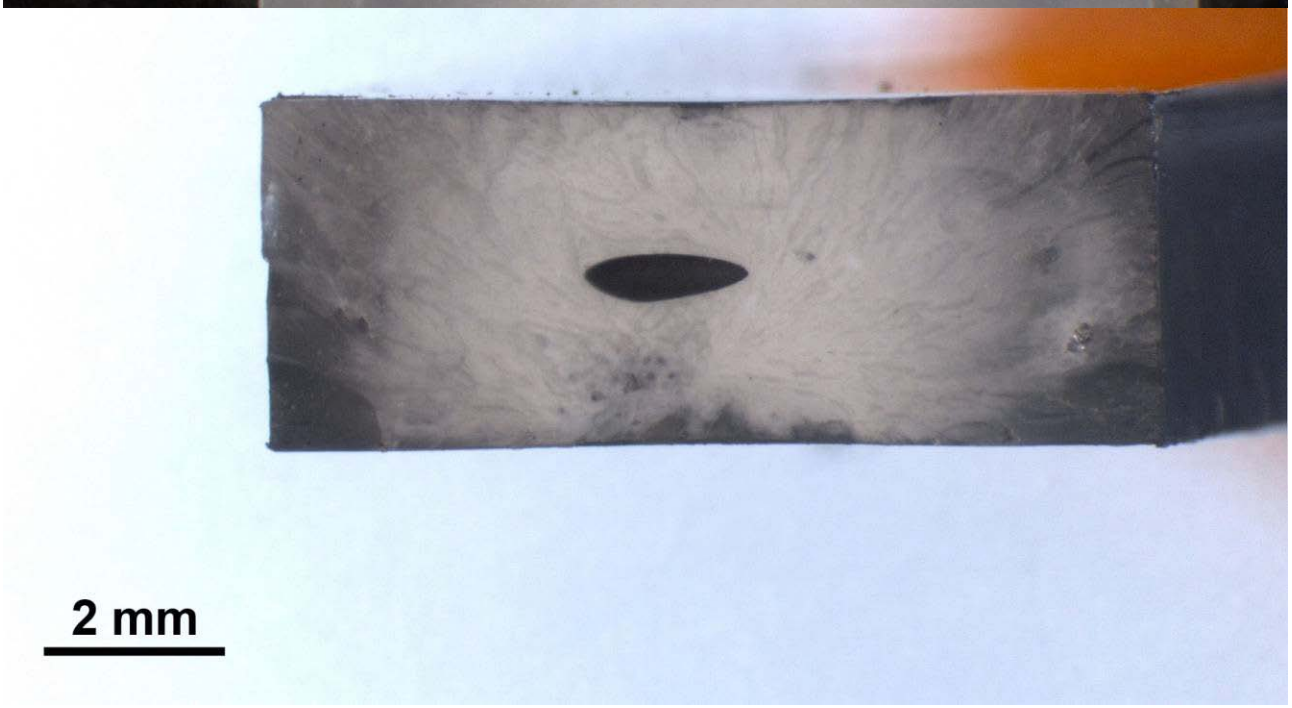
2.3 Microscope pictures of big dog bones of HH 315 MO (PP)

Specimen: 30 °C - 100 mm/sec

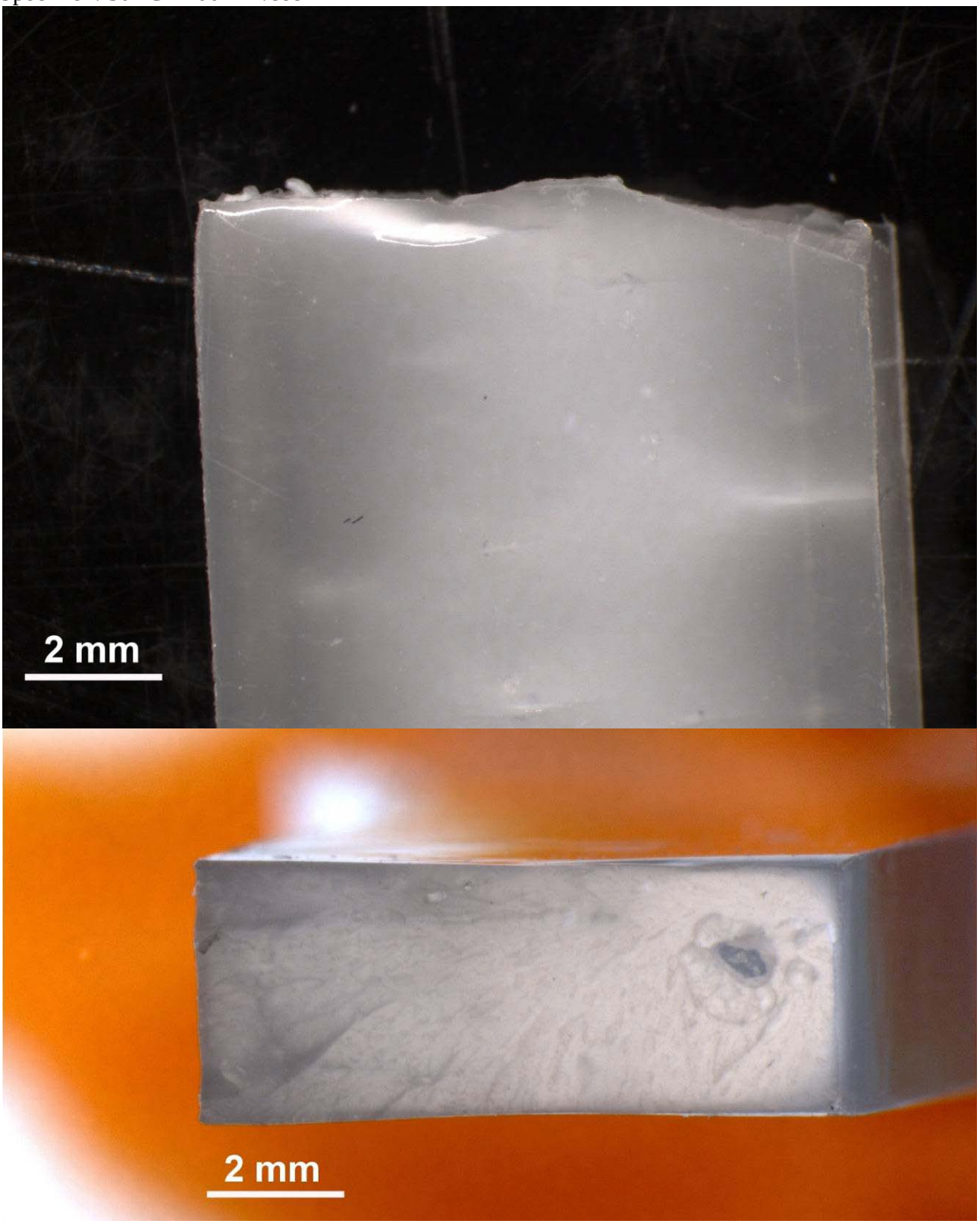


Specimen: 30 °C - 250 mm/sec

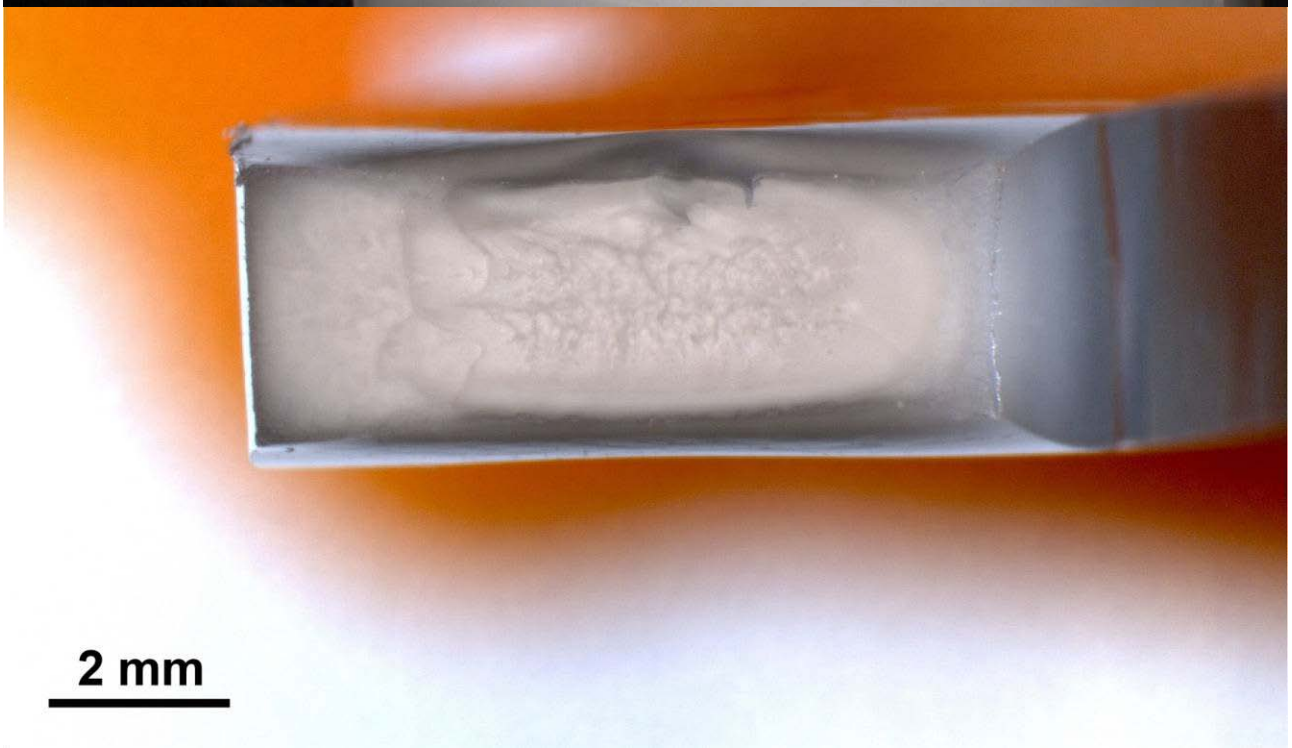




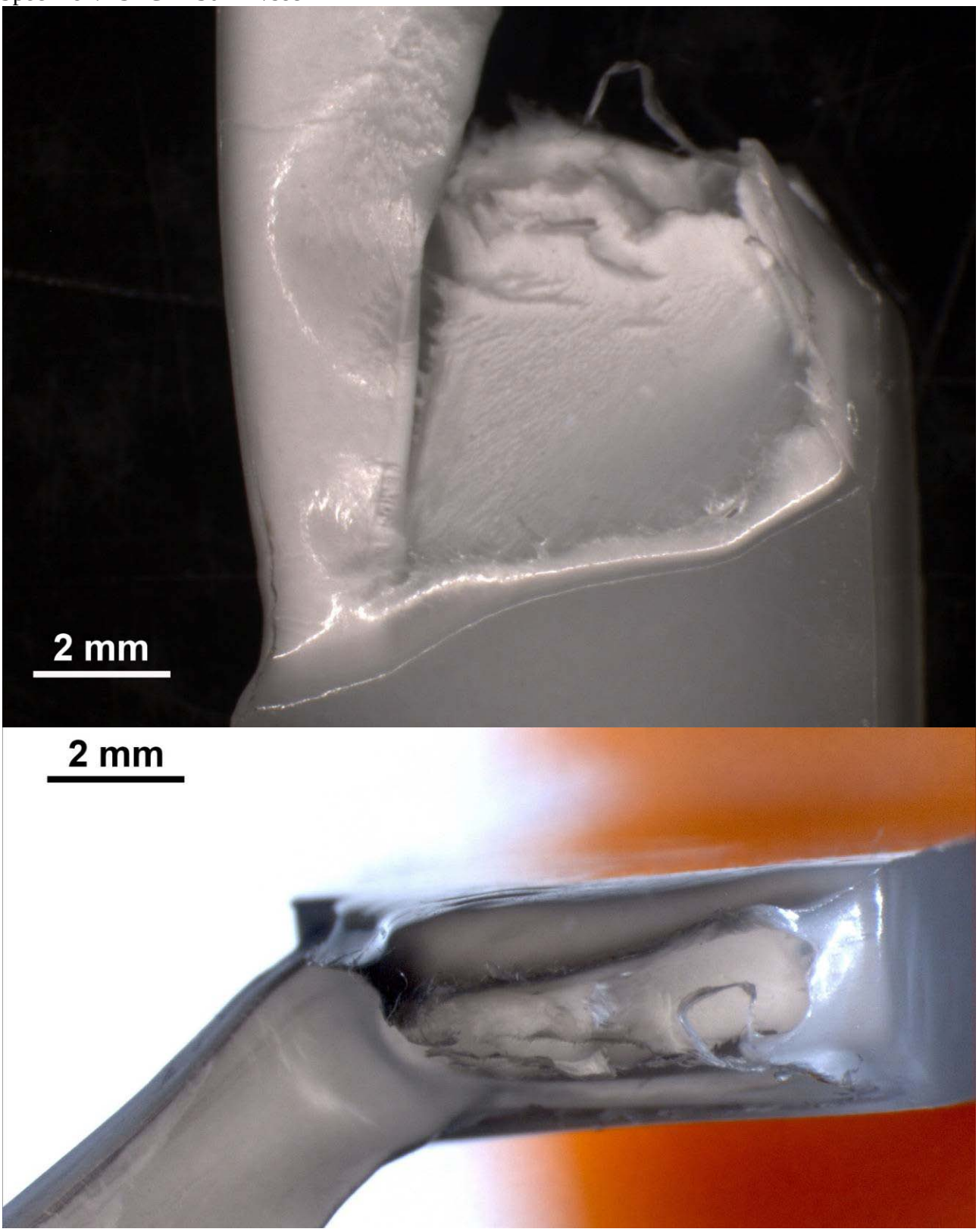
Specimen: 30 °C - 400 mm/sec



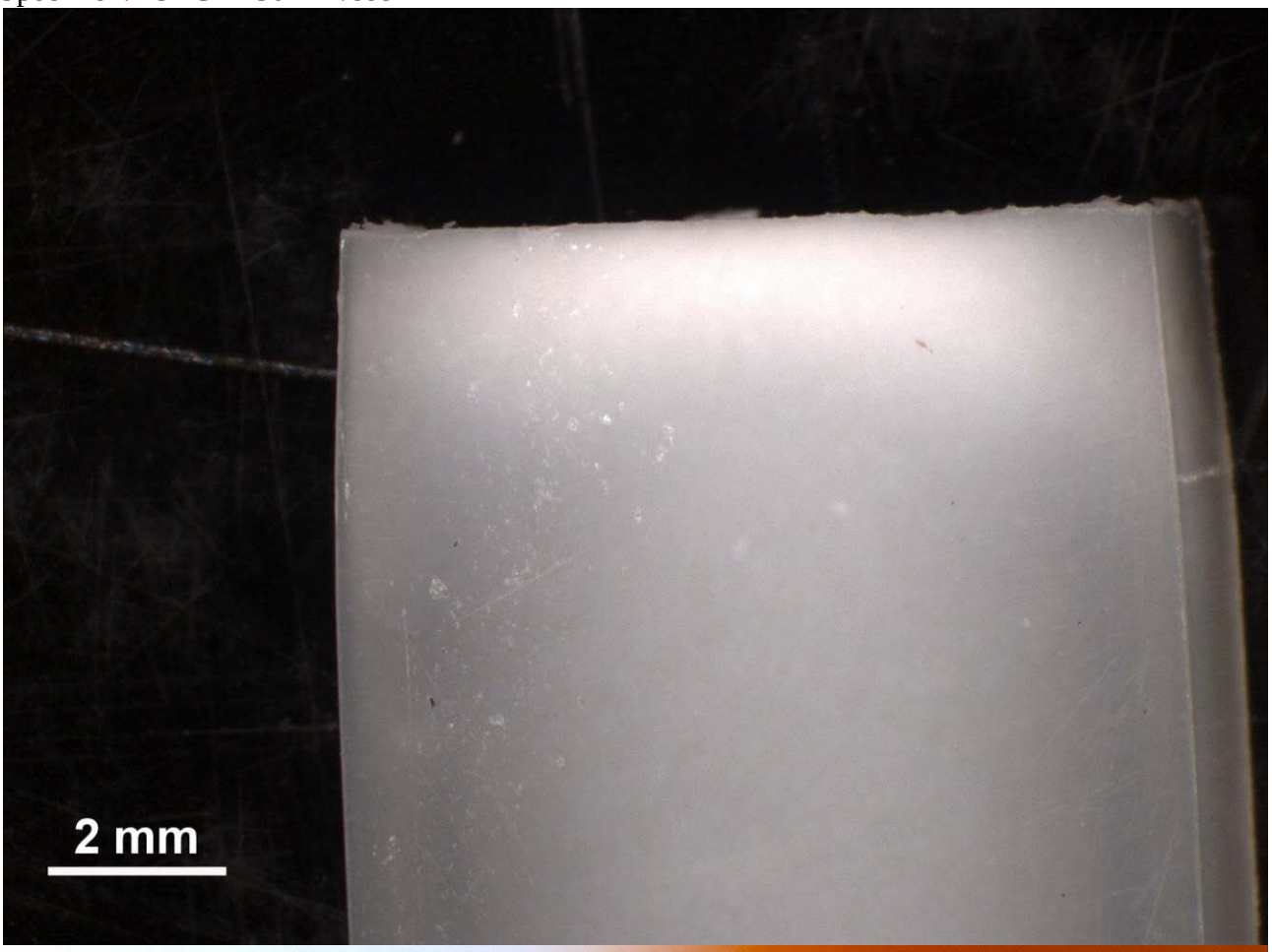
Specimen: 45 °C - 100 mm/sec

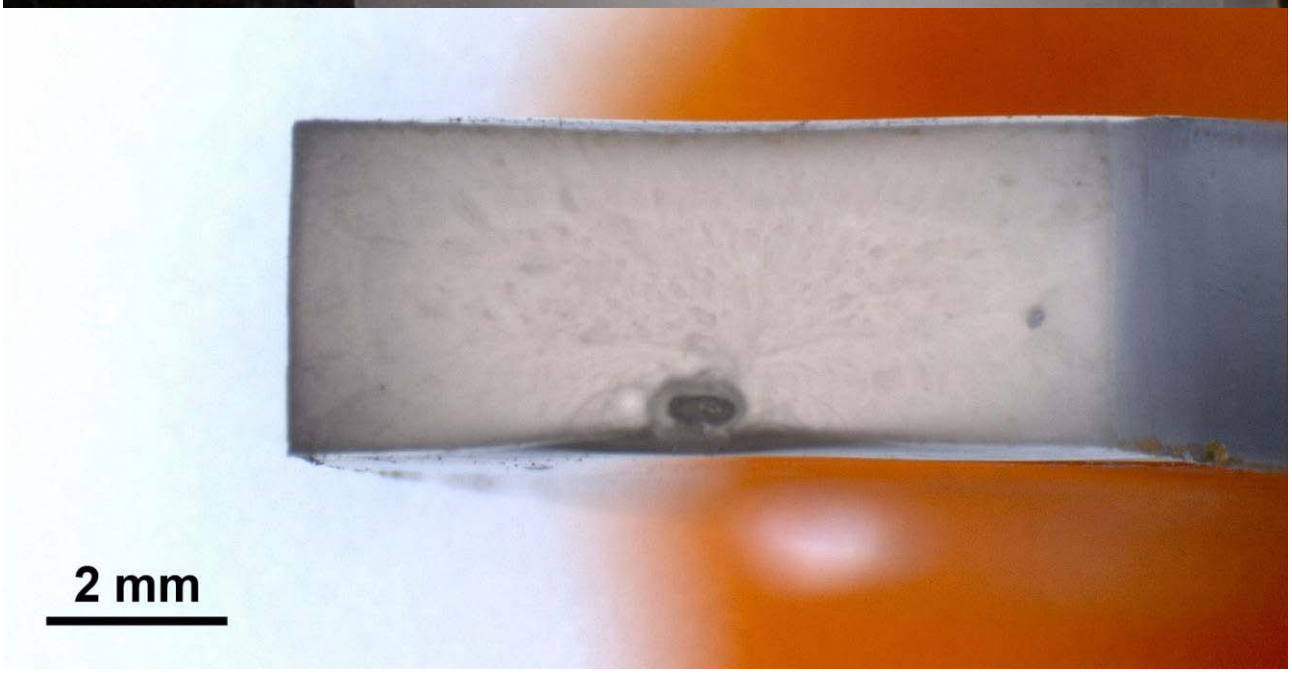


Specimen: 45 °C - 250 mm/sec

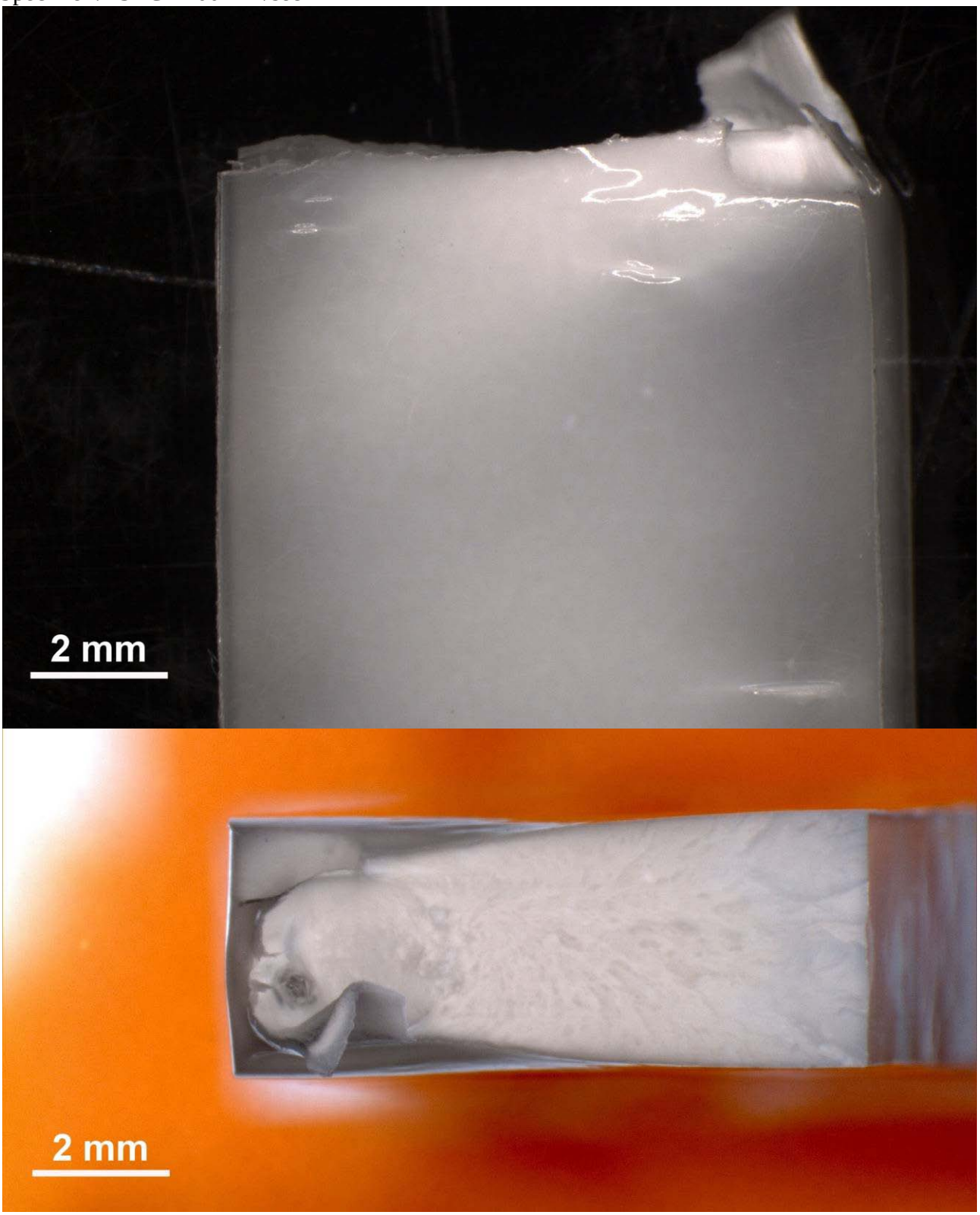


Specimen: 45 °C - 250 mm/sec

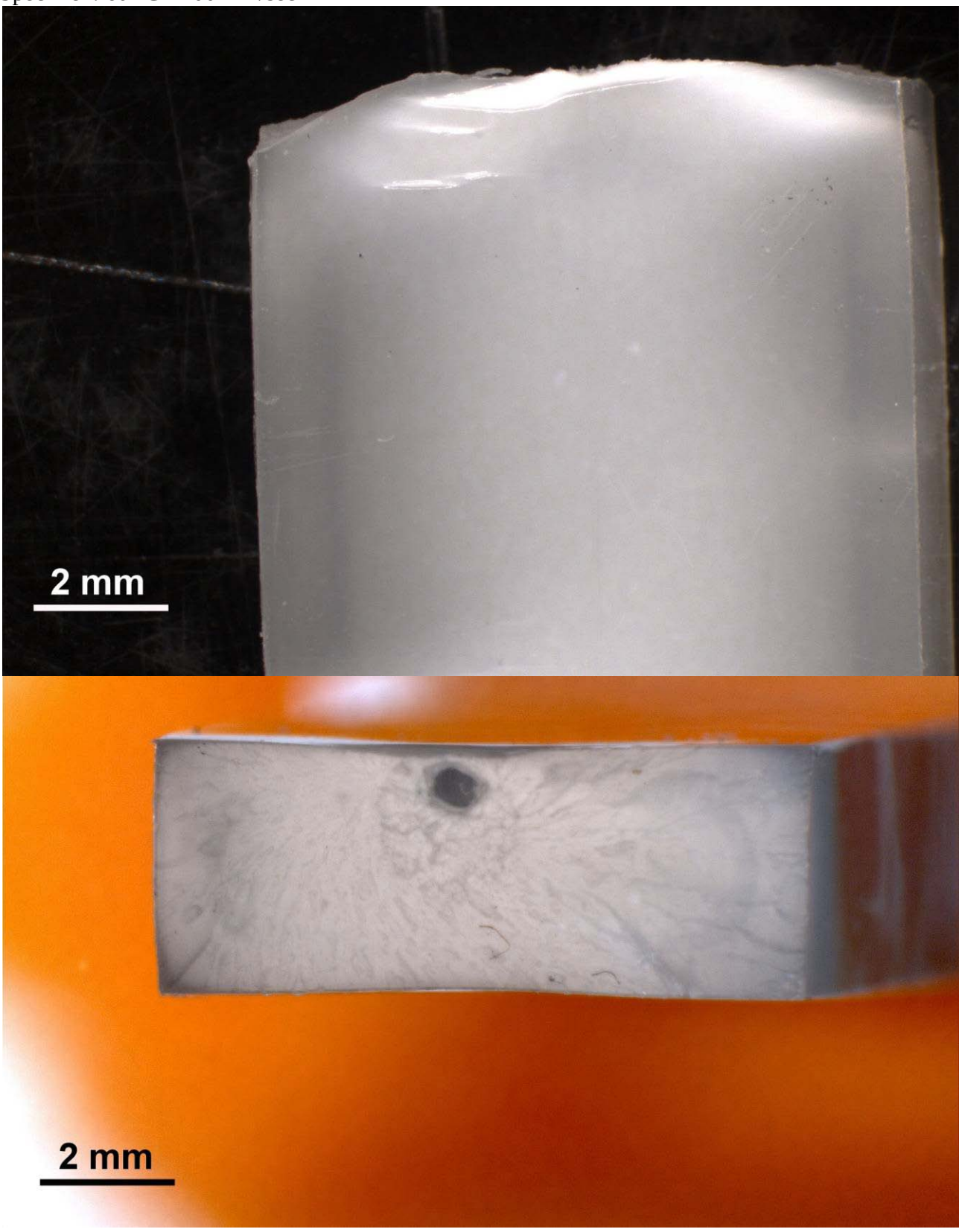




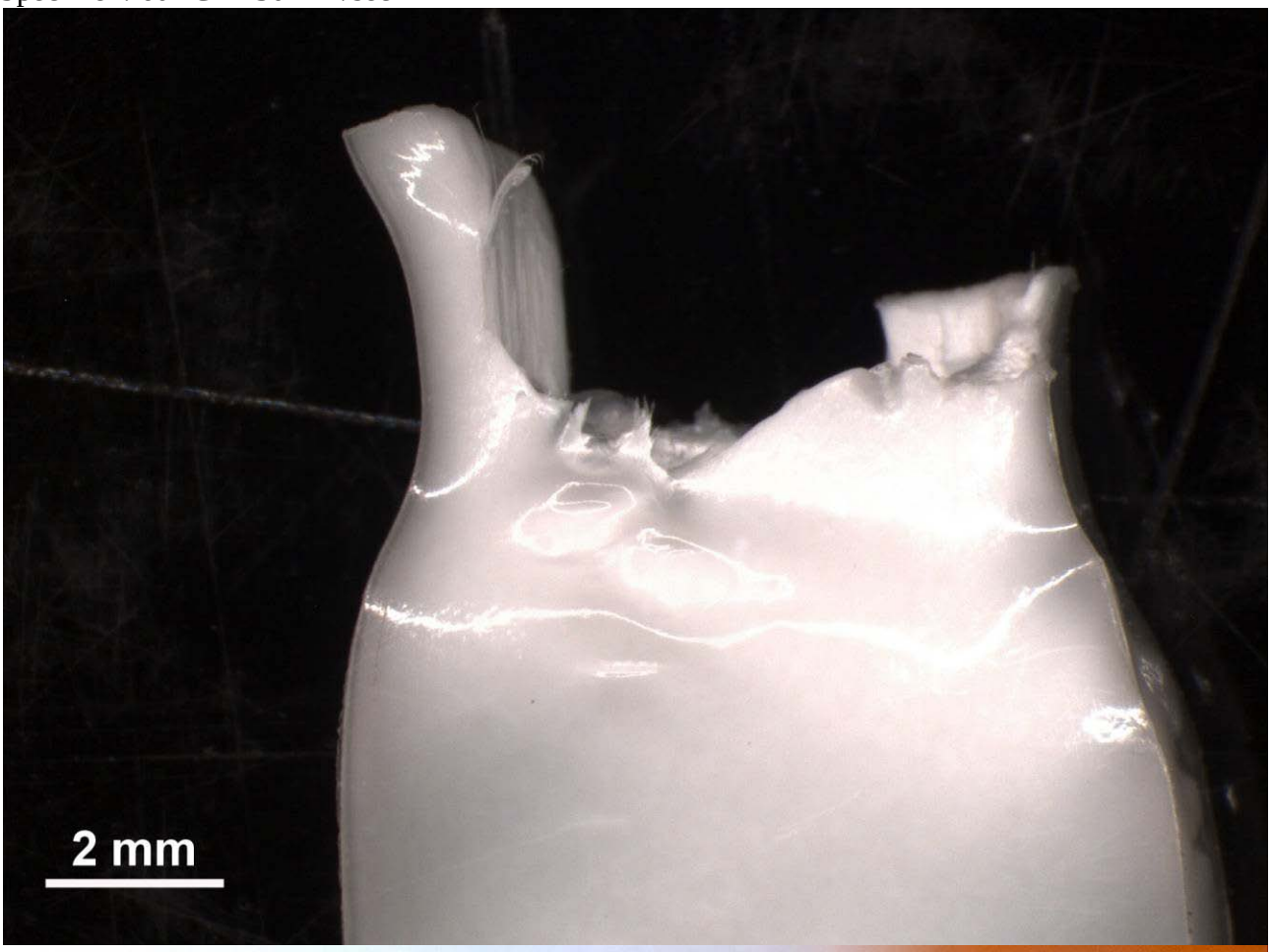
Specimen: 45 °C - 400 mm/sec

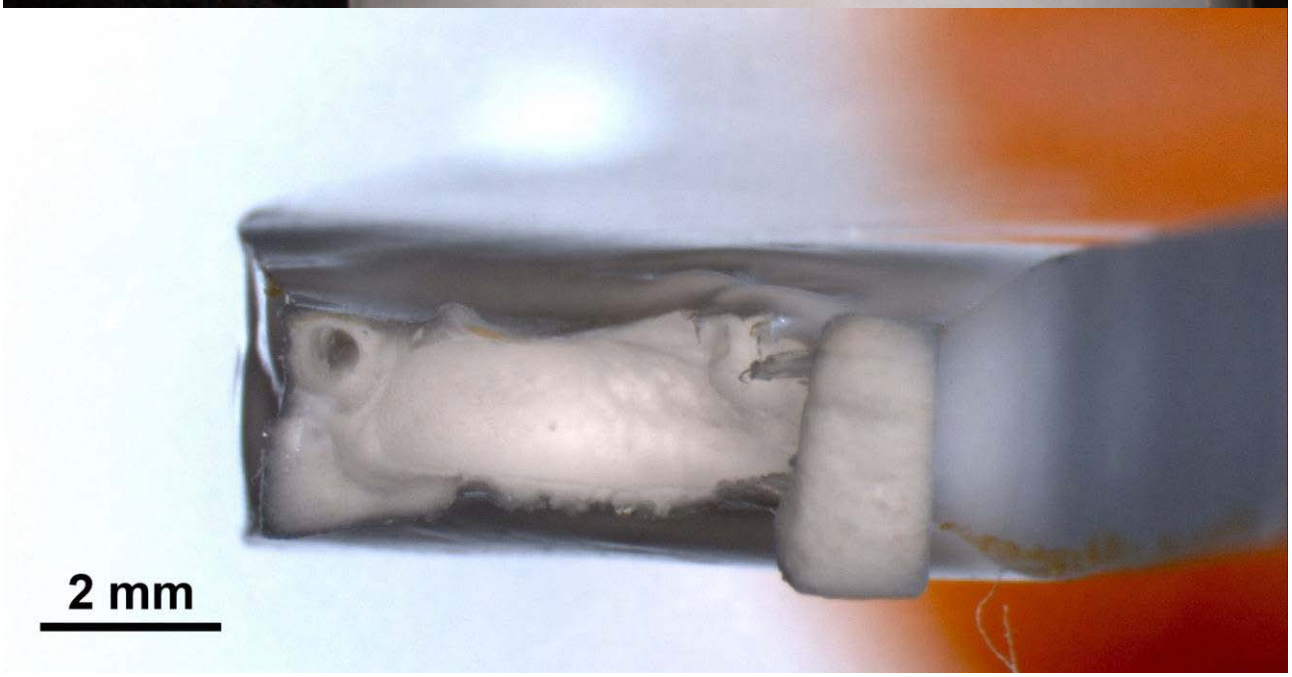


Specimen: 60 °C - 100 mm/sec

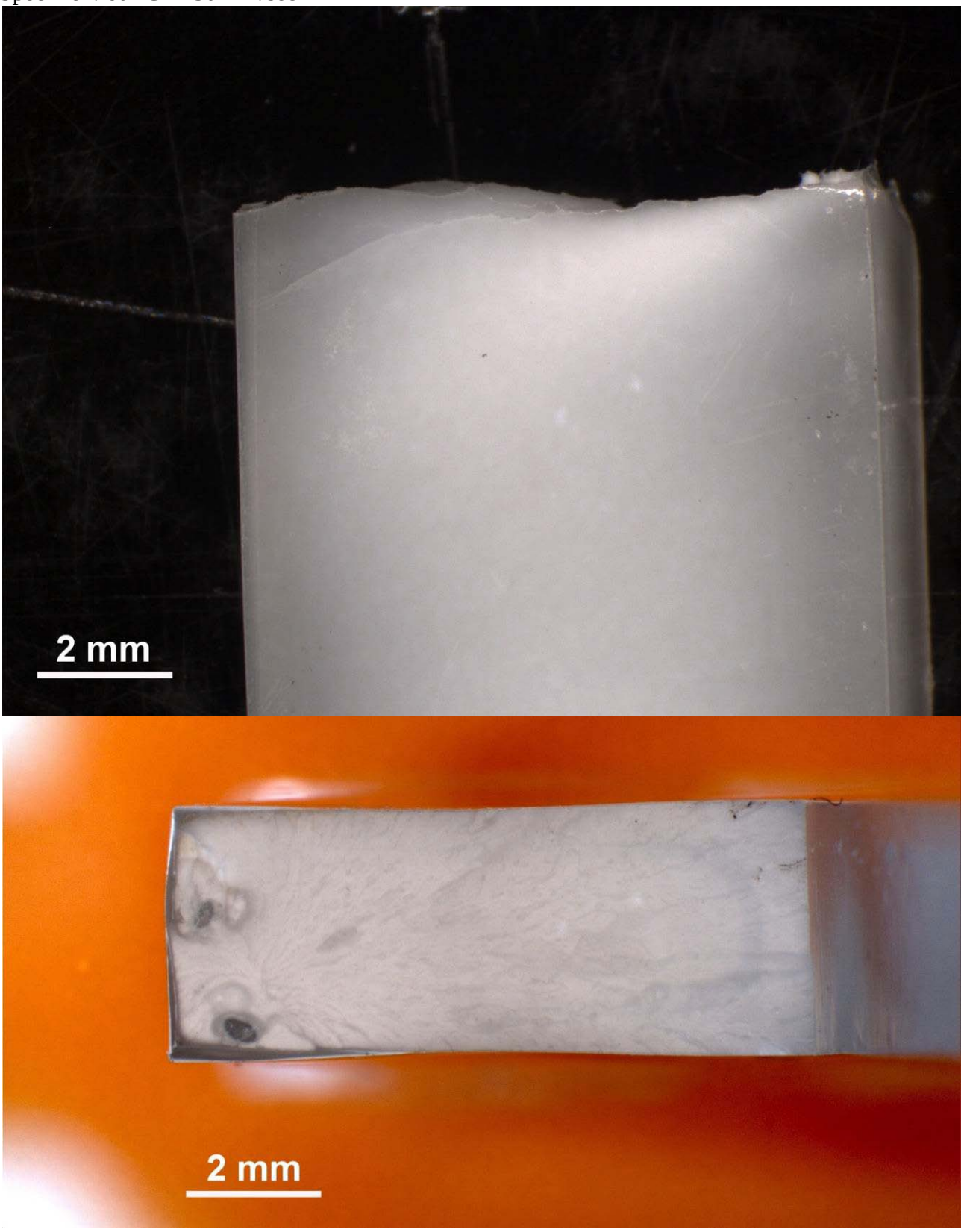


Specimen: 60 °C - 250 mm/sec



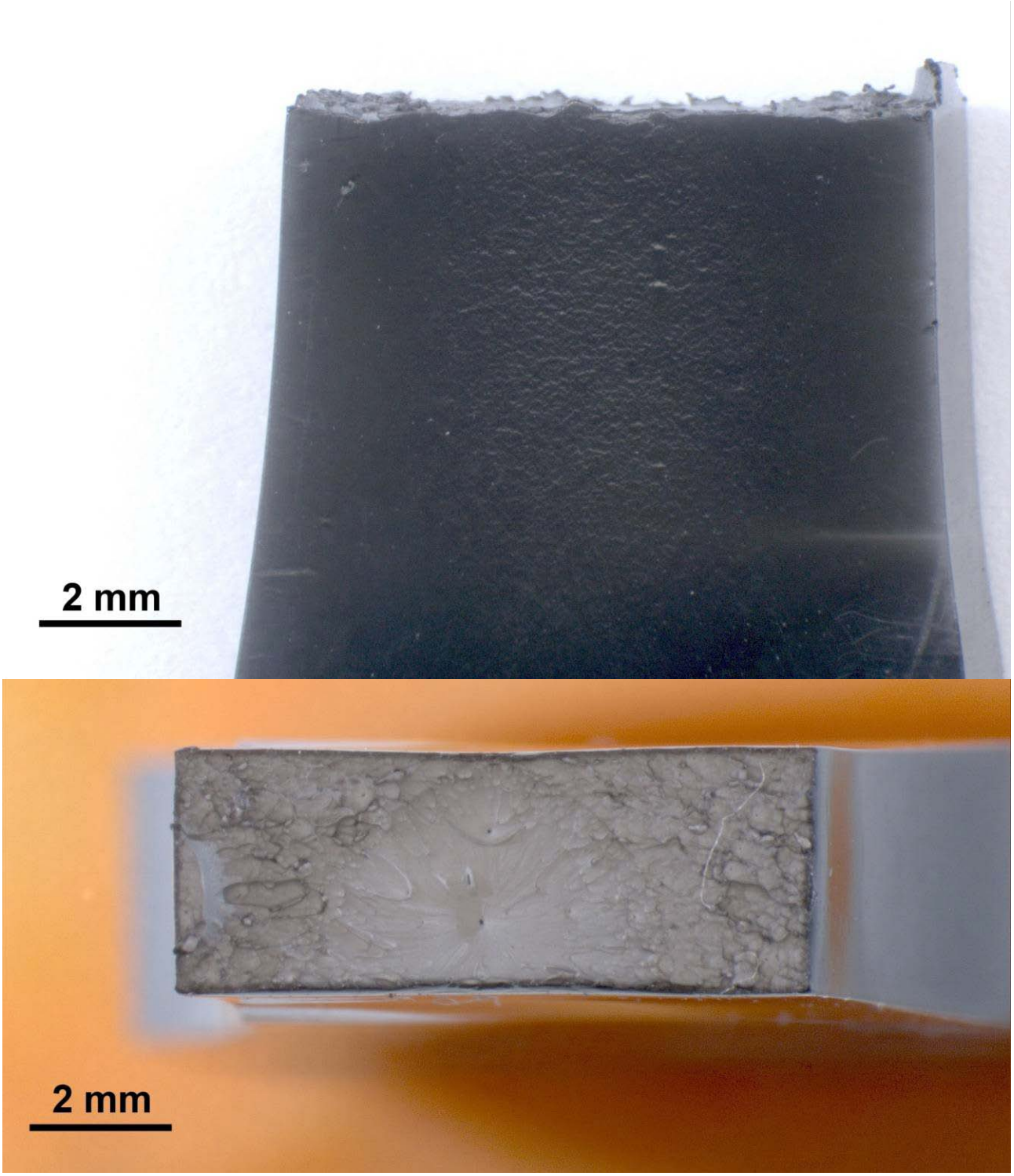


Specimen: 60 °C - 250 mm/sec

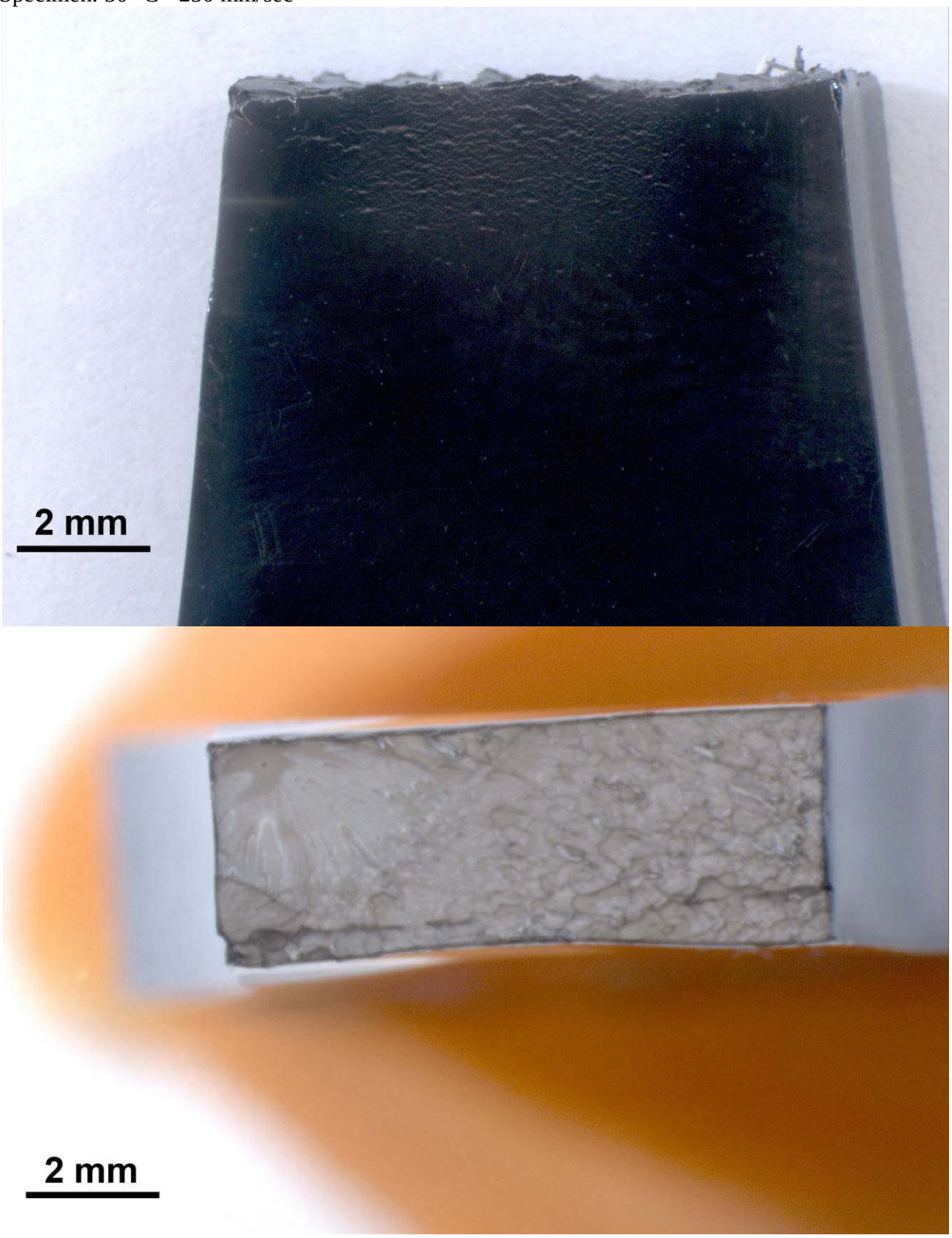


2.4 Microscope pictures of big dog bones of Terluran GP35

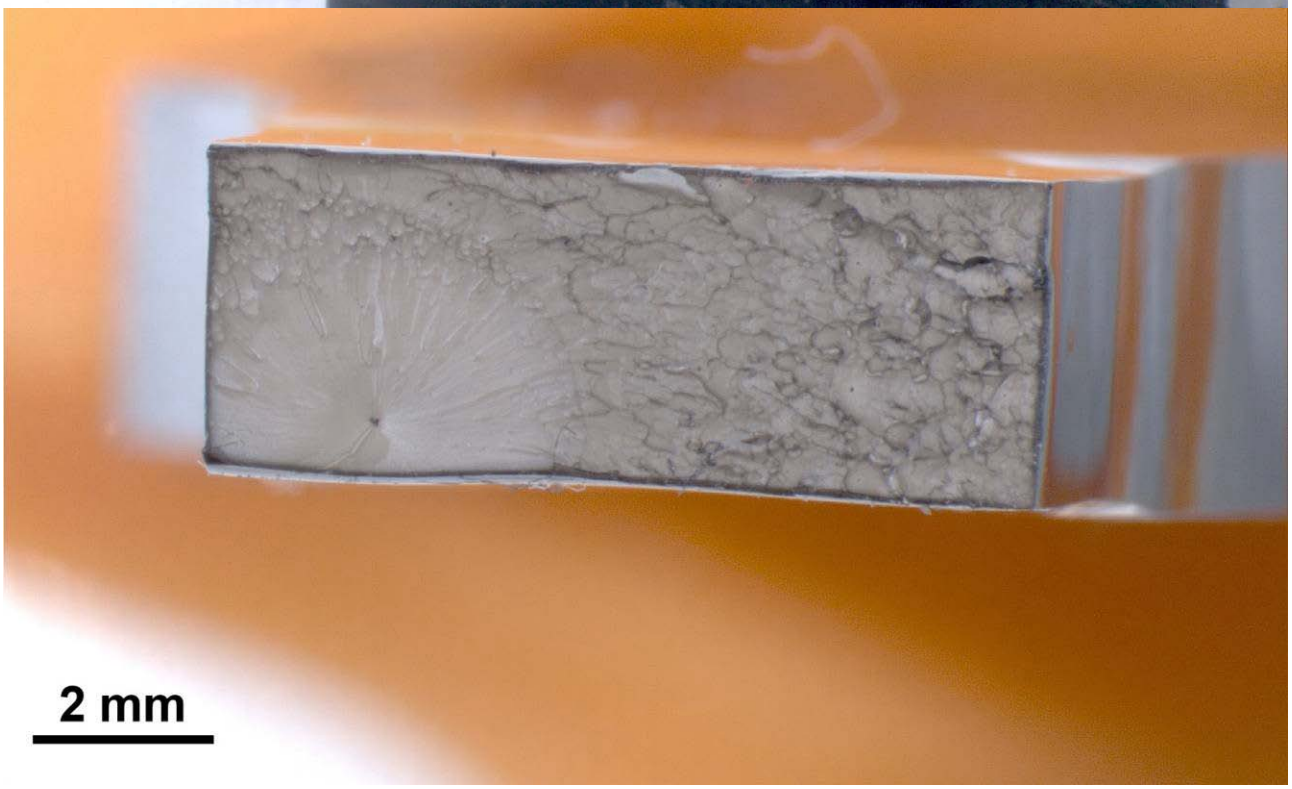
Specimen: 30 °C - 100 mm/sec



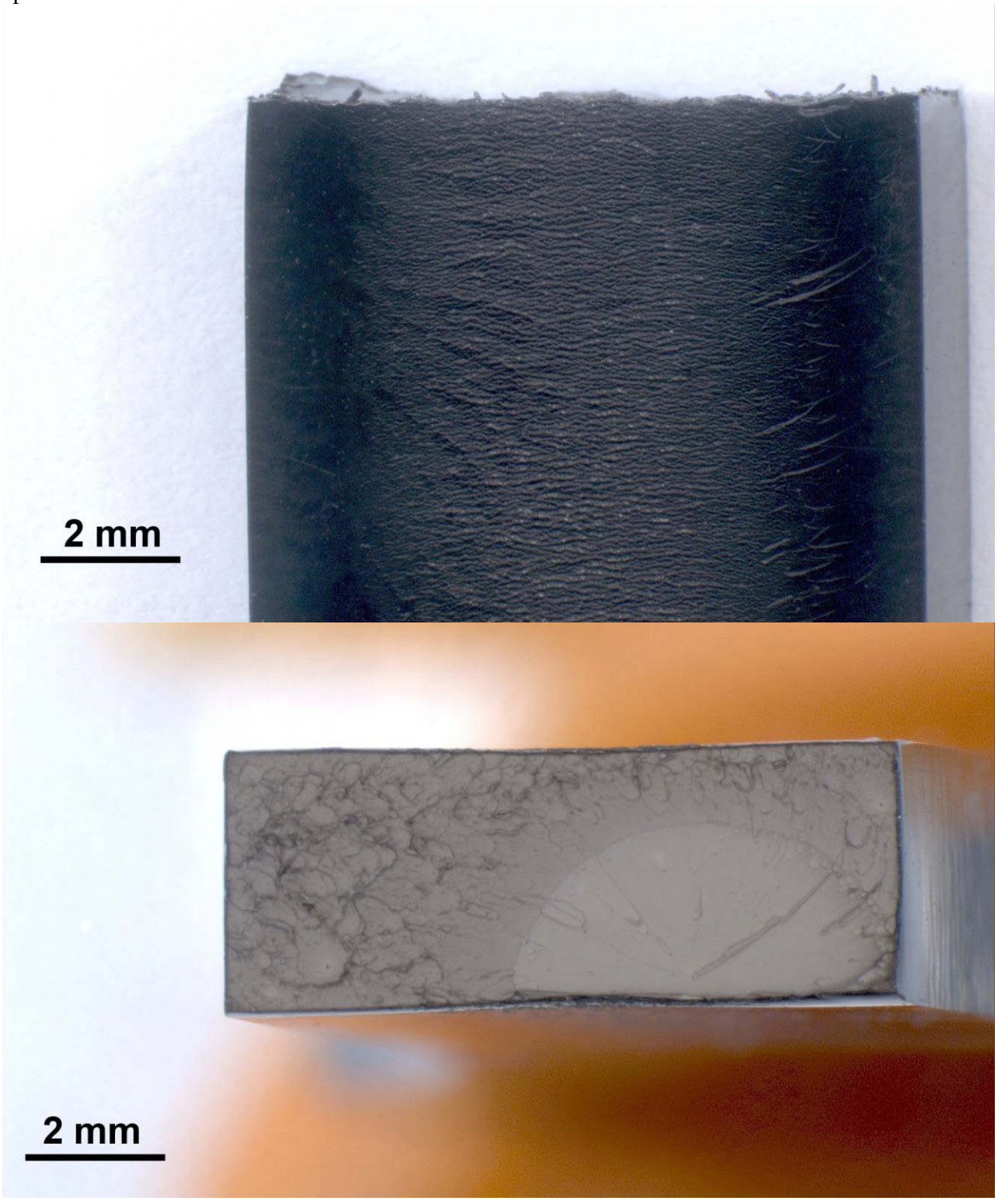
Specimen: 30 °C - 250 mm/sec



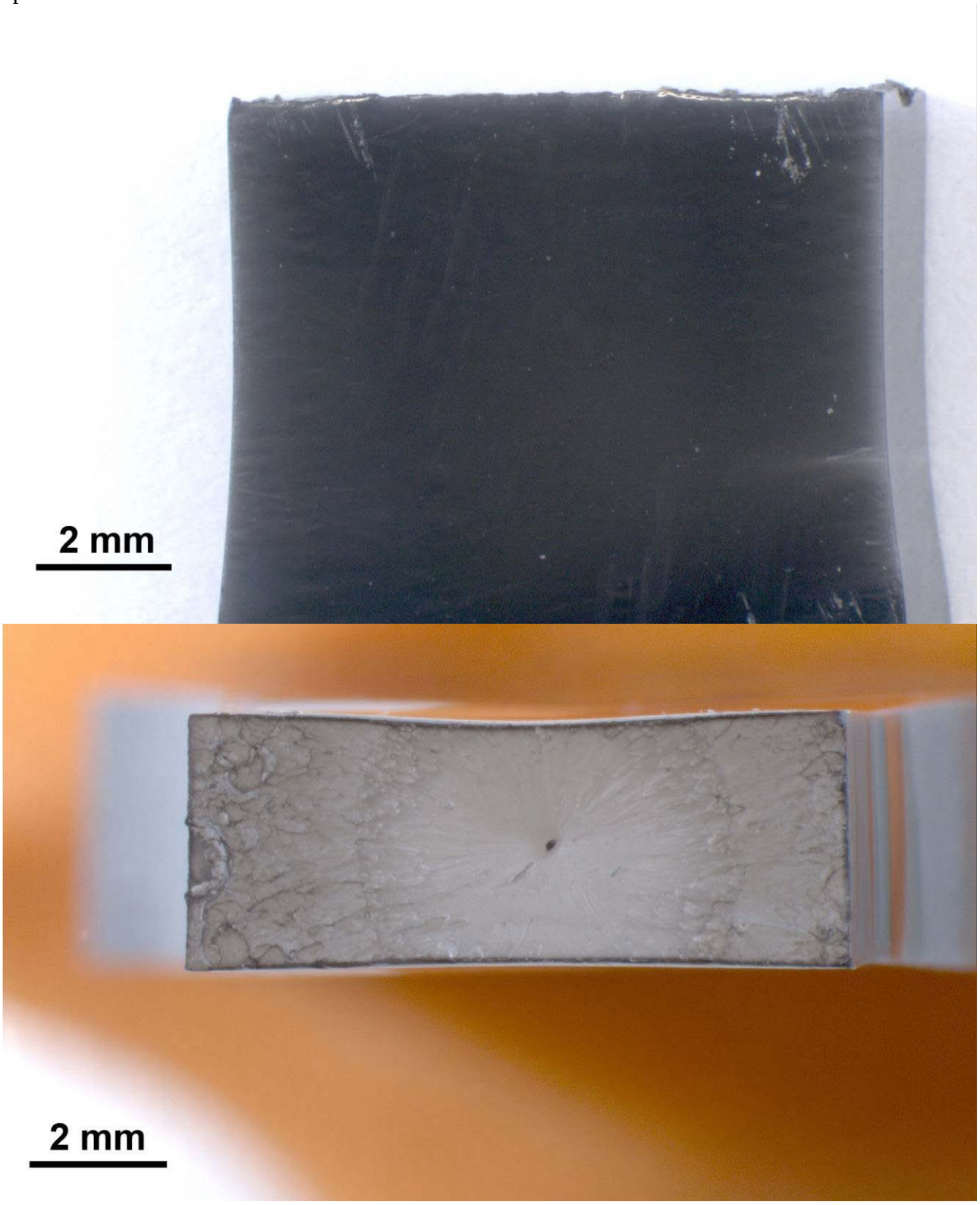
Specimen: 30 °C - 250 mm/sec (1332)



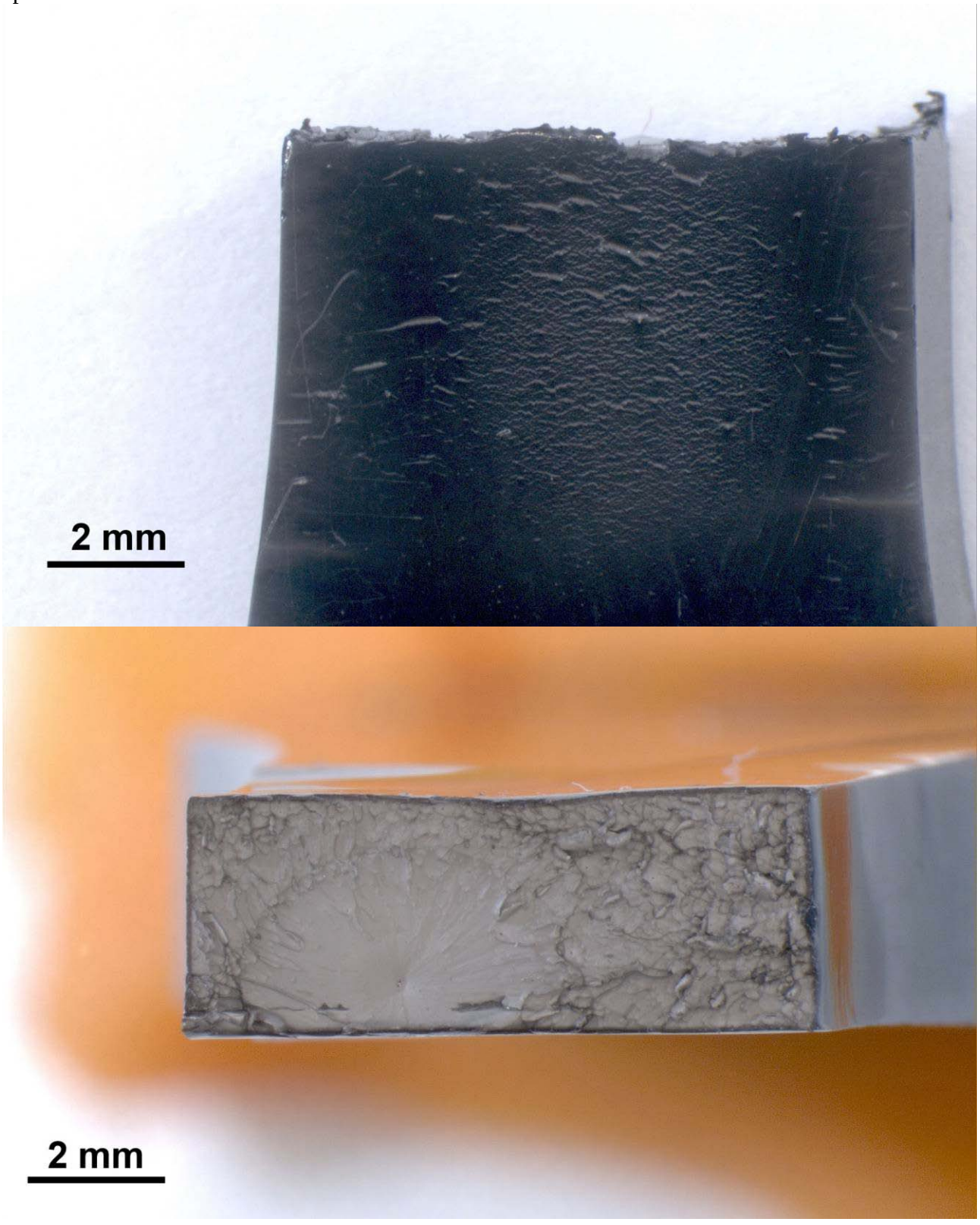
Specimen: 30 °C - 400 mm/sec



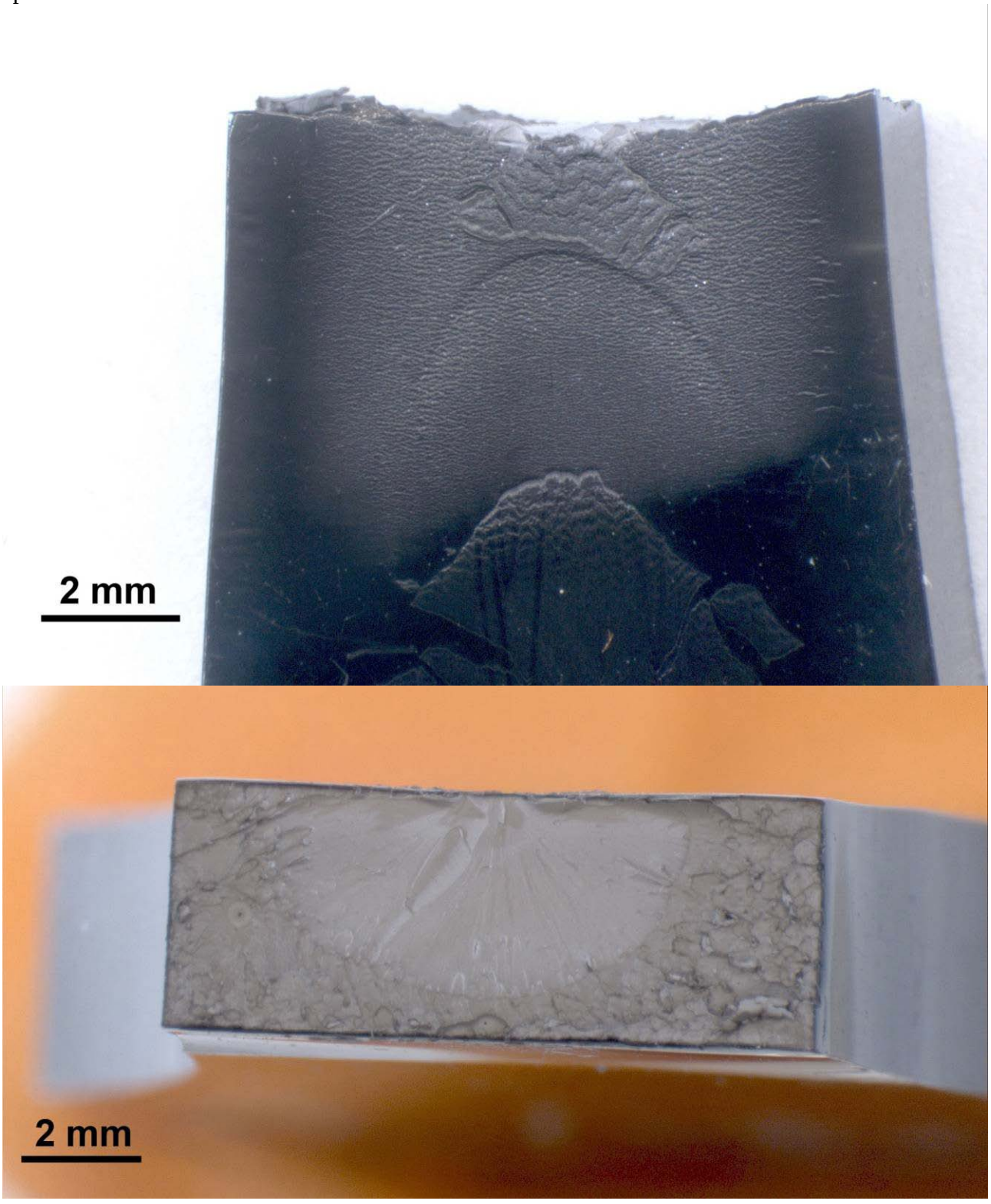
Specimen: 45 °C - 100 mm/sec



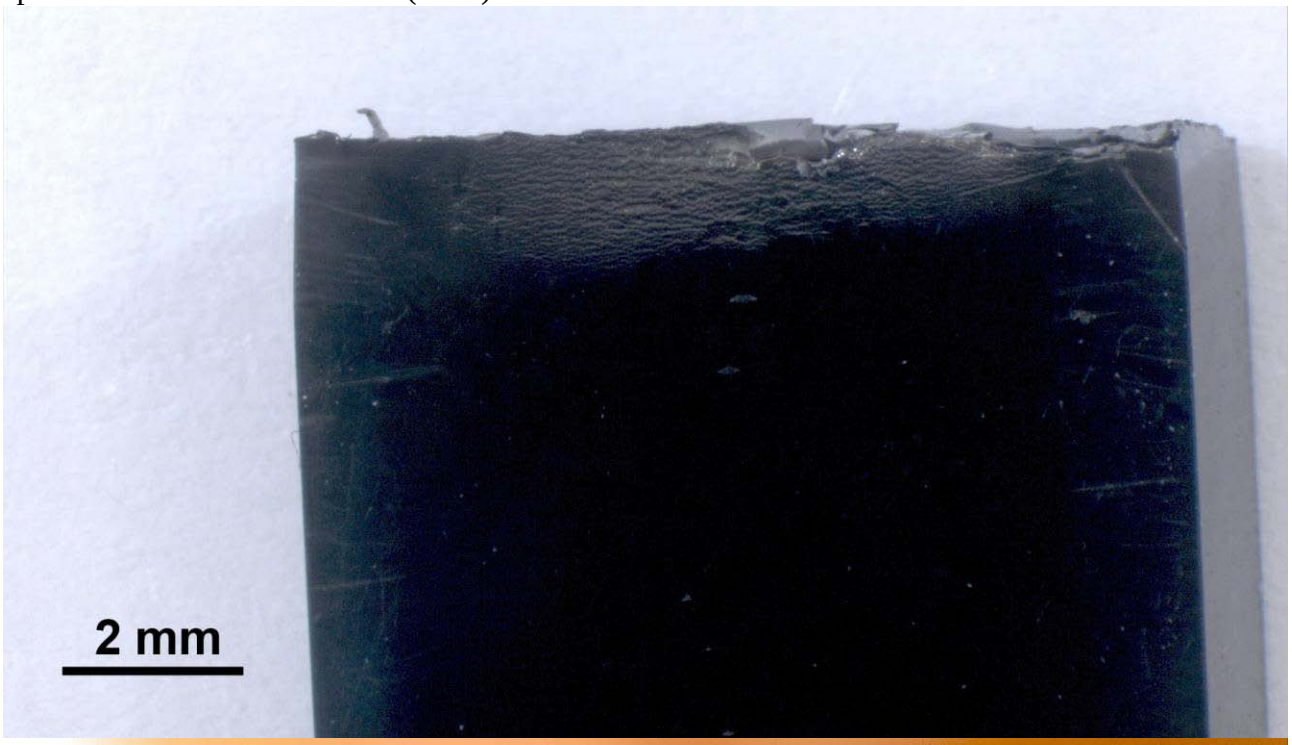
Specimen: 45 °C - 250 mm/sec

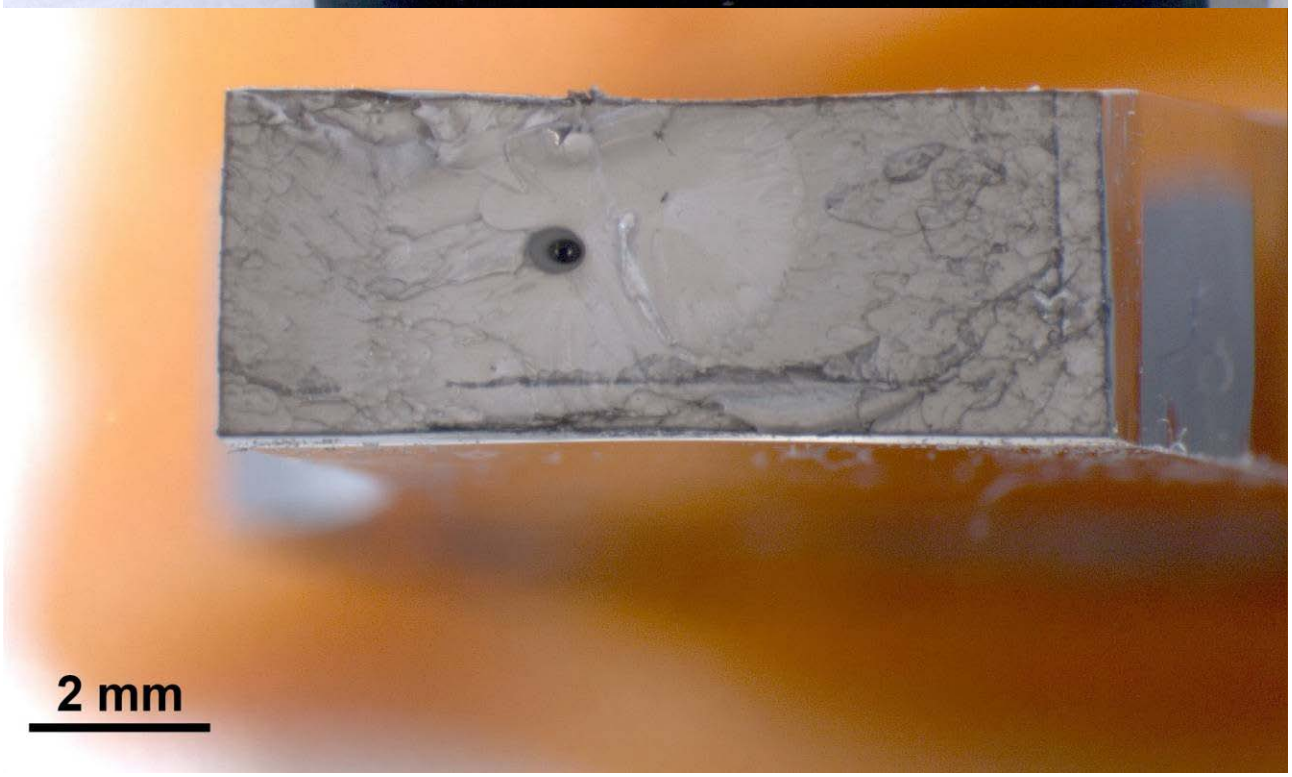


Specimen: 45 °C - 400 mm/sec

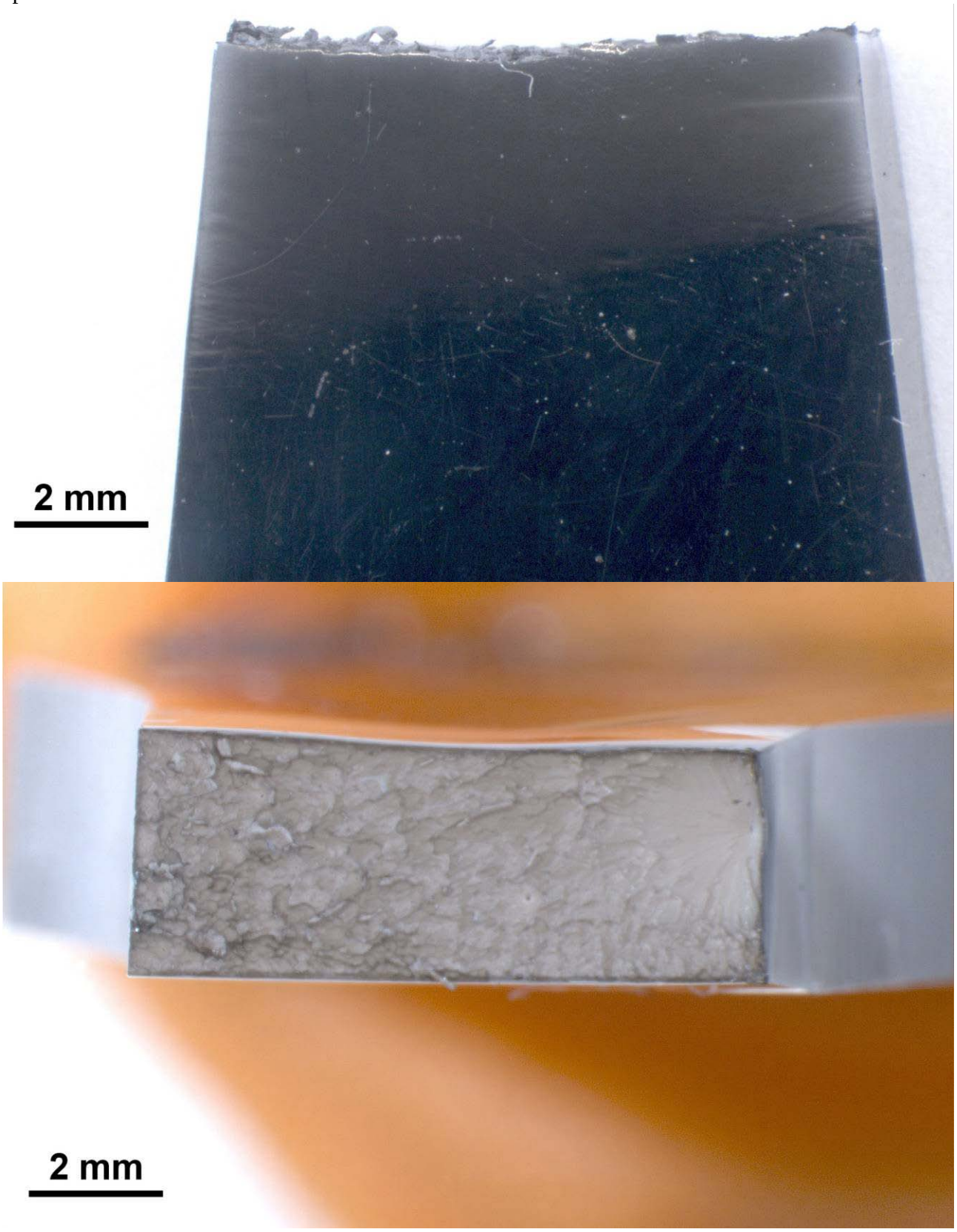


Specimen: 45 °C - 400 mm/sec (1236)

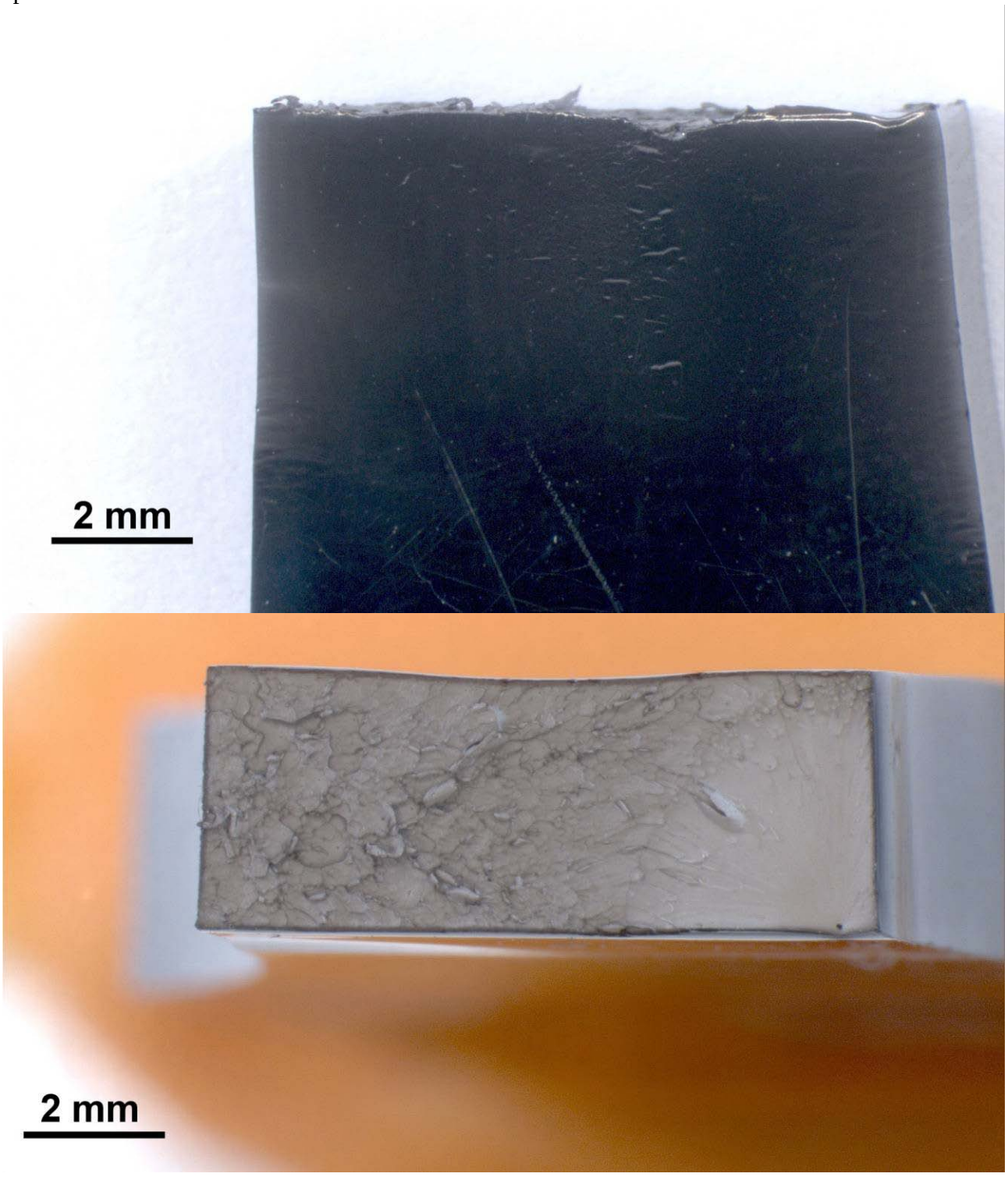




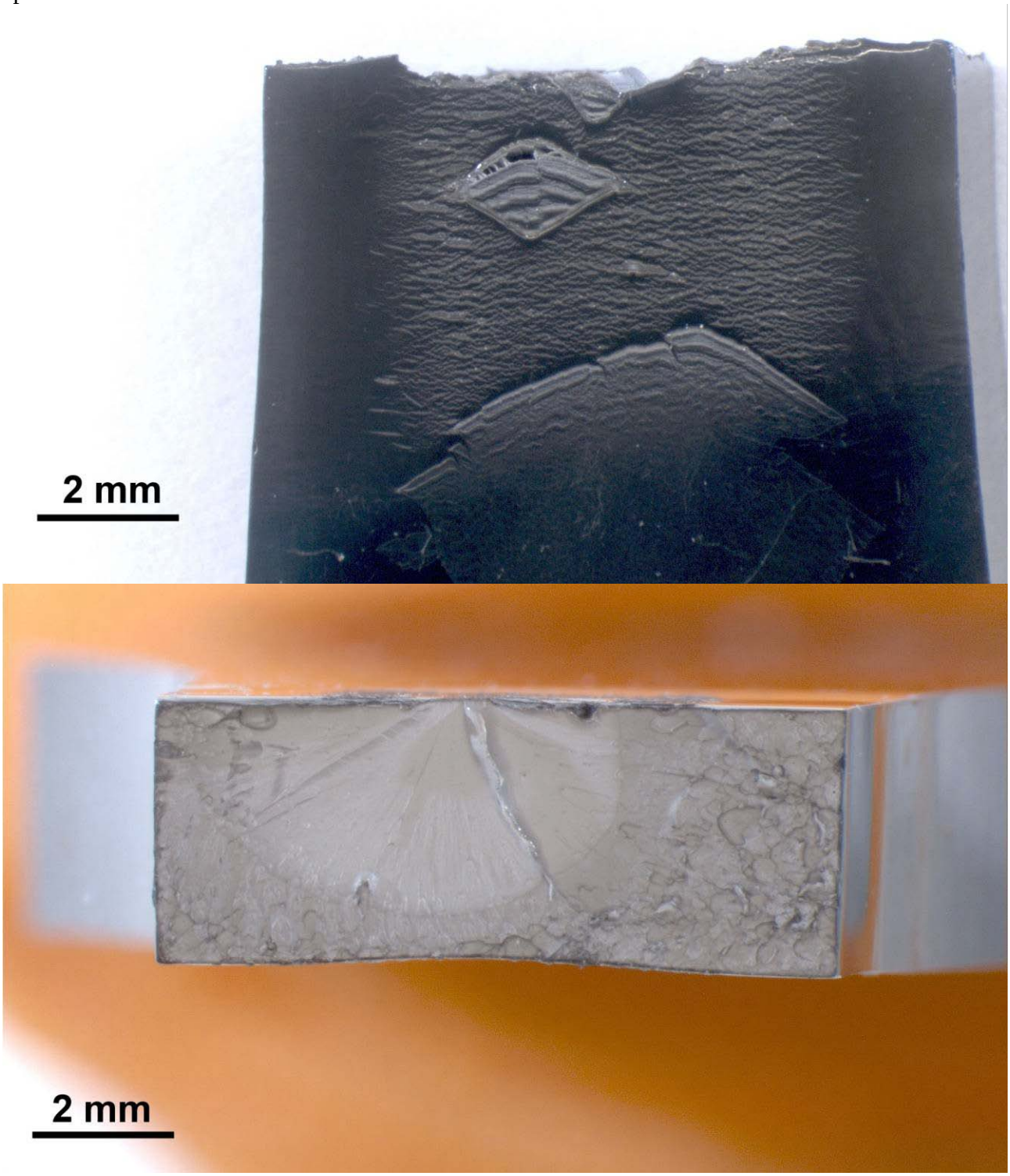
Specimen: 60 °C - 100 mm/sec



Specimen: 60 °C - 250 mm/sec

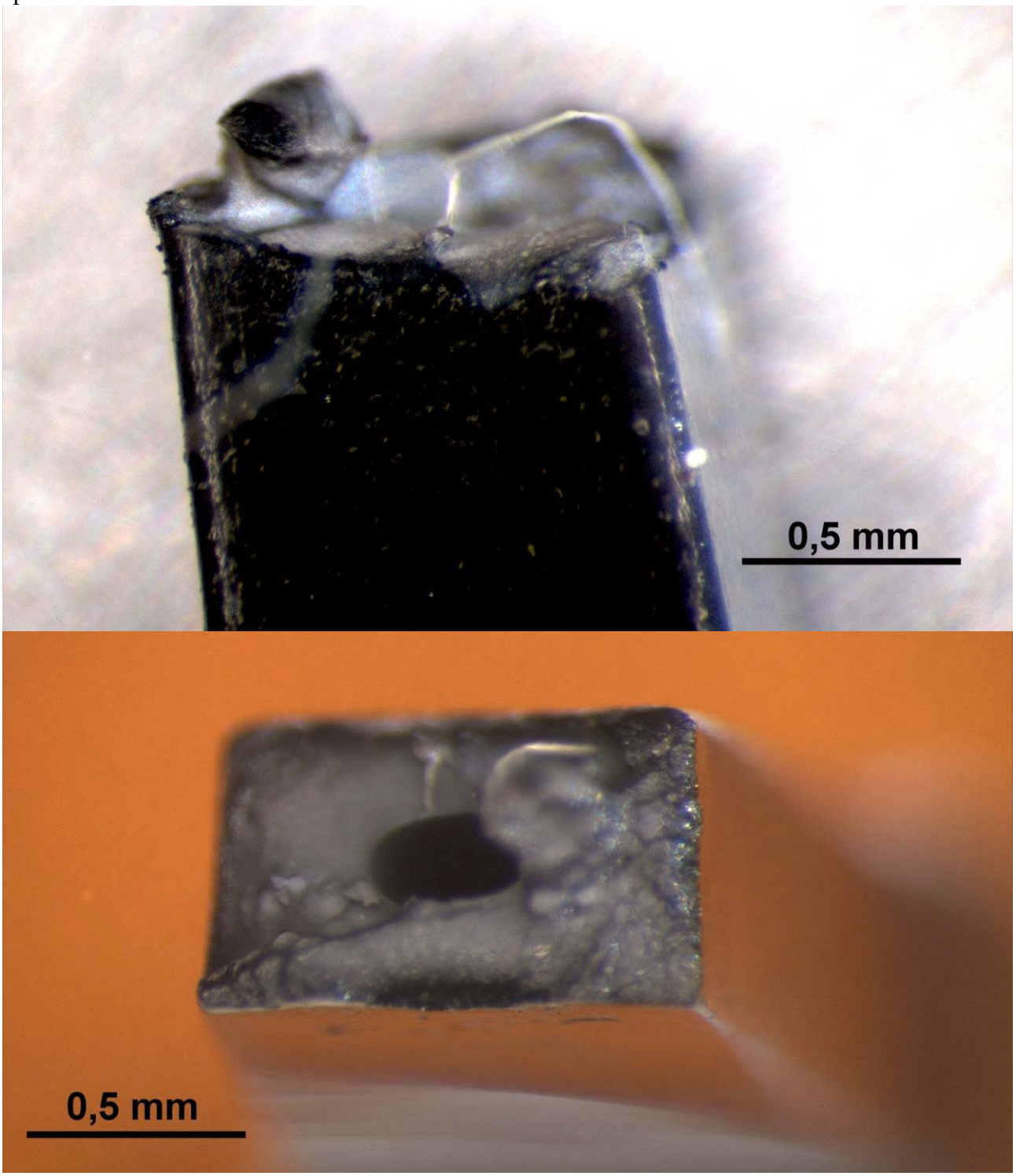


Specimen: 60 °C - 400 mm/sec

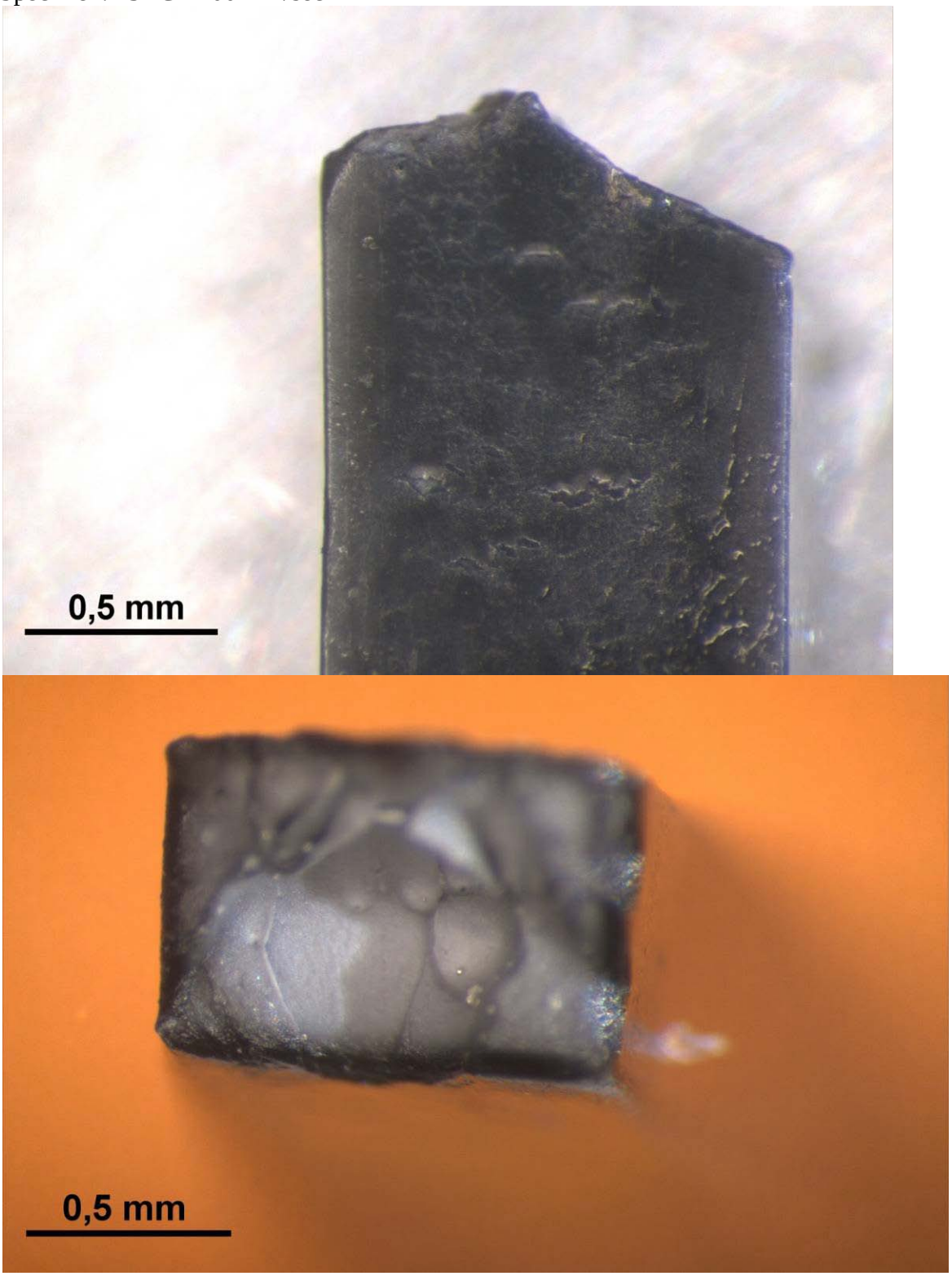


2.5 Microscope pictures of small dog bones of Terluran GP35

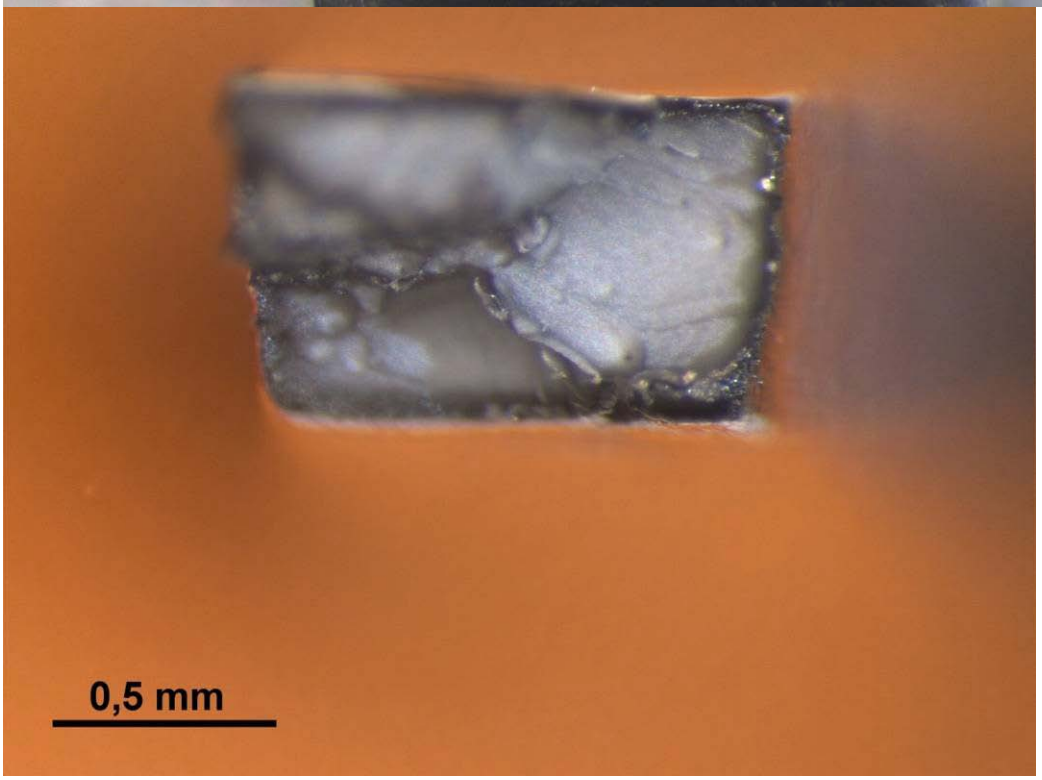
Specimen: 45 □C - 50 mm/sec



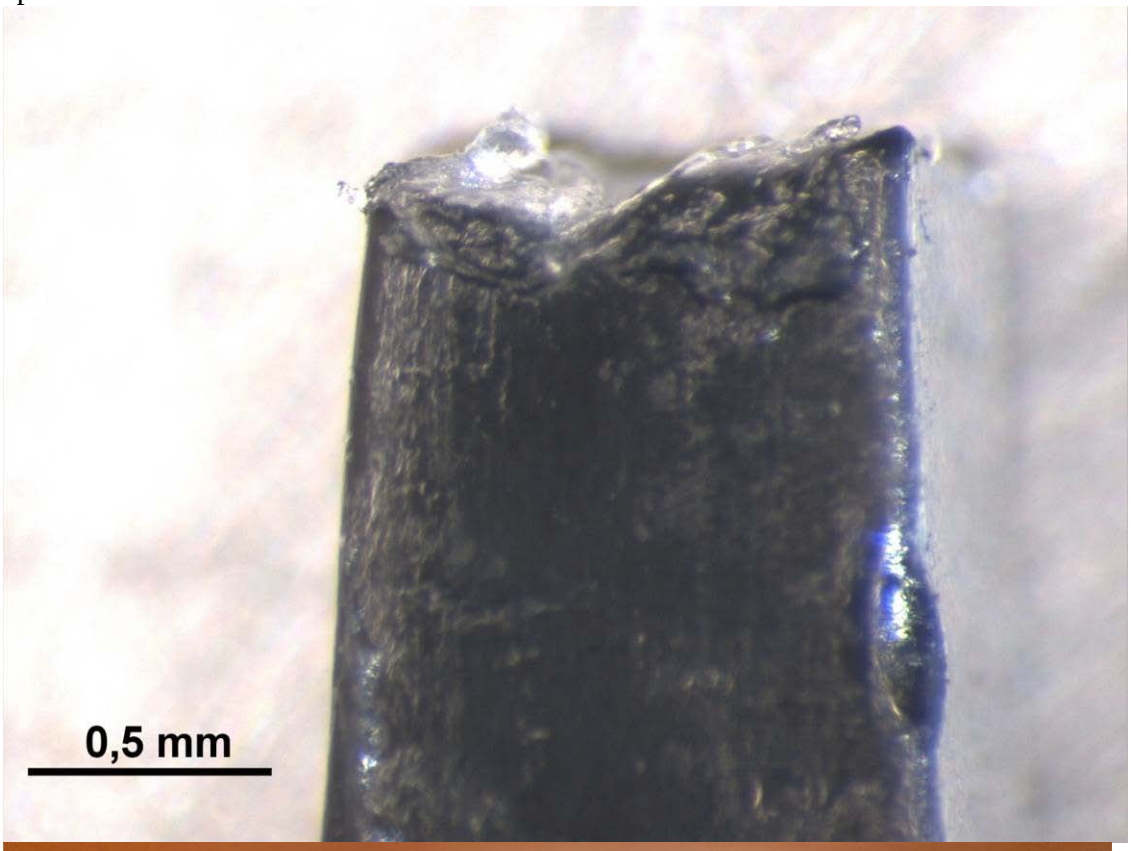
Specimen: 45 °C - 100 mm/sec

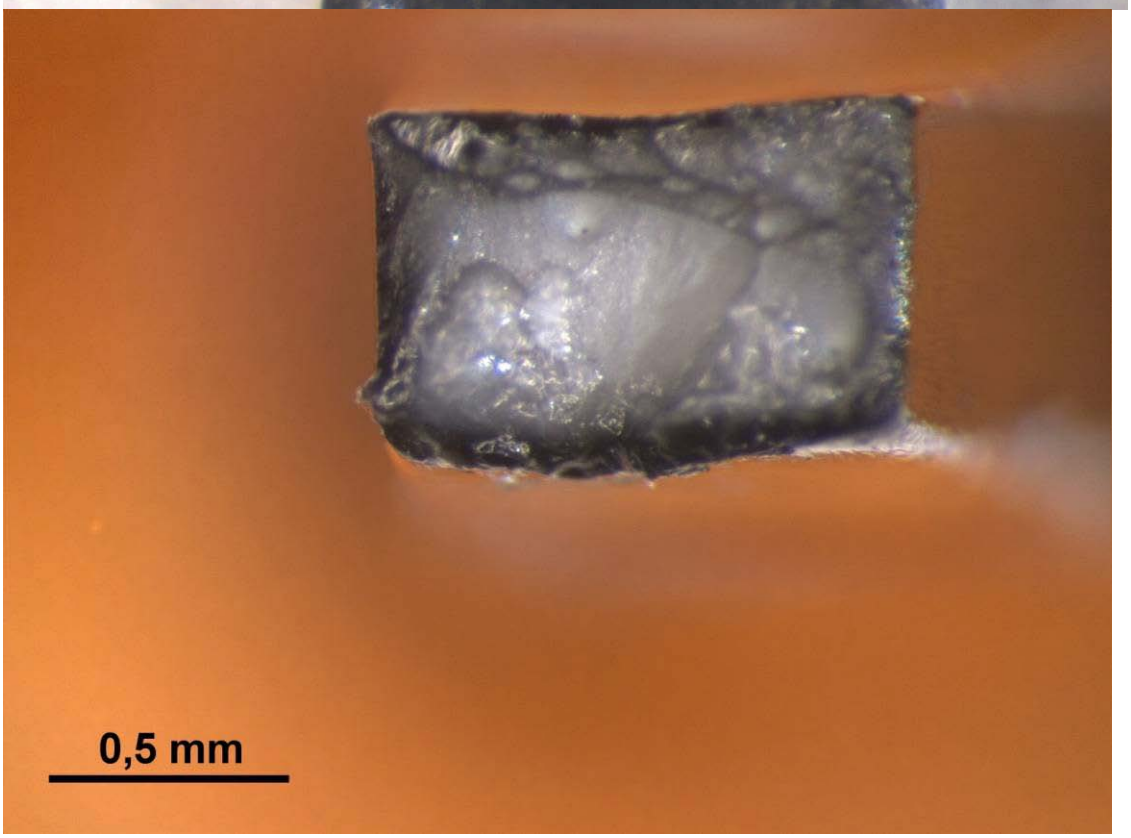


Specimen: 45 °C - 250 mm/sec

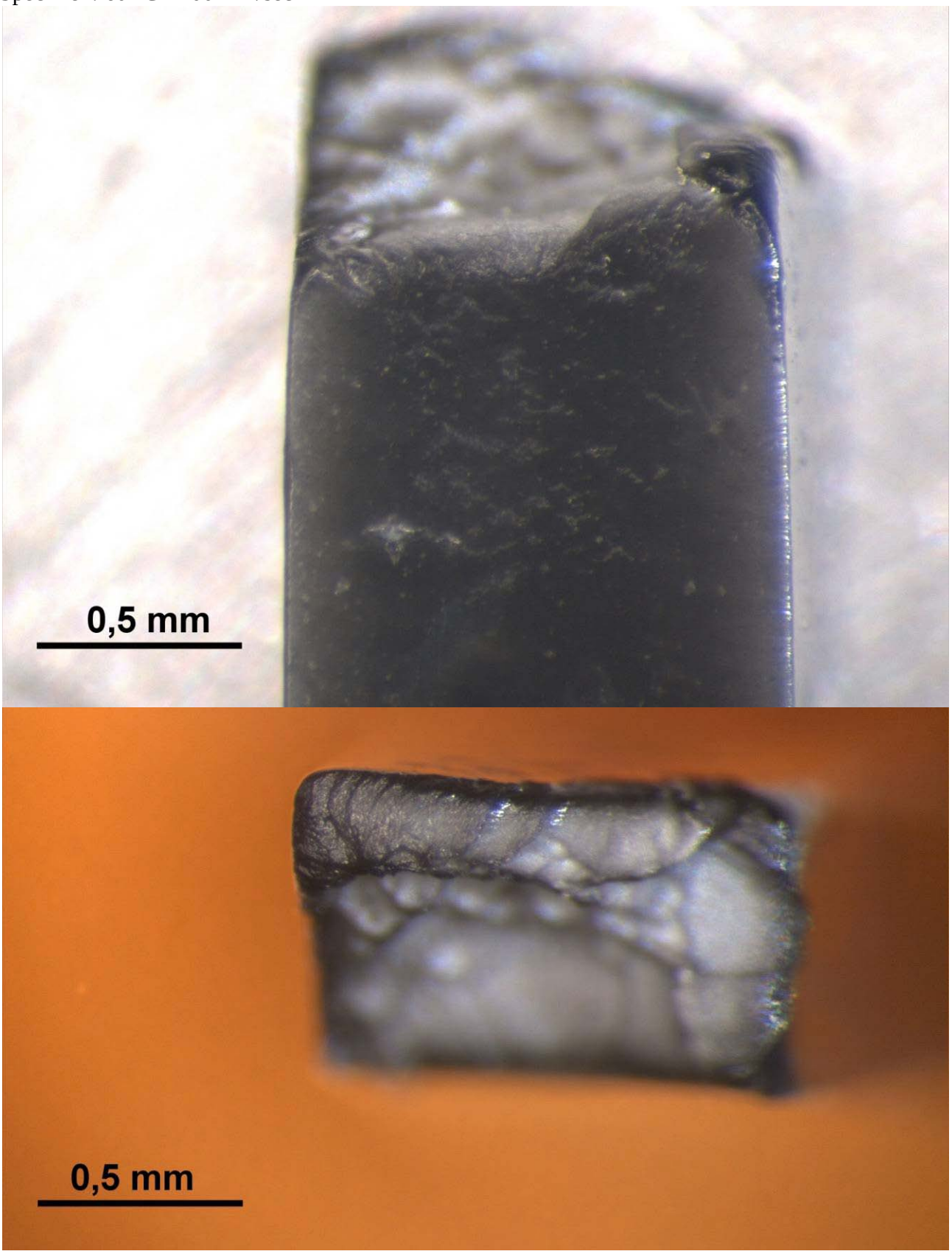


Specimen: 60 °C - 50 mm/sec

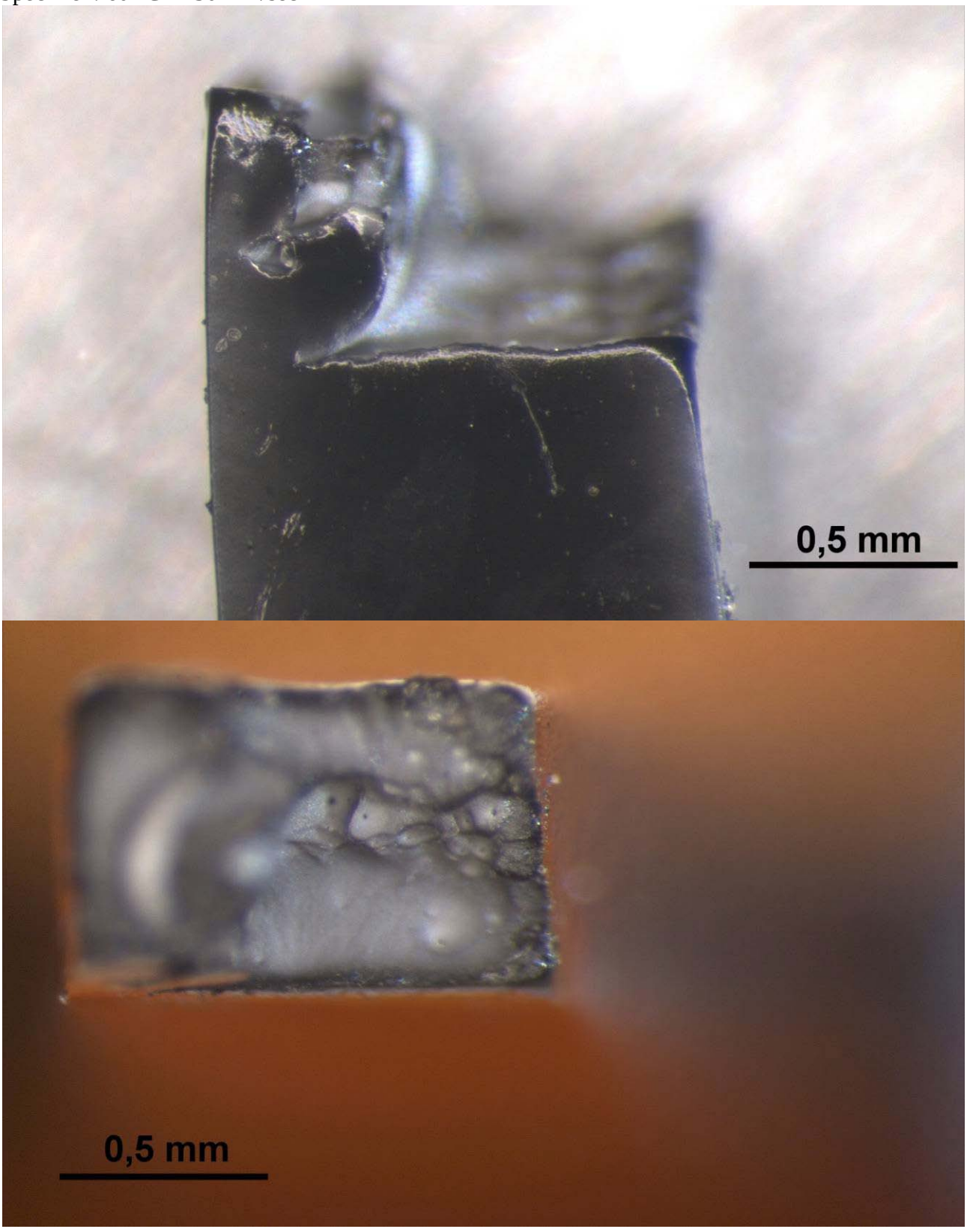




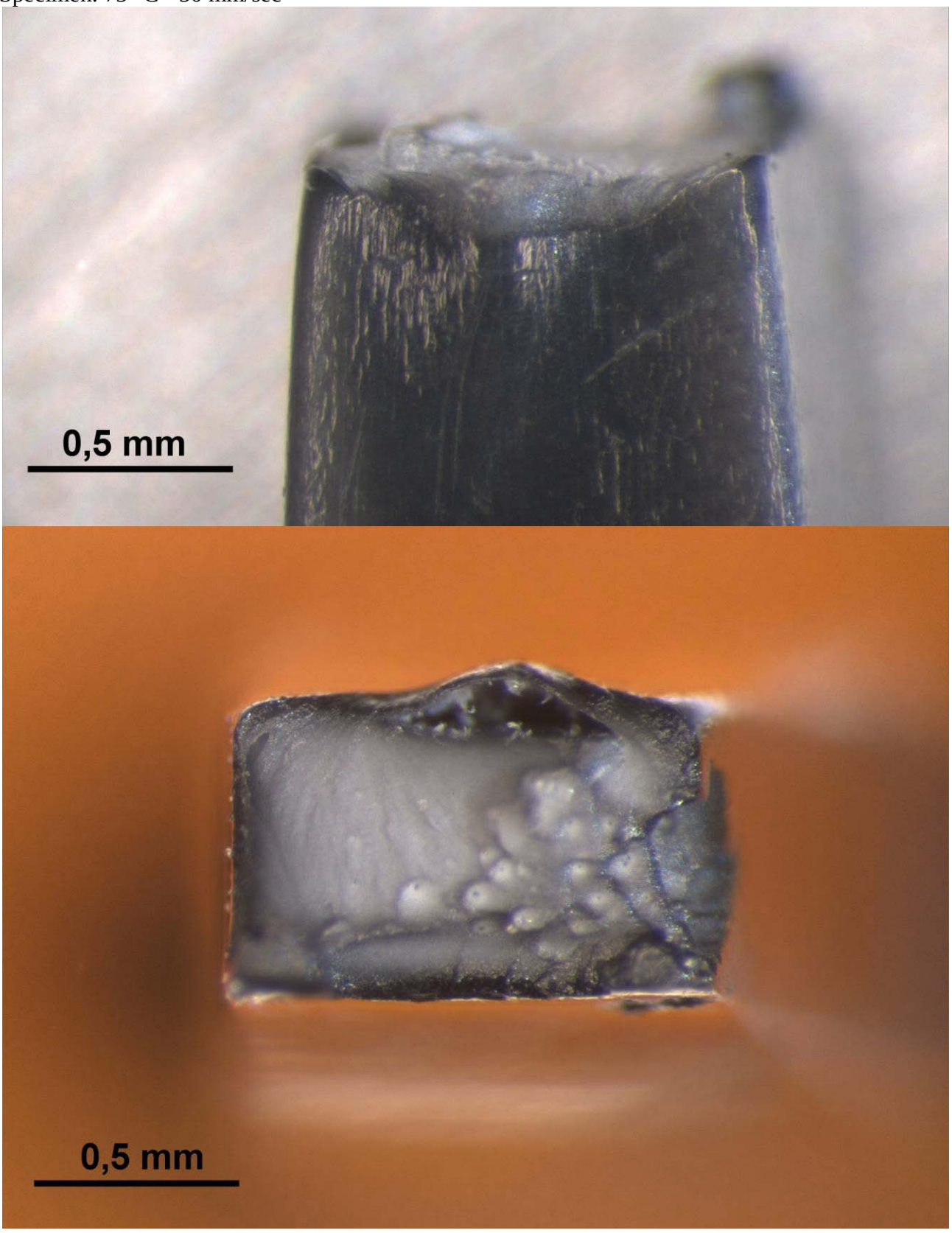
Specimen: 60 °C - 100 mm/sec



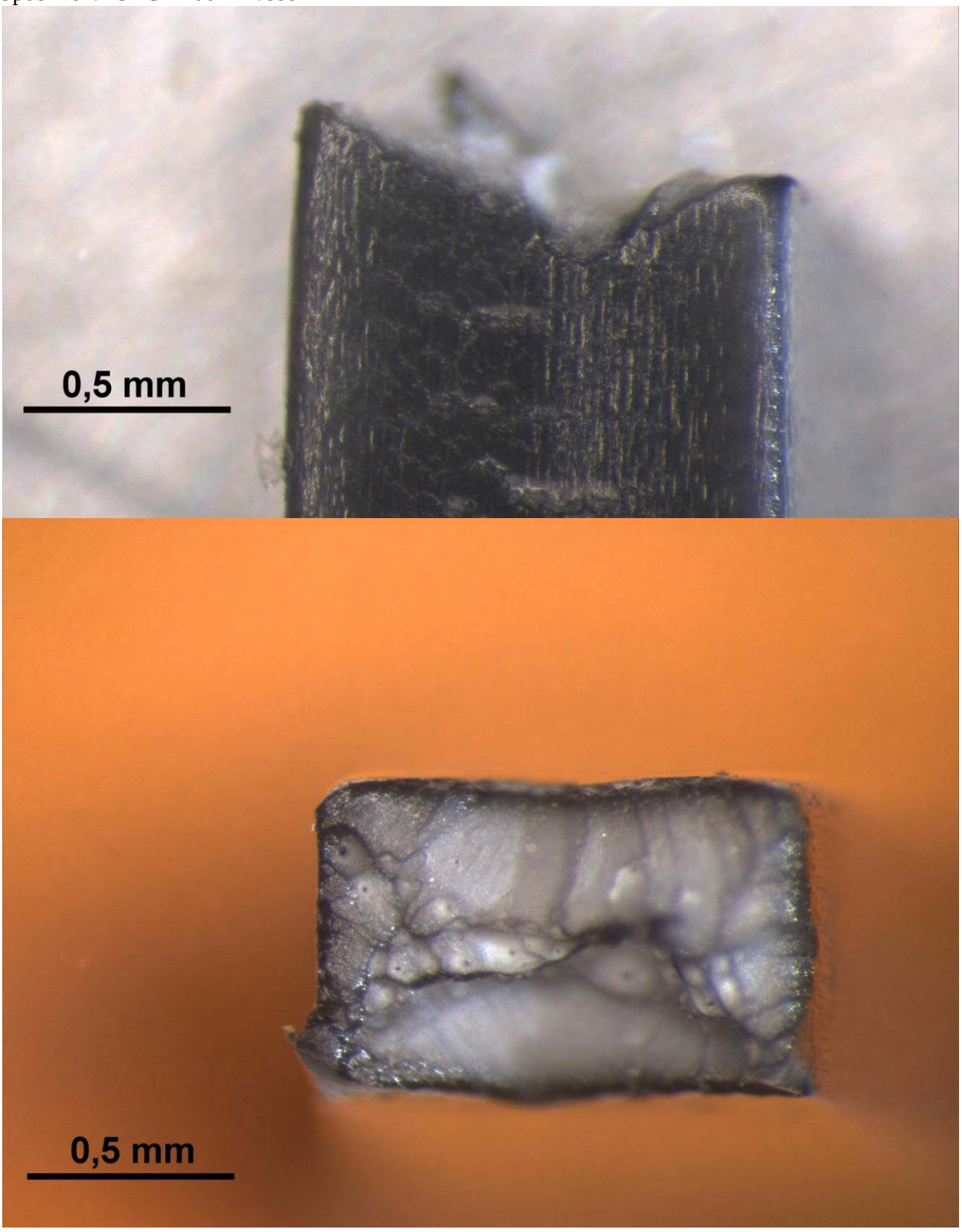
Specimen: 60 °C - 250 mm/sec



Specimen: 75 °C - 50 mm/sec



Specimen: 75 °C - 100 mm/sec



Specimen: 75 °C - 250 mm/sec