SAVONIA

THESIS - **BACHELOR'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

TESTING AND APPROVING PROCESS OF STEEL MATERIALS IN AN INTERNATIONAL COMPANY

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SAVONIA UNIVERSITY OF APPLIED SCIENCES | THESIS Abstract

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Abstract

The aim of this thesis was to develop a testing- and approving process for steels that are used in the production of Normet machines. A testing process was needed to verify the properties of steels that are manufactured in different countries, and to make sure that the materials are suitable for Normet production. The purpose was to test different steel grades that are manufactured in India and compare the results to steels that are used in Finland.

The steel grades for material testing were chosen according to what steels are generally used in the Normet products. The material testing was performed for two different steel grades that are manufactured in India, and for two steel grades that are used in the Normet Oy factory in Finland. Weld joints according to the welding procedure test were also made for the sample plates, to see differences in the weldability of different steels. The material mechanical properties were tested with several destructive material test methods that were: tensile-, impact-, hardness-, bend and microscopic examination tests. The welding of sample plates, manufacturing of the test specimens and the material testings were performed in laboratories of Savonia University of Applied Sciences.

As a result, the material properties of different steel grades were tested. From these results it was possible to see differences between the material mechanical properties that are manufactured in different countries. The testing methods for material approving process were chosen based on these results, by studying what steel properties have most variance and what mechanical properties are most critical.

Keywords
material testing, destructive testing, welding

Public. This version does not include all appendices.

SAVONIA-AMMATTIKORKEAKOULU

OPINNÄYTETYÖ
Tiivistelmä

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Tiivistelmä

Työn aiheena oli kehittää Normet Oy:lle testaus- ja hyväksymisprosessi tuotannossa käytettäville teräksille. Teräsmateriaalien testausprosessi haluttiin kehittää, jotta voidaan varmistua eri maissa valmistettujen teräksien ominaisuuksista, ja niiden sopivuudesta Normetin koneiden valmistukseen. Tarkoituksena oli testata Intiassa valmistettuja eri teräslaatuja, ja verrata niiden ominaisuuksia Suomessa käytettäviin teräksiin.

Työssä testattavat teräslaadut valittiin sen mukaan, mitä teräksiä Normetin koneiden valmistuksessa käytetään Suomessa. Testaukset suoritettiin kahdelle Intiassa valmistetulle teräsluokalle, ja kahdelle Normet Oy:n Suomen tehtaalla käytetylle teräsluokalle. Teräslevyille tehtiin myös menetelmäkokeen mukainen hitsausliitos, jotta voitiin tutkia eroavaisuuksia materiaalien hitsausominaisuuksissa. Testausmenetelminä teräksille käytettiin useita eri rikkovan aineenkoetuksen menetelmiä, joita olivat vetokoe, iskukoe, kovuusmittaus, taivutuskoe ja mikrohietutkimus. Koelevyjen hitsaus, koekappaleiden valmistus ja materiaalitestit suoritettiin Savonia-ammattikorkeakoulun laboratoriotiloissa.

Lopputuloksena saatiin materiaalitestien tulokset valituista teräsluokista, tuloksista on mahdollista nähdä eroavaisuudet eri maissa valmistettujen teräksien ominaisuuksissa. Kokeiden perusteella voitiin valita Normetille tarpeelliset materiaalitestit tutkimalla, missä tuloksissa on eniten vaihtelua ja mitkä mekaanisista ominaisuuksista ovat tärkeimpiä.

Avainsanat
materiaalitestaus, rikkova aineenkoetus, hitsaus

Julkinen. Tämä versio ei sisällä kaikkia liitteitä.

PREFACE

I would like to thank my supervisors Mr. Mika Mäkinen and Mr. Tero Kaatrasalo for inspiring guidance during this project.
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Kuopio, 24 April 2020
Timo Paananen

CONTENTS

TERMS AND ABBREVIATIONS

EN 10025	European material standard
IS 2062	Indian material standard
R_{eH}	Upper yield strength
R_{eL}	Lower yield strength
$R_{p0,2}$	0,2 % proof strength
R_m	Tensile strength
A	Percentage elongation
S_0	Cross-section area of tensile test piece
KV_2	Charpy-V impact test with 2 mm striker radius
HV10	Vickers hardness testing method, with 10 kg test force
HAZ	Heat affected zone
CEV	Carbon equivalent value
IIW	International Institute of Welding

1 INTRODUCTION

The aim of this thesis was to develop a testing and approving process for steels that are used in the production of Normet equipment. When manufacturing machines in different parts of the world, steels that are used are manufactured according to different material standards, and sometimes the steel properties cannot be equally compared.

With a testing and approving process, it is possible to find corresponding steels from different steel grades and compare steels that are manufactured according to different material standards. If the tested material meets the requirements that material grade can be approved to the production of Normet machines. This makes it easier to control the quality of Normet products that are manufactured in different countries.

This thesis focused on testing two steel grades that are manufactured in India. Material testing was also made for two steel grades that are used in Finland, to have test results that are made with the same testing process and can be compared. Material testing was processed for sheet plates and for weld joints, to sort out differences also in weldability. A variety of test methods was used and one purpose was to find the test methods that are necessary for Normet.

2 NORMET OY

Normet Oy develops, manufactures and sells equipment for different mining and tunneling processes. The products are used for example: concrete spraying and transport, scaling, explosive charging, lifting, installation works and underground logistics. Normet manufactures also construction chemicals like different sprayed concretes and chemicals for rock and ground support. The number of delivered underground mining machines is over 12,000 and Normet offers a wide range of maintenance and support services for the machines. Normet operates globally with over 50 locations in 28 countries, and it has amassed process expertise over thousands of mine and tunnel projects all over the world. The main equipment development and manufacturing facility is located in Iisalmi, Finland. (Normet, 2020)

3 STEEL GRADES

3.1 Materials for tests

In this work there was a possibility to test steels from different strength grades, the aim was to test commonly used steels with a yield strength of 355 MPa and high-strength steel with a yield strength of 600-700 MPa. The selection of steel materials for this work was done by finding out what steels are generally used in Normet products. The selected non-alloy structural steel was S355K2 that is commonly used in frames and with a wide thickness range up to 150 mm. Selected high strength steel was S690QL that is used for example in suspension arms.

The selected Indian steel for strength class S355 was E350C according to Indian steel standard IS 2062. The corresponding Indian manufactured steel for S690QL grade was difficult to find, hence other selected Indian manufactured steel was structural steel IS 2062 E450BR that has a yield strength of 450 MPa. By testing these four different steels, it is possible to see differences between the mechanical properties of steel materials and find the testing process that is suitable for Normet.

3.2 EN 10025-2 S355K2

S355K2 is a common hot rolled structural steel, according to the material standard EN 10025-2. There are different variations of impact strength properties at different temperatures, as steel becomes more brittle at lower temperatures, different impact strengths of S355 grade steel are shown in the table 1. The material standard EN 10025-2 includes different delivery conditions and the delivery condition of S355K2 used in this work was +N which means that it is normalized or normalized rolled. "the requirements on mechanical properties of the steel grades in standard are not depending on the delivery condition (SFS-EN 10025-2:2019, 2019 s. 48)." S355K2 is a commonly used steel grade in metal industry, especially in heavy industries like ship building. It has a good weldability and machinability, it is a good choice for low temperatures, due to its high impact strength at -20 °C. The mechanical requirements of S355K2 according to the material standard and manufacturer test certificate values are listed in the table 2 and chemical compositions in the table 3. The table 3 includes also chemical compositions of Indian steel grades. ID number in these tables is used to identify steel details that are listed in the table 11.

TABLE 1. Impact strength requirements of S355 grade (SFS-EN 10025-2:2019 s. 30.)

Steel grade	Steel number	Temperature	Minimum energy KV_2 (J) for thickness (mm)		
		°C	≤150	≥150 ≤250	≥250 ≤400
S355JR	1.0045	20	27	27	27
S355J0	1.0553	0	27	27	27
S355J2	1.0577	-20	27	27	27
S355K2	1.0596	-20	40	33	33

TABLE 2. Mechanical properties of S355K2 grade steel (SFS-EN 10025-2:2019 ss. 26-27.)

	Designation		Yield strength R_{eH} (MPa) for thickness (mm)			Tensile strength R_m (MPa) for thickness (mm)			Percentage elongation A (%) $L_0 = 5,65\sqrt{S_0}$			Impact strength KV_2 (J) at -20 °C
	Steel grade	ID number	≤16	≥16 ≤40	≥40 ≤63	≤3	≥3 ≤100	≥100 ≤150	≥3 ≤40	≥40 ≤63	≥63 ≤100	≤150 mm
Standard requirements	EN 10025-2 S355K2		355	345	335	510-680	470-630	450-600	22	21	20	40 J
Test certificate value	S355K2	11	441	-	-	-	567	-	26	-	-	160 J

TABLE 3. Chemical compositions of S355K2, E350C and E450BR (SFS-EN 10025-2:2019 s. 24) (IS 2062, 2011 s. 3.)

	Designation		C in % for thickness (mm)			Si	Mn	P	S	Cu
	Steel grade	ID number	≤16	≥16 ≤40	≥40	%	%	%	%	%
Standard max values	EN 10025-2 S355K2		0,200	0,200	0,220	0,550	1,60	0,025	0,025	0,550
	IS 2062 E350C			0,200		0,450	1,55	0,040	0,040	-
	IS 2062 E450BR			0,220		0,450	1,65	0,045	0,045	-
Test certificate values	S355K2	11	0,152			0,460	1,39	0,017	0,008	0,013
	E350C	32		0,183		0,185	1,40	0,016	0,009	
	E450BR	42		0,160		0,212	1,24	0,017	0,006	

3.3 IS 2062 E350C and E450BR

E350 and E450 are hot rolled structural steels manufactured according to the Indian material standard IS 2062, sample plates of these steels were ordered to Finland for material tests. Steel grade E350 is divided into four quality classes that are depending on steel impact properties, these four classes are A, BR, B0 and C. E350 steel quality grade tested in this work was C, so the impact test temperature is the same as with S355K2 steel. Grade E450 is divided into two different classes depending on impact strength requirement, E450 quality tested was BR, which requires an impact strength of minimum 20 J at room temperature. The chemical composition requirements according to the standard IS 2062 and material test certificate values of these steels are listed in the table 3. Requirements of mechanical properties according to the material standard and material test certificate values are listed in the table 4.

TABLE 4. Mechanical properties of E350 and E450 grade steels (IS 2062, 2011 s. 4.)

	Steel grade	Quality	Yield strength R_{eH} (MPa) for thickness (mm)			Tensile strength R_m (MPa)	Percentage elongation A (%) $L_0 = 5,65\sqrt{S_0}$	Internal bend diameter		Impact strength KV_2 (J)	
			<20	20-40	>40			≤25	>25	Temp (°C)	Min J
Standard IS 2062	E350	A	350	330	320	490	22	2t	-	-	-
		BR								Optional	27
		B0								0	27
		C								-20	27
	E450	A	450	430	420	570	20	2,5t	-	-	-
		BR								RT	20
Test certificate	E350	C	410	-	-	557	35,5			-20	51
	E450	BR	495	-	-	605	30,3			20	140

3.4 EN 10025-6 S690QL

EN 10025-6 S690QL is a high yield strength alloyed special steel. The delivery condition for S690QL is quenched and tempered (Q) (SFS-EN 10025-6:2019, 2019 s. 9). The mechanical requirements of S690QL according to material standard and reported mechanical properties of materials tested in this work are shown in the table 5. The impact strength requirements in different temperatures are listed in the table 6 and chemical compositions in the table 7.

Strength of this steel grade is based on quenching and tempering. Quench hardening properties of the material is improved with elements like chrome (Cr), nickel (Ni) and molybdenum (Mo) (Metalliteollisuuden keskusliitto, 2001 s. 77).

Quenching and tempering is a heat treatment process for metal, where steel is quenched and then tempered in a temperature area of 500-700 °C. With quenching and tempering it is possible to have steel with a good combination of tensile-, impact- and fatigue strength properties (Kivivuori, 2016 s. 84).

TABLE 5. Mechanical properties of S690QL grade steels (SFS-EN 10025-6:2019 ss. 20-21.)

	Designation		Upper yield strength R_{eH} (MPa) for thickness (mm)			Tensile strength R_m (MPa) for thickness (mm)			Percentage elongation A (%) $L_0 = 5{,}65\sqrt{S_0}$	Impact strength KV_2 (J) at -40 °C
	Steel grade	ID number	≥3 ≤50	≥50 ≤100	≥100 ≤200	3-50	50-100	≥100 ≤200	3-40	-
Standard requirements	EN 10025-2 S690QL		690	650	630	770-940	760-930	710-900	14	30
Test report values	S690 QL	21	787 ($R_{p0,2}$)		-	833	-	-	16	113

TABLE 6. Impact strength values of S690 grade (SFS-EN 10025-6:2019 s. 21.)

Steel name	Steel number	Minimum energy KV_2 (J) in temperature (°C)			
		0	-20	-40	-60
S690Q	1.8931	40	30	-	-
S690QL	1.8928	50	40	30	-
S690QL1	1.8988	60	50	40	30

TABLE 7. Chemical composition of S690QL grade steels (SFS-EN 10025-6:2019 s. 18.)

Designation		C	Si	Mn	P	S	N	B	CR	Cu	Mo	Nb	Ni	Ti	V	Zr
Grade	ID															
Standard max values EN 10025-6 S690QL		0,20	0,80	1,70	0,020	0,010	0,015	0,005	1,50	0,50	0,70	0,06	4,0	0,05	0,12	0,15
Test report values S690QL	21	0,15	0,31	1,15	0,011	0,001	0,003	0,0013	0,20	0,01	0,083	0,001	0,08	0,011	0,03	-

4 MATERIAL TESTING METHODS

Mechanical testing procedures are used to find out and verify properties of materials and make sure that the material meets the needed requirements. Material test methods are divided into non-destructive- and destructive testings, in this thesis the test methods used are mostly destructive testing. "The results of material tests are information of material that can be expressed in numbers. Testing methods are standardized, so that test results can be compared. Material behaviour in tests depends on for example about chemical composition and structure of material (Kivivuori, 2016 s. 235)."
The testing methods in this work were focused on tensile-, impact-, bend-, hardness- and microscopic examination tests, more information about these tests is outlined below.

4.1 Tensile test

An important feature of steel material is its behaviour under tensile load. These loads can be used as a basis of strength calculations. Tensile test is used to find out the material's static strength, test findings are normally yield strength, fracture strength and percentage elongation. These three properties are usually listed in the material certificate, and these properties were tested also in this thesis. Yield strength is the most important material property defined with tensile test because yield strength defines the maximum stress that the material can handle so that there is no permanent deformation in the material.
In tensile test the ends of the test piece are fixed into grips of a tensile testing machine. The test piece is strained with tensile force, usually to fracture so that mechanical properties can be defined. (SFS-EN ISO 6892-1:2016 s. 14.)

4.1.1 Stress-elongation curve

The force used in tensile test and elongation in consequence is registered to stress-elongation curve (picture 1), yield- and fracture stress are specified from this curve. Tensile force is raised until the test piece breaks, maximum force F_m is used to solve tensile strength R_m, it can be calculated from formula 1.

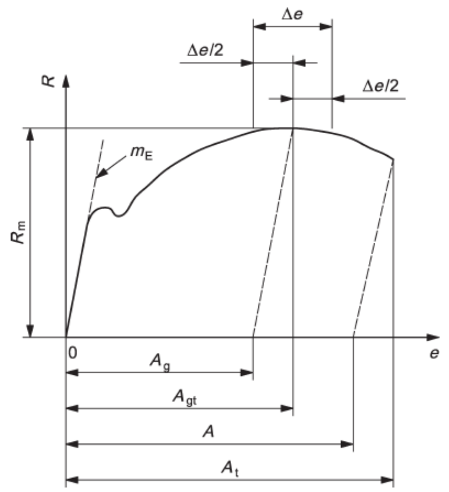
$$R_m = F_m / S_0 \quad (1)$$

Key:

R_m	Tensile strength
F_m	Maximum force
S_0	Original cross-section area of specimen

Steel materials have usually two different yield strength values in the yielding zone, those are called upper yield strength R_{eH} and lower yield strength R_{eL}. The difference between these two values for steel is normally 10-40 MPa. Stress-elongation curve can be very different for soft steel and aluminium.

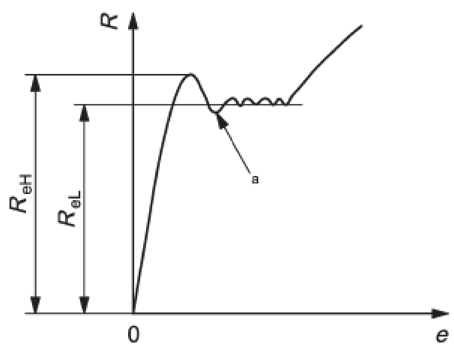
For materials that don't have a clear yield point in the stress-elongation curve, like aluminium and stainless steel, $R_{p0,2}$ limit is used, that tells the tensile which gives 0,2 % permanent elongation to material. (Suomen Hitsausteknillinen yhdistys, 2004 s. 30.) Picture 2 shows an example of a typical steel material yield zone in stress-elongation curve, where the upper- and lower yield points can be discovered.



PICTURE 1. Stress-elongation curve (SFS-EN ISO 6892-1:2016 s. 26.)

Key:

A	Percentage elongation after fracture
e	Percentage extension
m_E	Slope of the elastic part of the stress-percentage extension curve
R	Stress
R_m	Tensile strength



PICTURE 2. Example of lower and upper yield strengths (SFS-EN ISO 6892-1:2016 s. 27.)

Key:

e	Percentage extension
R	Stress
R_{eH}	Upper yield strength
R_{eL}	Lower yield strength
a	Initial transient effect

4.1.2 Percentage elongation

Elongation of material is determinated by measuring the length of the test piece after fracture compared to the start length. Original gauge length L_0 must be marked to test piece before test. After the test, broken test pieces are fitted back together so that the final gauge length can be measured. Elongation should be determined by using a measuring device with sufficient resolution. Percentage elongation after fracture can be calculated by using formula 2. (SFS-EN ISO 6892-1:2016 s. 23.)

$$A = \frac{L_u - L_0}{L_0} * 100 \qquad (2)$$

Key:

A	Percentage elongation
L_0	Original gauge length
L_u	Final gauge length after fracture

The percentage elongation of steels according to EN 10025 and IS 2062 shall be determined by using proportional test pieces having a gauge length L_0 according to formula 3, to have results that can be reliably compared, however non-proportional test pieces can also be used. When testing flat products with a thickness under 3 mm the test specimen must have a start gauge length L_0 of 80 mm and a width of 20 mm. The recommended original gauge length is usually indicated in the material standard.

$$L_0 = 5{,}65\sqrt{S_0} \qquad (3)$$

Key:

L_0	Original gauge length
S_0	Original cross-section area

If proportional test pieces are used where the original gauge length is not according to formula 3, the coefficient of proportionality used should be indicated with a subscript in symbol of percentage elongation A, for example $A_{11,3}$. The original gauge length is marked to the test piece with fine scribed lines with an accuracy of ±1 %. When using proportional test pieces, the calculated original gauge length value can be rounded to the nearest multiple of 5 mm, provided that the difference between marked and calculated gauge length is less than 10 %. (SFS-EN ISO 6892-1:2016, 2016 s. 16.)

The test piece must be done according to the standard EN ISO 377. Preparation of the test pieces should be carried out avoiding superficial work hardening and heating of the material likely to change the mechanical characteristics (SFS-EN ISO 377:2017, 2017 s. 9). Preparation can be done for example by sawing and machining. The shape, the dimensions and the tolerances of the test pieces are described in the standard EN ISO 6892-1. The cross-section of the specimen can be for example square or round, depending on the product where the specimen is obtained.

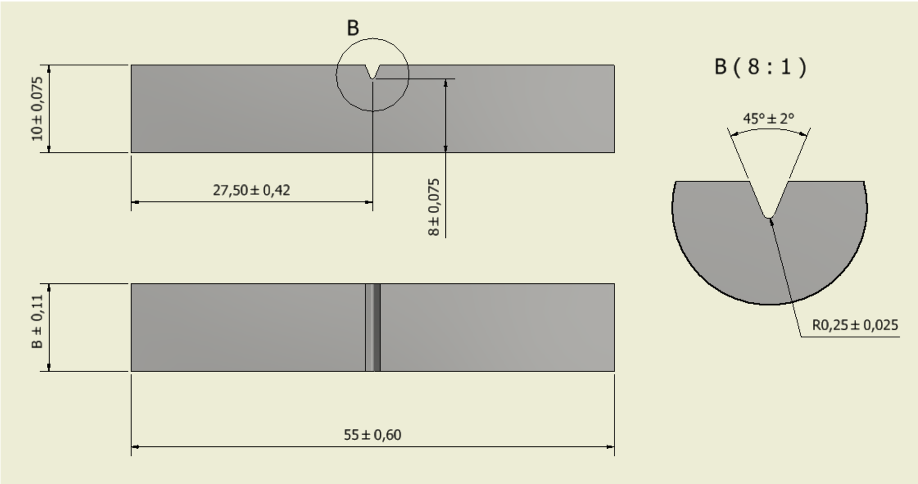
4.2 Impact test

Steel resistance against fast impact force is also an important steel feature. The material propensity for brittle fracture is possible to sort out with impact testing. Brittle fracture is a situation when cracking happens with no clear deformation. Impact test results are used for criterion of brittle and ductile fracture, usually the measured parameter is the force that is needed for fracturing of the test piece (Kivivuori, 2016 s. 243).

There are many different testing processes to measure impact strength. In this thesis the test type used was Charpy-V pendulum impact test according to the standard SFS EN ISO 148-1. The test piece of a Charpy-V test has a v-notch in the middle of the specimen, it is supported from both ends in the testing machine and broken with a swinging pendulum. Energy absorbed in the impact test is determined, also the lateral expansion and the shear fracture appearance can be determined. (SFS-EN ISO 148-1:2016 ss. 7-8.)

A standard test piece is 55 mm long with a square cross-section and 10 mm side length. If the material where the test piece is obtained, is too thin for a standard size specimen, subsize test pieces with a thickness *B* of 7,5 mm, 5 mm or 2,5 mm can be used (SFS-EN ISO 148-1:2016, 2016 s. 8). Dimensions and tolerances of the test piece according to the standard EN ISO 148-1 are shown in the picture 3, tolerance of thickness *B* is suitable for 10 mm and 7,5 mm specimens.

Test pieces with a U-shaped notch are also used in Charpy impact test, and the used notch is shown in the results with a marking: KV or KU. With these two different notches, V-notch gives lower impact test results and is used for ductile materials (Suomen Hitsausteknillinen yhdistys, 2004 s. 32). In Charpy impact test strikers with a 2 mm or 8 mm radius are used, these two different striker geometries give different results, so they should not be compared. Striker geometry that needs to be used is usually defined in the material standard, it is recommended to show the used striker radius as a subscript, for example: KV_2 or KV_8.



PICTURE 3. Drawing of Charpy-V test specimen (Paananen 2020.)

4.3 Hardness test

Hardness of material is associated to many material properties, for example strength, toughness, and durability against scratching and wearing. Hardness testing is used to measure these properties, because hardness testing as a testing process is simple and easy to carry out. Hardness of the material does not tell directly these properties of the material, however there is a connection between them. (Kivivuori, 2016 s. 216.) In an hardness test, the hardness of the material is described by how the material can resist depressions made by another harder material. Material properties vary between different materials, and that's why there are several different methods to measure the hardness of the material.
The most common hardness test methods are Vickers, Brinell and Rockwell. These methods differ from each other by measuring range and geometry of sensor head. Registration of hardness usually start with the letter H and the next letter informs the test method used. The testing method used in this work was Vickers method.

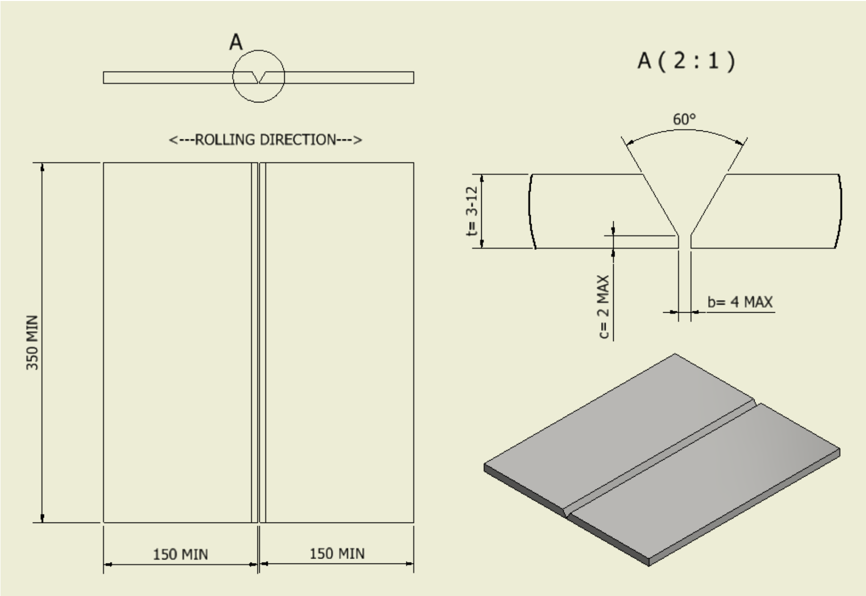
Vickers method is widely used for different materials. The geometry of a sensor head always stays the same, but the test load can be easily changed according to the need for test. Hardness is informed with test load, for example HV 10 means Vickers method with 10 kg mass. Test load masses used are usually between 0,5-150 kg. In Vickers method hardness is defined from cross-section area formed in measured surface. The measured surface must be ground, so that the light reflected from the surface to measuring microscope and makes it possible to measure the formed area precisely. Vickers method also leaves the smallest mark to the test surface, therefore it is good to use when defining hardness distribution. (Kivivuori, 2016 s. 217.)

Vickers hardness testing is specified in the standard EN ISO 6508-1. A verification and calibration of testing machines are specified in the standard EN ISO 6507-2. Hardness testings performed in this work were made for base material and for weld joints, these tests are described in the chapters 6.5 and 7.4.

5 WELDING OF TEST MATERIALS

5.1 Preparation and welding

Weld joints were made for tested steels, to explore a weldability of different steel grades. Welding of plates was performed according to the welding procedure test, that is described in the standard EN ISO 15614-1. In this work it was not necessary to meet all the welding procedure test standard requirements, but the process was suitable for preparing test pieces for material tests. The type of weld was butt joint with full penetration, welded from one side with multiple layers and using flat welding position (PA). Welding quality level for imperfection used was C according to the standard EN ISO 5817. Joint preparation used was single-v preparation (Ref. No. 1.3) and dimensions of the joint according to the standard EN ISO 9692. Dimensions of the plates and the joint preparation are shown in the picture 4.



PICTURE 4. Drawing of plates for welding (Paananen 2020.)

Preparation of plates was done by chamfering the plate edges with a milling machine, to have a good quality v-notch for robot welding. The plates were welded in HitSavonia welding laboratory with an ABB welding robot that is shown in the picture 5. Welding was performed using an ceramic backing strip to ease the welding of the root. Filler materials were chosen according to what fillers are generally used for these steels, the filler material for S355K2, E350C and E450BR grades was Esab OK AristoRod 12.50. The high strength steel S690QL was welded with a Esab OK AristoRod 69 to have a weld that is equally strong compared to the parent metal. Part of the welded test plates is shown in the picture 6. Detailed information about welds and preparations is listed in weld test reports in the tables 6-9.

PICTURE 5. ABB welding robot (Paananen 2020.)

TABLE 6. Weld report of S355K2.

Report of weld

- Parent material specification: EN 10025-2 S355K2
- Filler material specification: Esab OK AristoRod 12.50 1,0 mm
- Welding process: 135 Pulse
- Shield gas specification: EN ISO-14175-M21 (80AR/20CO_2)
- Shield gas flow: 12 L/min
- Material thickness: 12 mm
- Joint type Ref. No. (ISO 9692-1): 1.3, Single-V preparation
- Welding position: PA
- Welder/operator: TP
- Date: 2.3.2020

Test piece No.	Pass number	Current *I*	Voltage *U*	Wire feed speed	Travel speed	ALC	DYN	Oscillation		Free wire distance	Torch angle
		(A)	(V)	(m/min)	(mm/s)	%		WL	WW	(mm)	(°)
11W	1	243	27,8	13,0	7,7	0,0	0,0	3	2	20	90
11W	2-4	274	29,3	15,0	7,7	5,0	0,0	3	2	20	90

TABLE 7. Weld report of E350C.

Report of weld test

- Parent material specification: IS 2062 E350
- Filler material specification: Esab OK AristoRod 12.50 1,0 mm
- Welding process: 135 Pulse
- Shield gas specification: EN ISO-14175-M21 (80AR/20CO_2)
- Shield gas flow: 12 L/min
- Material thickness: 12 mm
- Joint type Ref. No. (ISO 9692-1): 1.3, Single-V preparation
- Welding position: PA
- Welder/operator: TP
- Date: 3.4.2020

Test piece No.	Pass number	Current I	Voltage U	Wire feed speed	Travel speed	ALC	DYN	Oscillation		Free wire distance	Torch angle
		(A)	(V)	(m/min)	(mm/s)	%		WL	WW	(mm)	(°)
32W	1	243	27,8	13,0	7,7	0,0	0,0	3	2	20	90
32W	2-4	274	29,3	15,0	7,7	5,0	0,0	3	2	20	90

TABLE 8. Weld report of E450BR.

Report of weld test

- Parent material specification: IS 2062 E450
- Filler material specification: Esab OK AristoRod 12.50 1,0 mm
- Welding process: 135 Pulse
- Shield gas specification: EN ISO-14175-M21 (80AR/20CO_2)
- Shield gas flow: 12 L/min
- Material thickness: 8 mm
- Joint type Ref. No. (ISO 9692-1): 1.3, Single-V preparation
- Welding position: PA
- Welder/operator: TP
- Date: 3.4.2020

Test piece No.	Pass number	Current I	Voltage U	Wire feed speed	Travel speed	ALC	DYN	Oscillation		Free wire distance	Torch angle
		(A)	(V)	(m/min)	(m/min)	%		WL	WW	(mm)	(°)
42W	1	206	25,1	10,5	7,7	0,0	0,0	3	2	20	90
42W	2	243	27,8	13,0	7,7	5,0	0,0	3	2	20	90

TABLE 9. Weld report of S690QL.

Report of weld test

- Parent material specification: EN 10025-6 S690QL
- Filler material specification: Esab OK AristoRod 69 1,2 mm
- Welding process: 135 Pulse
- Shield gas specification: EN ISO-14175-M21 (80AR/20CO_2)
- Shield gas flow: 12 L/min
- Material thickness: 8 mm
- Joint type Ref. No. (ISO 9692-1): 1.3, Single-V preparation
- Welding position: PA
- Welder/operator: TP
- Date: 9.3.2020

Test piece No.	Pass number	Current I	Voltage U	Wire feed speed	Travel speed	ALC	DYN	Oscillation		Free wire distance	Torch angle
		(A)	(V)	(m/min)	(mm/s)	%		WL	WW	(mm)	(°)
21W	1	192	23,1	6,4	7,7	0,0	-3,0	3	1,2	20	90
21W	2	286	26,8	9,0	7,7	5,0	-3,0	3	2	20	90

PICTURE 6. Welded E450BR and E350C plates (Paananen 2020.)

5.2 Weldability

Weldability of material can be estimated by calculating the maximum carbon equivalent value (CEV) for material. CEV can be determined using formula 4, that is defined by IIW (SFS-EN 10025-2:2019 s. 12). The maximum values for CEV are defined in material standards, and it should be calculated using material heat analysis values. Calculated CEV values for materials used in this work are listed in the table 10, the values are based on the chemical analysis of the material test reports. The table includes also maximum CEV values according to the material standards for thickness range that was tested. Generally steel is good to weld when the CEV value is less than 0,41, CEV value of 0,41-0,45 guarantees a good weldability when using filler with a low hydrogen value (Ruukki Metals Oy, 2013 s. 5). A higher CEV value may require for example pre-heating for the material to avoid cold cracking.

$$CEV = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (4)$$

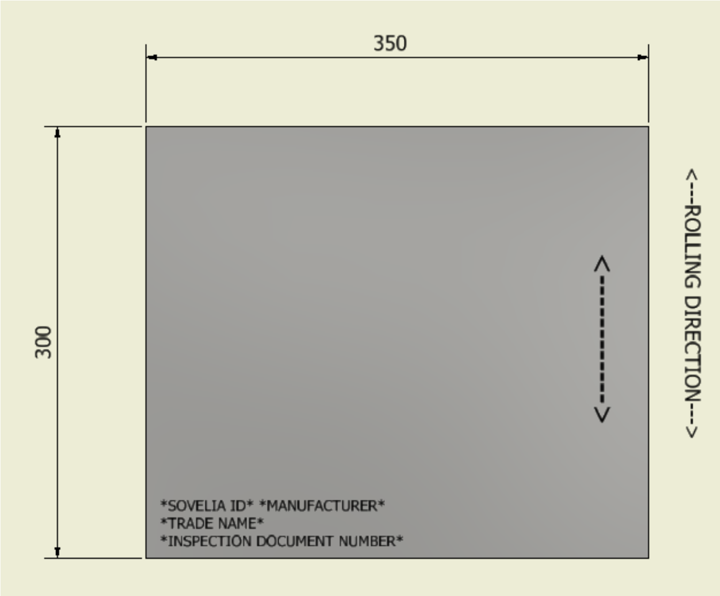
TABLE 10. CEV values (SFS-EN 10025-2:2019 s. 25) (SFS-EN 10025-6:2019 s. 19) (IS 2062, 2011 s. 3.)

Max values according to material standard	Steel grade	Steel ID number	Standard	For thickness (mm)	CEV value
	S355K2	-	EN 10025-2	≤30	0,45
	E350C	-	IS 2062	All	0,45
	E450BR	-	IS 2062	All	0,52
	S690QL	-	EN 10025-6	≤50	0,65
According to test report chemical composition	S355K2	11		12	0,40
	E350C	32		12	0,43
	E450BR	42		8	0,38
	S690QL	21		8	0,41

6 TEST PROCEDURE

6.1 Sample plates

The sample plates were ordered in 300x350 mm size plates, drawing of sample plate is shown in picture 7. To identify plates, information marked to the plate was: Sovelia PDM number, steel manufacturer, steel trade name and inspection document number. It is important that rolling direction of the material is like shown in drawing, so that it is possible to manufacture test pieces in the required orientation relative to rolling direction. The test pieces from plate of this size are easy to obtain with a band saw and the plates for welded butt joint can be made by cutting the plate in half.



PICTURE 7. Drawing of sample plate (Paananen 2020.)

6.2 Identification of test pieces

Every test piece was marked with an identification code according to the table 11. This identification system was used because the number of the test specimens manufactured and tested was quite high and it makes also easy to mark and identify the small test pieces like in Charpy V-test.

TABLE 11. Test piece identification.

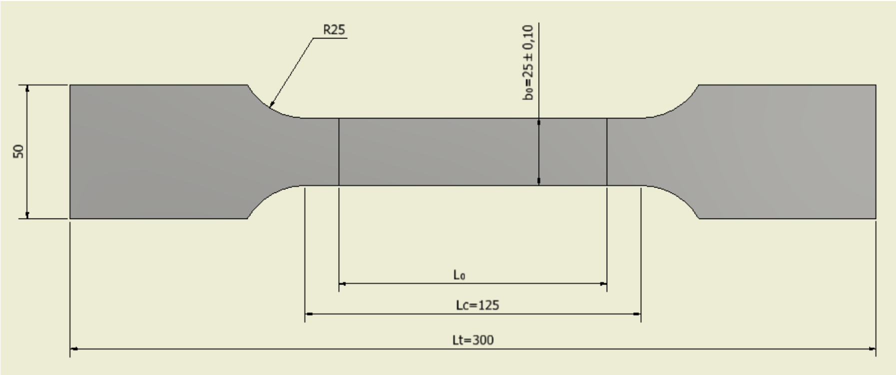
Steel grade	EN 10025-2 S355K2 = 1	EN 10025-6 S690QL Strenx 700 E = 2	IS 2062 E350C = 3	IS 2062 E450BR = 4
Manufacturer	SSAB = 1		Other (India) = 2	
Welded	Yes=W No=-			
Test method	Tensile = T, Impact = I, Bend = B, Hardness = H, Macroscopic = M			
Test piece number of series	1-5			
For example: S355K2 manufactured by SSAB, welded plate tensile test specimen No.1 from test series. ID = 11WT1				

6.3 Tensile test

Tensile test was performed according to the standard SFS-EN ISO 6892-1, steel manufacturer can choose between methods A or B for the test, the difference between these methods is in the testing speed in different areas of elongation (SFS-EN ISO 6892-1:2016 s. 95). For steels S355K2, E350C and E450BR the yield strength is measured in a upper yield strength R_{eH}. With high strength steels like S690QL, upper and lower yield phenomenon is not usually presented, therefore with these materials the 0,2 % proof strength $R_{p0,2}$ is used. The original gauge length L_0 used for determination of the percentage elongation A is $5{,}65\sqrt{S_0}$ for all materials, to have a results that can be equally compared, L_0 for 8 mm plate was 80 mm and for 12 mm plate 100 mm.

Drawing of the tensile test piece is shown in picture 8. The test pieces used were full section test pieces, where the thickness is the original thickness of the plate.

Width of the cross-section b_0 is 25 mm, which is typical width for a flat test piece, it is also same size as the specimen used for testing welded plates. The cross-section area S_0 is calculated from these two dimensions. The tensile test pieces were manufactured using parallel length L_c of 125 mm for both 8 mm and 12 mm test pieces and using 25 mm roundings in the area where the parallel length connects the gripped ends. This makes it possible to manufacture all the tensile test pieces according to the standard from base- and welded material with the same machining program.



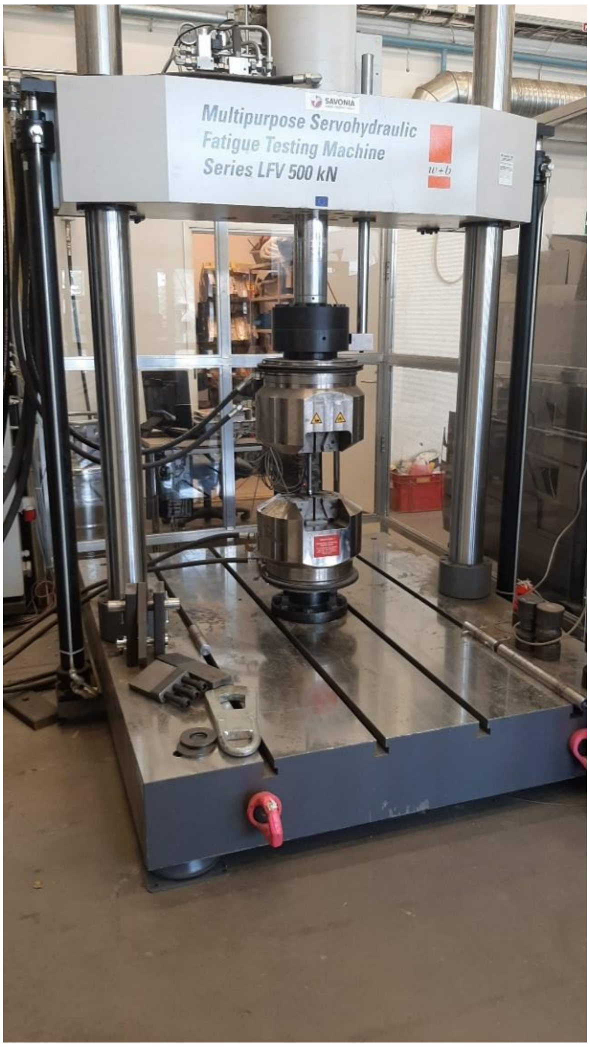
PICTURE 8. Drawing of tensile test piece (Paananen 2020.)

Key:

L_0	Original gauge length
L_c	Parallel length
Lt	Approximately total length
b_0	Width of the cross-section

A part of machined tensile test specimens is presented in picture 9. Tensile testing was performed in HitSavonia laboratory with a Walter+Bai AG LFV 500 kN -testing machine (picture 10). The tensile test results for different steel grades are shown in tables 12-15. Percentage elongation values were rounded to the nearest 0,5 % (SFS-EN ISO 6892-1:2016 s. 103). Tensile test reports of base materials are shown in the appendices 1-20.

PICTURE 9. Part of tensile test specimens (Paananen 2020.)



PICTURE 10. Testing machine used for tensile tests (Paananen 2020.)

TABLE 12. Tensile test results of S355K2.

Tensile test (EN ISO 6892-1:2016, B)

Temperature:	20 °C
Steel grade:	EN 10025-2 S355K2 1.0596
Product:	Plate 12x300x350
Orientation of test pieces:	Longitudal

Test piece number	Thickness *a*	Widht *b0*	Cross-section area S_0	Maximum force *Fm*	Lower yield strenght *ReL*	Upper yield strenght *ReH*	Tensile strenght *Rm*	Original gauge lenght *L0*	Final gauge lenght *Lu*	Percentage elongation *A*
	(mm)	(mm)	(mm^2)	(kN)	(MPa)	(MPa)	(MPa)	(mm)	(mm)	(%)
11T1	12,25	25	306,25	176,35	442	459	576	100	125,0	25,0
11T2	12,25	25	306,25	177,25	-	-	579	100	124,5	24,5
11T3	12,25	25	306,25	178,05	447	454	581	100	124,5	24,5
11T4	12,25	25	306,25	178,48	448	455	583	100	124,5	24,5
11T5	12,25	25	306,25	178,54	450	453	583	100	124,5	24,5
Average					447	455	580			24,6
Standard requirements (for thickness 12 mm)					-	355	470-630			20,0

TABLE 13. Tensile test results of E350C.

Tensile test (EN ISO 6892-1:2016, B)

Temperature: 20 °C
Steel grade: IS 2062 E350
Product: Plate 12x300x350
Orientation of test pieces: Longitudal

Test piece number	Thickness *a*	Widht *b0*	Cross-section area S_0	Maximum force *Fm*	Lower yield strenght *ReL*	Upper yield strenght *ReH*	Tensile strenght *Rm*	Original gauge lenght *L0*	Final gauge lenght *Lu*	Percentage elongation *A*
	(mm)	(mm)	(mm^2)	(kN)	(MPa)	(MPa)	(MPa)	(mm)	(mm)	(%)
32T1	12	25	300	159,9	388	391	533	100	129,0	29,0
32T2	12	25	300	159,8	388	390	533	100	129	29,0
32T3	12	25	300	159,9	385	400	533	100	130	30,0
32T4	12	25	300	159,9	383	400	533	100	130	30,0
32T5	12	25	300	160,3	385	403	534	100	130	30,0
Average					386	397	533			29,6
Standard requirements (for thickness <20 mm)					-	350	490			22,0

TABLE 14. Tensile test results of E450BR.

Tensile test (EN ISO 6892-1:2016, B)

Temperature: 20 °C
Steel grade: IS 2062 E450
Product: Plate 8x300x350
Orientation of test pieces: Longitudal

Test piece number	Thickness *a*	Widht *b0*	Cross-section area S_0	Maximum force *Fm*	Lower yield strenght *ReL*	Upper yield strenght *ReH*	Tensile strenght *Rm*	Original gauge lenght *L0*	Final gauge lenght *Lu*	Percentage elongation *A*
	(mm)	(mm)	(mm^2)	(kN)	(MPa)	(MPa)	(MPa)	(mm)	(mm)	(%)
42T1	8	25	200	104,4	411	428	522	80	105,0	31,0
42T2	8	25	200	103,8	407	423	519	80	105	31,0
42T3	8	25	200	103,3	405	420	516	80	104	30,0
42T4	8	25	200	102,1	396	414	510	80	104	30,0
42T5	8	25	200	103,1	404	420	516	80	104	30,0
Average					405	421	517			30,4
Standard requirements (for thickness <20 mm)					-	450	570			20,0

TABLE 15. Tensile test results of S690QL.

Tensile test (EN ISO 6892-1:2016, B)

Temperature: 20 °C
Steel grade: EN 10025-6 S690QL 1.8928
Product: Plate 8x300x350
Orientation of test pieces: Longitudal

Test piece number	Thickness *a*	Widht *b0*	Cross-section area S_0	Maximum force *Fm*	0,2% Proof strenght $Rp_{0,2}$	Upper yield strenght *ReH*	Tensile strenght *Rm*	Original gauge lenght *L0*	Final gauge lenght *Lu*	Percentage elongation *A*
	(mm)	(mm)	(mm^2)	(kN)	(MPa)	(MPa)	(MPa)	(mm)	(mm)	(%)
21T1	8	25	200	162,0	741	-	810	80	95,5	19,4
21T2	8	25	200	163,1	698	-	815	80	93,0	16,3
21T3	8	25	200	163,1	730	-	816	80	93,0	16,3
21T4	8	25	200	163,0	743	-	815	80	94,5	18,1
21T5	8	25	200	161,9	738	-	810	80	93,0	16,3
Average					738		813			17,3
Standard requirements (For thickness 3-50 mm)					690	690	770-940			14,0

6.4 Impact test

Impact test was performed in the material technology laboratory of Savonia University of Applied sciences, with a Charpy impact testing instrument which have an initial potential energy K_p of 150 J and striker with a 2 mm rounding. The test pieces were prepared and machined in Savonia machining laboratory, a part of finished test pieces is shown in picture 11.

PICTURE 11. Charpy-V impact test specimens (Paananen 2020.)

The testing temperature for EN 10025-2 S355K2 and IS 2062 E350C steel is -20 °C. The sample plates ordered had a thickness of 12 mm and the test pieces manufactured were standard size 10x10 mm specimens, with dimensions according to the picture 3. A set of five test pieces were tested, and the average impact value calculated. The impact test temperature for IS 2062 E450BR is room temperature (20 °C) according to the material standard, however this steel was tested also in -20 °C to see the differences of impact strength in different temperatures, a set of three test pieces were tested in both temperatures. The test temperature for EN 10025-6 S690QL steel is -40 °C, when the minimum requirement for impact strength is 40 J.

S690QL and E450BR plates ordered had a thickness of 8 mm, hence sub size test pieces were manufactured with a thickness B of 7,5 mm. When using subsize test pieces, the impact force decreases in relation to the test piece cross-section area, however impact test done with different-sized specimens can not be directly compared (SFS-EN ISO 148-1:2016 s. 40). Impact test results are listed in the tables 16-19. Impact absorbed energy K, should not exceed 80 % of initial potential energy K_p, if this happens it should be noted in the test report as exceeding 80 % of the machine capacity (SFS-EN ISO 148-1:2016 s. 43). Fracture surfaces of impact test specimens are shown in the picture 12.

TABLE 16. Results of S355K2 impact test.

Charpy-V impact test	(EN ISO 148-1:2016)		
Steel grade	EN 10025-2 S355K2		
Product:	Plate 12x300x350 mm		
Orientation of test pieces:	Longitudal		
Specimen dimensions:	10x10x55 mm		
Test temperature:	-20 °C		
Test specimen	**Impact absorbed energy *K***	**Impact toughness *KV* 2**	**Remarks**
ID Number	(J)	(J/cm^2)	
11I1	70	70	
11I2	145	145	Exceed 80 % of *Kp*
11I3	54	54	
11I4	80	80	
11I5	89	89	
Average	88	**88**	
Requirements according to EN 10025-2: S355K2 for thickness <150 mm			
Min		40	
Manufacturer test certificate value:		160	

TABLE 17. Results of E350C impact test.

Charpy-V impact test	(EN ISO 148-1:2016)		
Steel grade	IS 2062 E350C		
Product:	Plate 12x300x350 mm		
Orientation of test pieces:	Longitudal		
Specimen dimensions:	10x10x55 mm		
Test temperature:	-20 °C		
Test specimen	**Impact absorbed energy *K***	**Impact toughness *KV* 2**	**Remarks**
ID Number	(J)	(J/cm^2)	
32I1	82	82	
32I2	51	51	Exceed 80 % of *Kp*
32I3	52	52	
32I4	112	112	
32I5	111	111	
Average	82	**82**	
Requirements according to standard IS 2062			
Min		27	
Manufacturer test certificate value:		51	

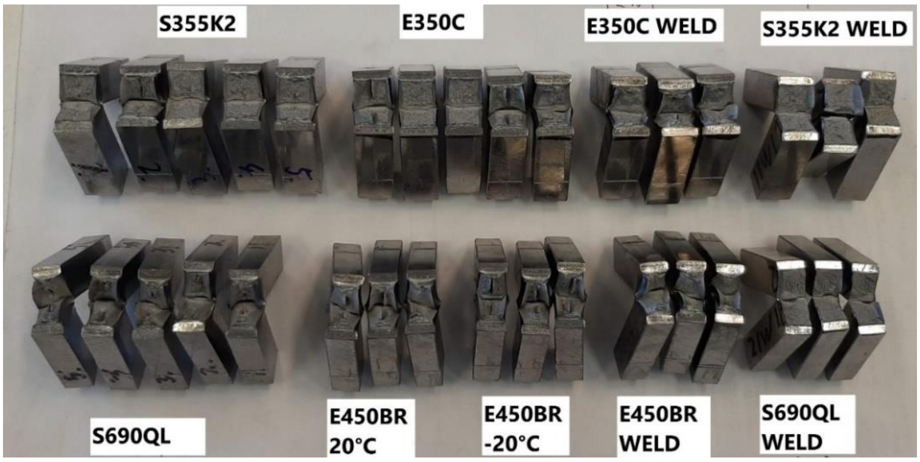
TABLE 18. Results of E450BR impact test.

Charpy-V impact test	(EN ISO 148-1:2016)			
Steel grade	IS 2062 E450BR			
Product:	Plate 8x300x350 mm			
Orientation of test pieces:	Longitudal			
Specimen dimensions:	7,5x10x55 mm			
Test specimen	**Test temperature**	**Impact absorbed energy *K***	**Impact toughness *KV* 2**	**Remarks**
ID Number	°C	(J)	(J/cm^2)	
42I1	20	120	150	
42I2	20	145	181	Exceed 80 % of *Kp*
I42I3	20	112	140	
Average	**20**		**157**	
42I4	-20	105	131	
42I5	-20	95	119	
42I6	-20	115	144	
Average	**-20**		**131**	
Requirements according to IS 2062: E450BR at 20°C				
Min			25	
Manufacturer test certificate value:			140	

TABLE 19. Results of S690QL impact test.

Charpy-V impact test	(EN ISO 148-1:2016)
Steel grade	EN 10025-6 S690QL
Product:	Plate 8x300x350 mm
Orientation of test pieces:	Longitudal
Specimen dimensions:	7,5x10x55 mm
Test temperature:	-40 °C

Test specimen	**Impact absorbed energy *K***	**Impact toughness KV_2**	**Remarks**
ID Number	(J)	(J/cm^2)	
21I1	136	181	Exceed 80 % of *Kp*
21I2	88	117	
21I3	136	181	Exceed 80 % of *Kp*
21I4	116	155	
21I5	139	185	Exceed 80 % of *Kp*
Average	123	**164**	
Requirements according to: EN 10025-6 S690QL at -40 °C			
Min		40	
Manufacturer test certificate value:		144	



PICTURE 12. Fracture surface of impact test specimens (Paananen 2020.)

6.5 Hardness test

Hardness test was done according to the standard EN ISO 6507-1. The test method used was Vickers HV10, where the nominal test force is 98,07 N. Testing was performed in Savonia material technology laboratory using Stuers Duran Scan- hardness testing machine (picture 13). Results of material hardness testings is shown in the diagram 1, hardness values are the average of three measures.

PICTURE 13. Stuers hardness testing machine (Paananen 2020.)

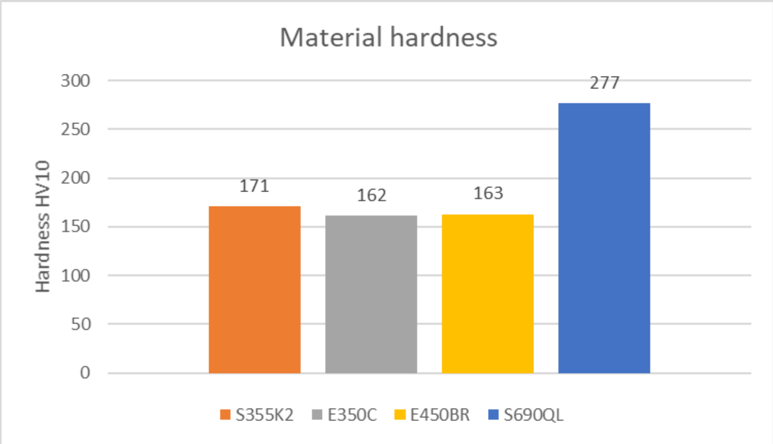
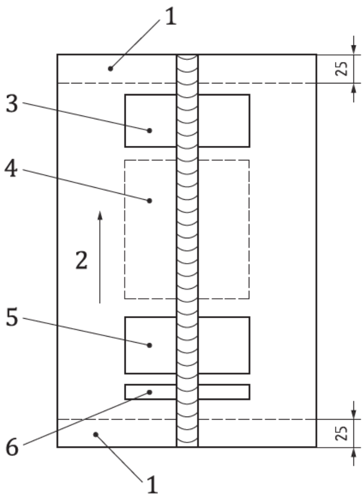


DIAGRAM 1. Hardness test results.

7 MATERIAL TESTING OF WELDED PLATES

Material tests for welded plates were done according to the welding procedure test standard EN ISO 15614-1, level 2. The test pieces were obtained from butt welded plate from given locations, that are shown in the picture 14.



PICTURE 14. Location of test specimens. (SFS-EN ISO 15614-1:2017 + A1:2019 s. 15.)

Key:

1:	Removed area
2	Welding direction
3	Area for 1 tensile test and bend test specimen
4	Area for impact specimens
5	Area for 1 tensile test and bend test specimens
6	Area for 1 macro and hardness test specimens

7.1 Tensile test

Tensile test for welded plates was done according to the standard EN ISO 4136 and EN ISO 6892-1. Testing process is corresponding to non-welded materials, and the standard EN ISO 4136 includes additional information about preparation of the test pieces from welded material.

"Test piece should be taken transversely from the welded joint in such a way, that after machining, the weld is in the middle of the test piece. Mechanical cutting should not be used for thicknesses over 8 mm, and when using thermal cutting, the cutting line should not be closer than 8mm of the final surface of test piece (SFS-EN ISO 4136, 2012 s. 10)."

Surfaces of the test pieces were machined so that all excess weld metal was removed, and plate surfaces were parallel. Only a necessary amount of material was removed so that test piece thickness was as close as possible of the original plate thickness. Original gauge length L_0 was calculated from thickness of machined surfaces according to the formula 2, other dimensions and tolerances of specimens were according to the picture 8.

Standard EN ISO 4136 define the tensile test piece grip end width to be *b*+12 mm, however in this thesis all the tensile test specimens were manufactured with the same dimensions, and the grip end width used was 50 mm. This width was selected because the machining jig used was designed for a 50 mm test piece. The results of tensile tests are listed in the table 18, testing was made for series of two specimens. The reports of tensile tests for welded plates are shown in the appendices 21-28. According to the standard EN ISO 15614-1, tensile strength of the welded test piece should not be less than the minimum value of parent material used.

TABLE 18. Tensile test results of welded plates.

Tensile test (EN ISO 6892-1:2016, B)				
Test piece ID	11WT	32WT	42WT	21WT
Steel grade	S355K2	E350C	E450BR	S690QL
Material standard	EN 10025-2	IS 2062	IS 2062	EN 10025-6
Product	Plate 12x300x350 mm		Plate 8x300x350 mm	
Orientation of test piece	Longitudal			
Filler material	Esab OK AristoRod 12.50			Esab OK AristoRod 69
Test temperature	20 °C			

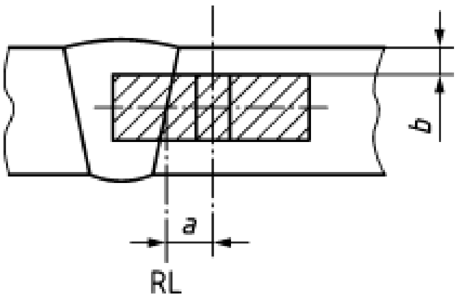
Test piece number	**Thickness *a***	**Widht b_0**	**Cross-section area S_0**	**Maximum force *Fm***	**0,2% Proof strenght *Rp0,2***	**Lower yield strenght *ReL***	**Upper yield strenght *ReH***	**Tensile strenght *Rm***	**Original gauge lenght L_0**	**Final gauge lenght *Lu***	**Percentage elongation *A***
	(mm)	(mm)	(mm^2)	(kN)		(MPa)	(MPa)	(MPa)	(mm)	(mm)	(%)
11WT1	10,25	25	256,25	150,04	434	429	438	586	90	109	21
11WT2	10,60	25	265,00	154,22	435	430	440	582	90	110	22
Average						430	439	584			22
Base material result							455	580			25
32WT1	11,15	25	278,75	150,09	389	394	404	538	90	110	22
32WT2	11,10	25	277,50	149,81	388	393	397	540	90	110	22
Average						394	401	539			22
Base material result							397	533			30
42WT1	7,00	25	175,00	95,76	394	-	-	547	75	90	20
42WT2	7,00	25	175,00	97,48	399	431	434	557	75	90	20
Average						216	434	552			20
Base material result							421	517			30
21WT1	7,05	25	176,25	143,46	655	-	-	814	75	83	11
21WT2	6,90	25	172,50	139,80	650	-	-	810	75	83	11
Average					653	0	0	812			11
Base material result					738			813			17

7.2 Impact test

Impact test for welded plates was done in the same way as for the non-welded plates, Charpy pendulum impact test is described in the standard EN ISO 148-1 and for welded material, standard EN ISO 9016 includes additional information about the testing process and orientation of test pieces. Dimensions of the test pieces were according to the picture 3.

Test pieces were obtained from plates in transverse direction relative to weld, v-notch trough the thickness (T-position) and position of notch center in fusion/joint line. Test notch of the test piece was positioned to fusion/joint line to see differences between materials in the heat affected zone.
The distance between the fusion line and notch center point should be 1-2 mm (SFS-EN ISO 15614-1:2017 + A1:2019 s. 19). The position of the test piece was as shown in the picture 15, denomination for this position is VHT a/b, where *a* is the distance from notch center to fusion line and *b* is the distance between the test piece and the plate surface (SFS-EN ISO 9016, 2012 s. 12). The set of three test specimens were manufactured and tested from each material, the results of welded material impact test are listed in the table 19.

Denomination for test pieces were:
-S355K2 and E350C: VHT 1/1
-S690QL and E450BR: VHT 1/0,25



PICTURE 15. VHT position for impact test pieces. (SFS-EN ISO 9016, 2012 s. 12.)

TABLE 19. Impact test results of welded plates.

Impact test Charpy-V (EN ISO 148-1:2016)				
Test piece ID	11WI	32WI	42WI	21WI
Steel grade	S355K2	E350C	E450BR	S690QL
Material standard	EN 10025-2	IS 2062	IS 2062	EN 10025-6
Product	Plate 12x300x350 mm		Plate 8x300x350 mm	
Orientation of test piece	VHT 1/1		VHT 1/0,25	
Filler material	Esab OK AristoRod 12.50			Esab OK AristoRod 69
Test temperature	-20 °C	-20 °C	20 °C	-40 °C

Test specimen	**Specimen dimensions**	**Test temperature**	**Impact absorbed energy *K***	**Impact toughness *KV*$_2$**	**Remarks**
ID Number	(mm)	(°C)	(J)	(J/cm^2)	
11WI1	10x10x55	-20	49	49	
11WI2	10x10x55	-20	41	41	
11WI3	10x10x55	-20	44	44	
Average			45	**45**	
Parent metal test result average:				88	
32WI1	10x10x55	-20	130	130	Exceed 80 % of *Kp*
32WI2	10x10x55	-20	148	148	Exceed 80 % of *Kp*
32WI3	10x10x55	-20	143	143	Exceed 80 % of *Kp*
Average			140	**140**	
Parent metal test result average:				82	
42WI1	7,5x10x55	20	145	181,25	Exceed 80 % of *Kp*
42WI2	7,5x10x55	20	143	178,75	Exceed 80 % of *Kp*
42WI3	7,5x10x55	20	146	182,5	Exceed 80 % of *Kp*
Average			145	**181**	
Parent metal test result average:				157	
21WI1	7,5x10x55	-40	25	31	
21WI2	7,5x10x55	-40	25	31	
21WI3	7,5x10x55	-40	25	31	
Average			25	**31**	
Parent metal test result average:				164	

7.3 Bend test

Bending test is used to estimate the forming properties of weld metal and heat affected zone. It reveals faults in close to weld surface, especially in root side. Forming is done with three-point bending, the test piece is placed on two support rollers so that the weld is in the middle point, the test piece is bent with a plunger with a prescribed radius. (Suomen Hitsausteknillinen yhdistys, 2004 s. 35.)

The bending test was done according to the standard EN ISO 5173 and EN ISO 15614-1. Four bending tests were done from each weld, two transverse face bend tests (TFBB) and two root bend tests (TRBB) were done for the 8mm plate. When testing materials with a thickness of 12 mm or greater, it is also possible to use four side bend (SBB) specimens instead of root and face bend tests. (SFS-EN ISO 15614-1:2017 + A1:2019 s. 18). These side bend test pieces were used with 12 mm plates, with side bend test the test piece thickness should be (10 ± 0,5) mm.

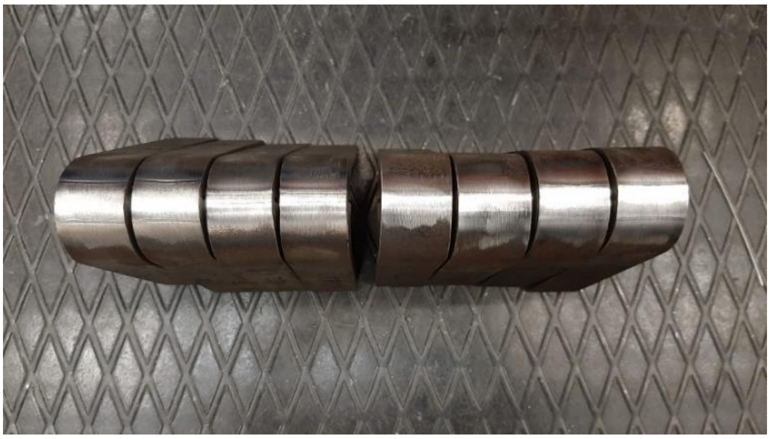
With face- and root bend tests, plate surfaces should be machined so that all excess weld metal is removed. When testing plates with a thickness greater than 10 mm, plate thickness can be machined to dimension (10 ± 0,5) mm, a width of the test pieces made from plate shall be 4 times plate thickness or greater.

The distance between support rollers can be calculated from formula 5 (SFS-EN ISO 5173 + A1, 2012 s. 26). During the bend test, there should not be faults greater than 3 mm in any direction in the test piece (SFS-EN ISO 15614-1:2017 + A1:2019, 2019 s. 18). The report of bend test is shown in table 20 and part of bent test pieces is shown in the picture 16. There was no faults in any weld that could have been noted from bend test pieces.

$$d+2t_s+3<l<d+3t_s \quad (5)$$

Key:

d	Diameter of plunger
t_s	Thickness of test plate
l	Distance between support rollers



PICTURE 16. S690QL and E450BR bend test pieces (Paananen 2020.)

TABLE 20. Bend test report.

Bend test (EN ISO 5173:2009)				
Test piece ID	11WB	32WB	42WB	21WB
Steel grade	S355K2	E350C	E450BR	S690QL
Material standard	EN 10025-2	IS 2062	IS 2062	EN 10025-6
Product	Plate 12x300x350 mm		Plate 8x300x350 mm	
Filler metal	Esab OK AristoRod 12.50			Esab OK Aristo-Rod 69
Test tempe-rature	20 °C			

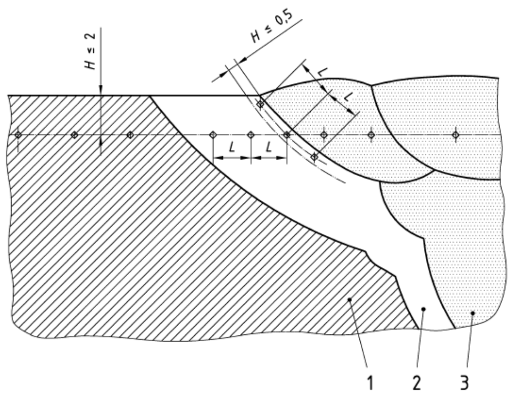
Test piece number	**Type of test**	**Dimensions**	**Former diameter**	**Distance between rollers**	**Bend angle**	**Remark**
		(mm)	(mm)	(mm)	(°)	
11WB1	SBB	10x12	40	63	160	OK
11WB2	SBB	10x12	40	63	160	OK
11WB3	SBB	10x12	40	63	160	OK
11WB4	SBB	10x12	40	63	160	OK
32WB1	SBB	10x12	40	63	160	OK
32WB2	SBB	10x12	40	63	160	OK
32WB3	SBB	10x12	40	63	160	OK
32WB4	SBB	10x12	40	63	160	OK
42WB1	TFBB	8X32	32	52	160	OK
42WB2	TFBB	8X32	32	52	160	OK
42WB3	TRBB	8X32	32	52	160	OK
42WB4	TRBB	8X32	32	52	160	OK
21WB1	TFBB	8X32	32	52	160	OK
21WB2	TFBB	8X32	32	52	160	OK
21WB3	TRBB	8X32	32	52	160	OK
21WB4	TRBB	8X32	32	52	160	OK

7.4 Hardness test

The hardness test for weld joint was done according to the standards EN ISO 9015-1 and EN ISO 6507-1. The test pieces were obtained from the welded plate with a band saw and the test piece location was according to the picture 14. Test piece surface was ground and etched, so that it is possible to identicate different zones in weld joint.
Hardness testing was procedured with a Vickers HV10 test, where the test load is 98,07 N. When testing butt welds welded from one side with a single- or multi-run, and when the weld thickness is over 5 mm, indentation rows shall be made to the both sides of test piece. Indentation rows depth from plate surface should not be greater than 2 mm. Each row should include at least three individual indentations in weld area, both heat affected zones (HAZ) and both parent metal areas. (SFS-EN ISO 15614-1:2017 + A1:2019 s. 19.)

Locations of the individual indentations are shown in the picture 17. Recommended distance between indentations *L*, in heat affected zone for ferrous metal is 1 mm (SFS-EN ISO 9015-1, 2011 s. 12). The results of hardness tests are listed in the tables 21 and 22, which include also picture about numbering of indentation series locations. Diagrams 2 and 3 show the changes in hardness through weld with 15 test points.

According to the standard (CEN ISO/TR 15608:2017:fi, 2017 s. 6) steel grades S355K2, E350C and E450BR belongs to material group 1, and steel grade S690QL to group 3. Maximum HV10 hardness values for steel group 1 is 380 and for group 3 steel 450 (SFS-EN ISO 15614-1:2017 + A1:2019 s. 20). Hardness in all the tested welds remained below the standard limit.



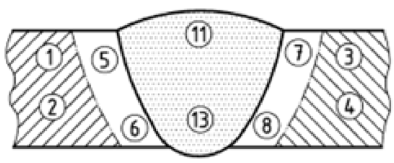
PICTURE 17. Location of indentations in ferrous material butt weld (SFS-EN ISO 9015-1, 2011 s. 20.)

Key:

1	Parent metal
2	Heat affected zone
3	Weld

TABLE 21. Report of hardness test for materials S355K2 and E350C.

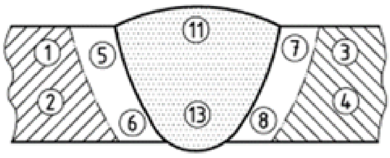
Type of hardness test:	Vickers HV10 (ISO 9015-1, ISO 6507-1)
Thickness of material:	12 mm
Type of weld:	V-notch butt joint, multi-layer
Welding process:	135
Consumable:	Esab OK AristoRod 12.50



			S355K2		E350	
		Area	Hardness values HV10	Average HV10	Hardness values HV10	Average HV10
Parent metal	Unaffected metal	1	180/178/175	178	180/179/187	182
		2	185/190/188	188	173/180/176	176
		3	181/181/181	181	210/182/168	187
		4	187/185/182	185	178/182/186	182
	HAZ	5	245/280/293	273	178/200/162	180
		6	202/219/266	229	189/202/220	204
		7	294/278/221	261	222/246/233	234
		8	275/242/211	243	208/205/184	199
Weld metal		11	214/216/218	216	231/213/212	219
		13	242/232/240	238	208/209/205	207

TABLE 22. Report of hardness test for materials S690QL and E450BR.

Type of hardness test:	Vickers HV10 (ISO 9015-1, ISO 6507-1)
Thickness of material:	8 mm
Type of weld:	V-notch butt joint, multi-layer
Welding process:	135
Consumable:	Esab OK AristoRod 12.50 / AristoRod 69



			S690QL		E450	
		Area	Hardness values HV10	Average HV10	Hardness values HV10	Average HV10
Parent metal	Unaffected metal	1	265/270/271	269	177/183/196	185
		2	282/277/269	276	176/176/183	178
		3	280/285/283	283	172/175/175	174
		4	274/282/281	279	175/179/174	176
	HAZ	5	227/271/262	253	229/210/211	217
		6	223/234/298	252	189/210/234	211
		7	266/277/215	253	202/182/180	188
		8	267/303/225	265	225/194/186	202
Weld metal		11	254/261/254	256	212/210/226	216
		13	265/266/261	264	217/216/218	217

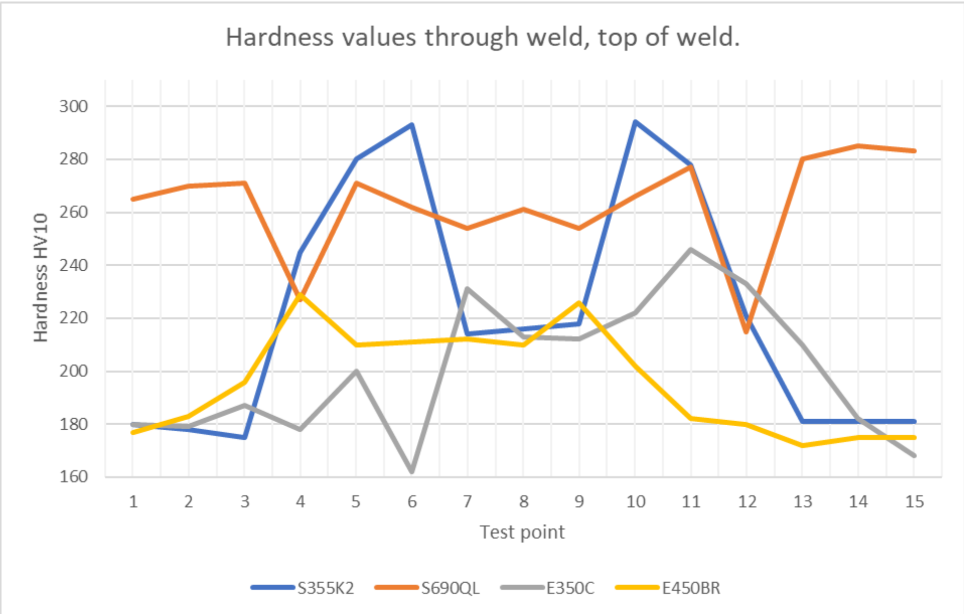


DIAGRAM 2. Weld hardness values, top side of weld.

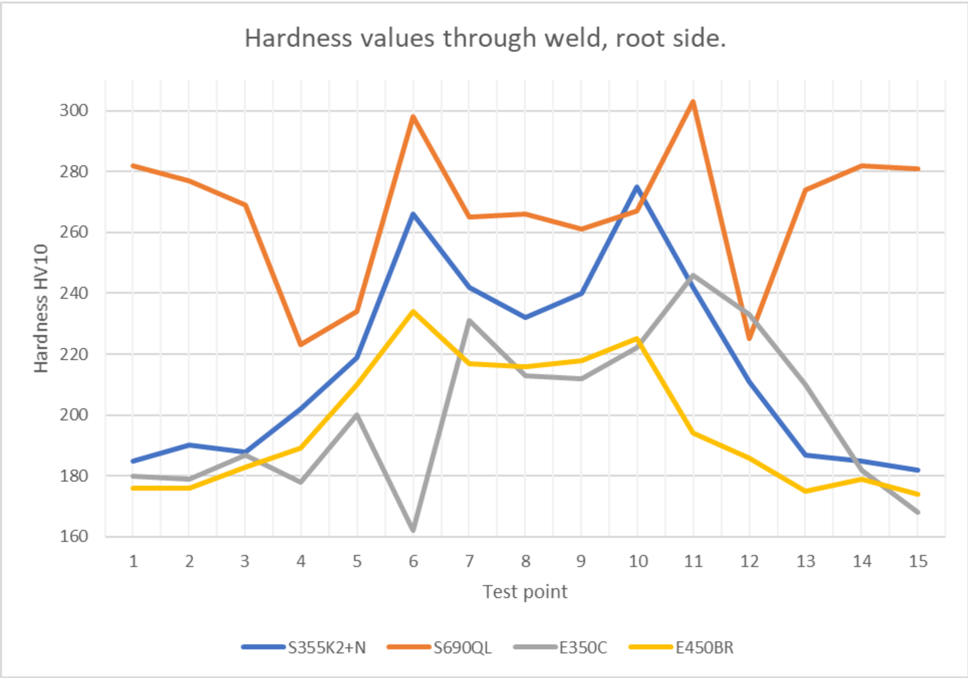
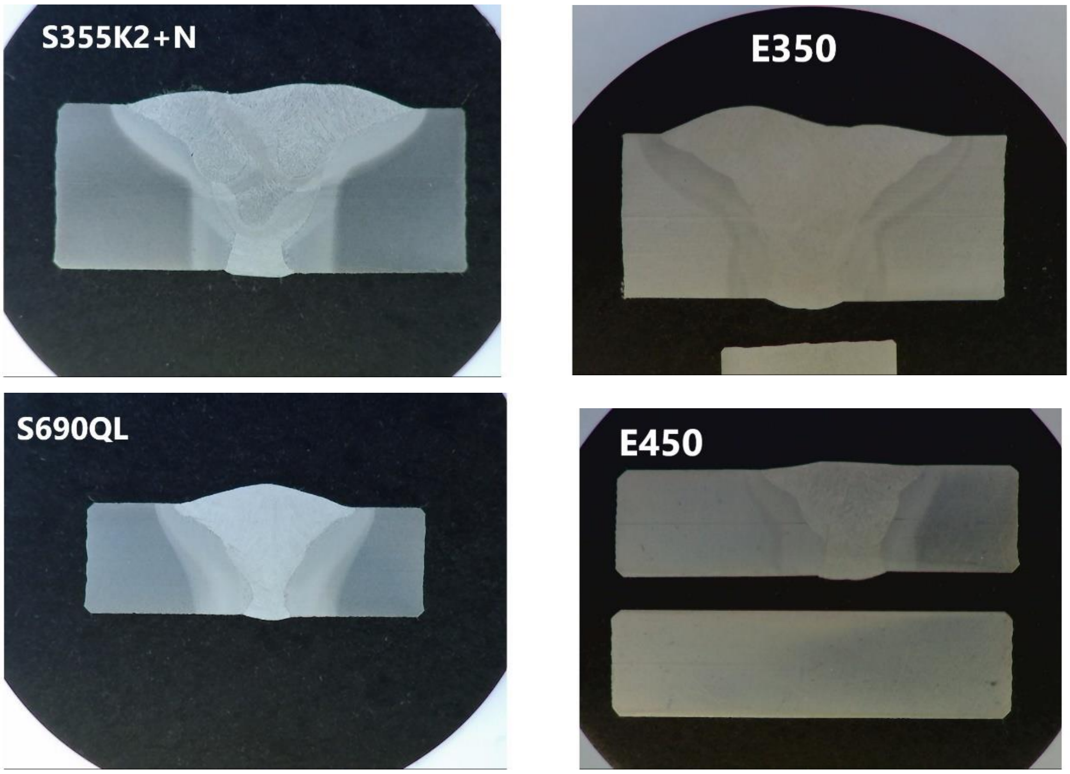


DIAGRAM 3. Weld hardness values, root side.

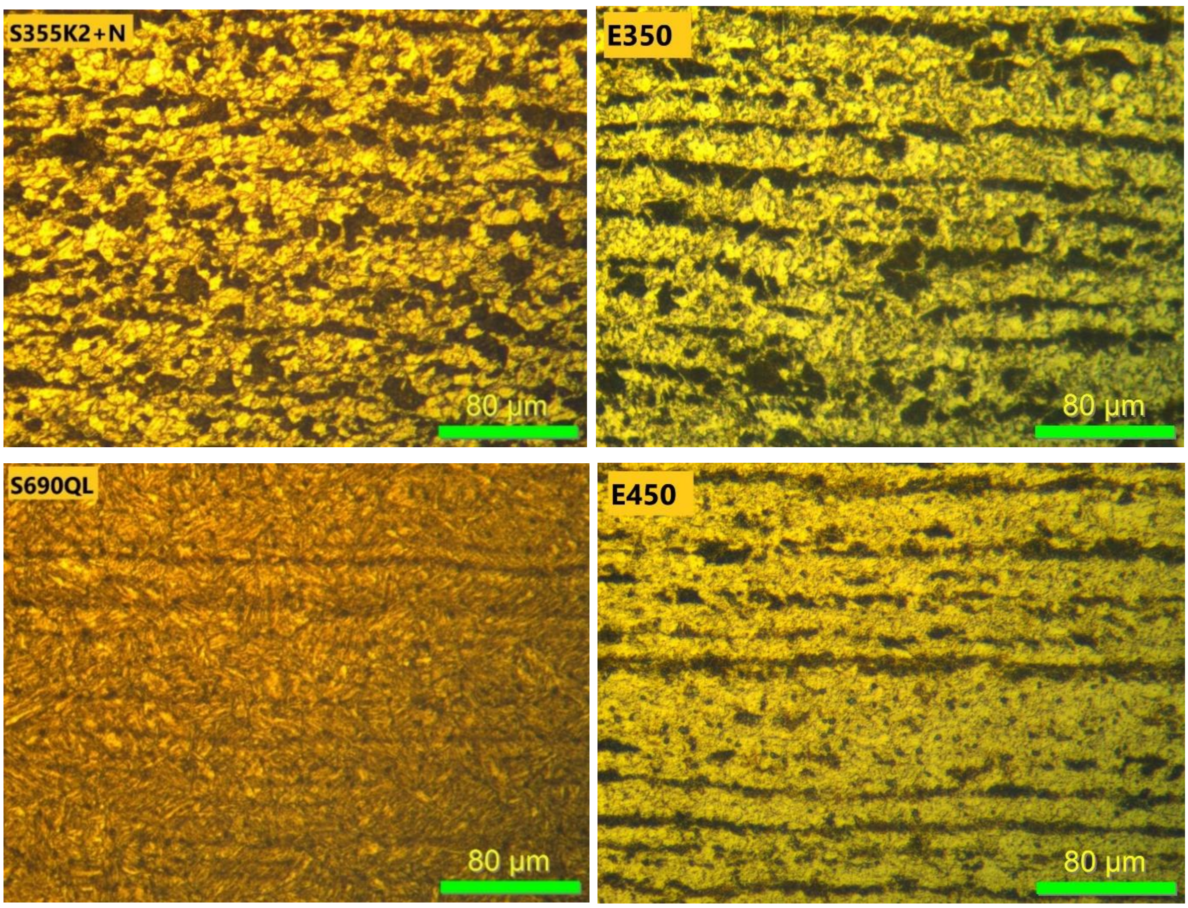
7.5 Micro- and macroscopic examination

Macroscopic examination is used to assess material and weld joint structure. Test specimens are oriented perpendicular to the weld axis, including the weld deposit and both heat affected zones (SFS-EN ISO 17639, 2013 s. 10.) The test specimens were cast to a plastic mass, so that cross-section of the weld joint was in the top of the sample. Surface of the test piece was grinded with a abrasive papers up to grit 1200 and then polished. Surface of polished test piece was etched with etchant fluid, to separate different zones in weld joint.

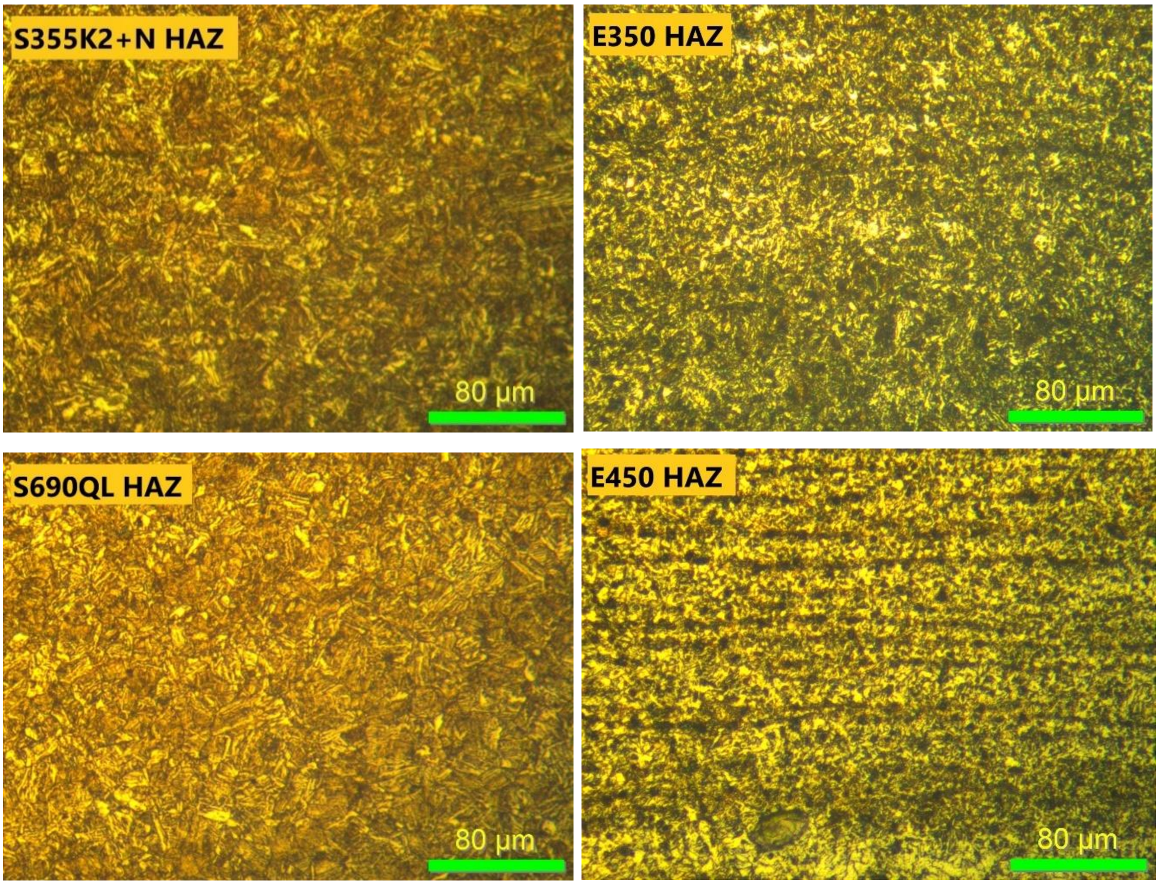
When examination of test specimen is done with low magnification, usually less than x50, it is called macroscopic examination. When using microscope with a magnification of x50 to x500, test process is called microscopic examination (SFS-EN ISO 17639, 2013 s. 8.)
Macroscopic pictures of etched weld joints are shown in the picture 18. Microscopic pictures of base materials, welds and heat affected zones with x200 magnification are shown in the pictures 19-21.



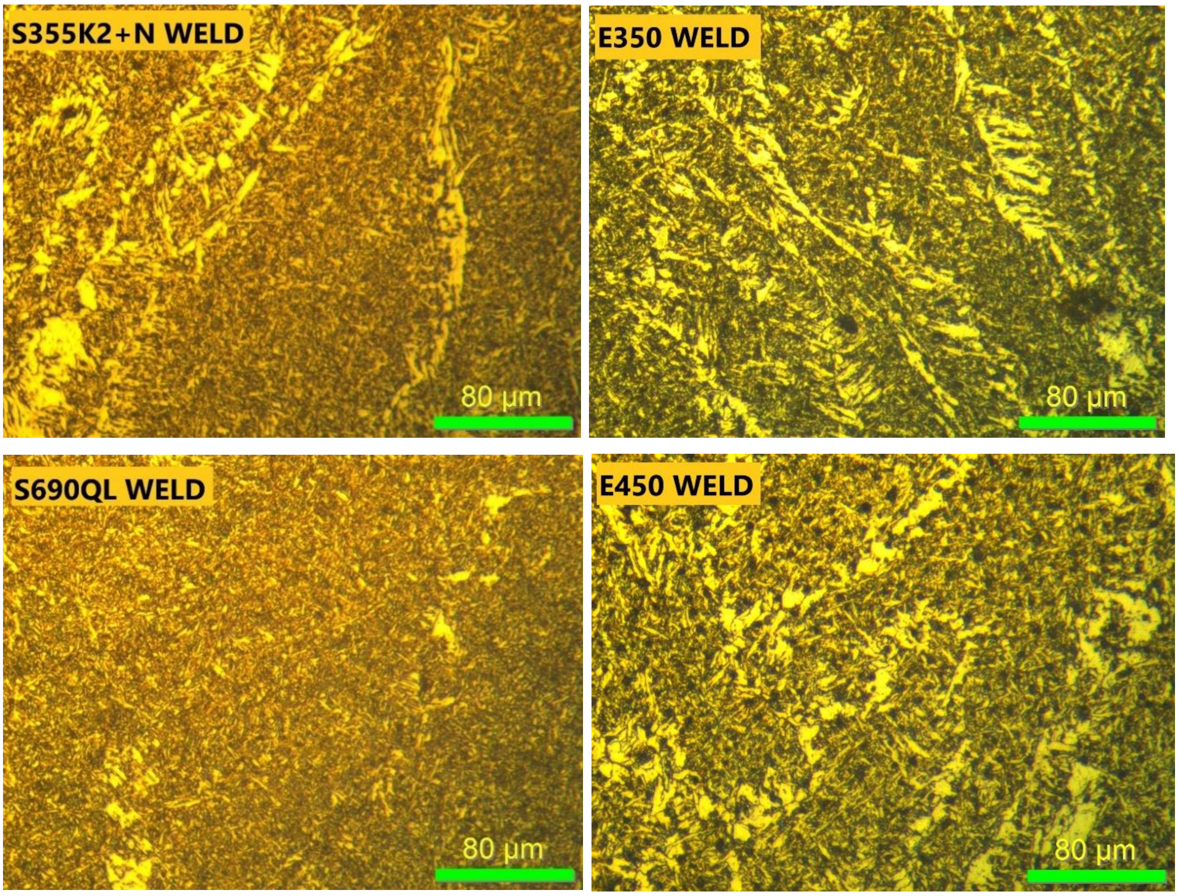
PICTURE 18. Etched specimens of welds.



PICTURE 19. Microscopic pictures of base materials.



PICTURE 20. Microscopic pictures of heat affected zones.



PICTURE 21. Microscopic pictures of welds.

8 RESULTS

The average results of material testings are collected in the table 23, where it is easy to compare the results of different steels, result values in the parentehesis with a smaller font size shows the minimum and maximum value from the test series. More detailed results can be seen in the chapters 6 and 7, and all the tensile test reports are shown in the appendices. In this table the welded material hardness value is the maximum value from parent metal or HAZ-area and the base material hardness value is the average of three measures. In the tensile test of welded plate, S690QL broke from next to weld, all other steel grades broke from the parent material area.

TABLE 23. Comparison table about mechanical properties.

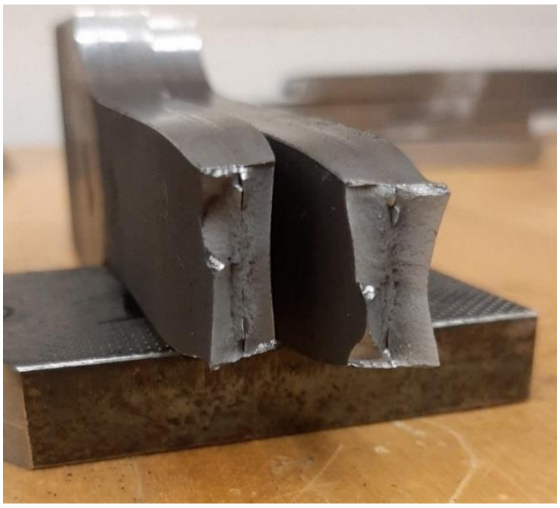
Base material									
Steel grade	**Test piece**	**Thickness**	**0,2 % Proof strenght $R_{p0,2}$**	**Upper yield strenght R_{eH}**	**Tensile strenght R_m**	**Percentage elongation *A***	**Impact toughness KV_2**		**Hardness**
	ID number	(mm)	(MPa)	(MPa)	(MPa)	(%)	(J/cm^2)	(°c)	HV10
S355K2	11T 1-5	12	-	455 (453-459)	580 (576-583)	25	88	-20	171
E350C	32T 1-5	12	-	397 (390-403)	533 (533-534)	30	82	-20	162
E450BR	42T 1-5	8	-	421 (414-428)	517 (510-522)	30	157	20	163
S690QL	21T 1-5	8	738 (698-473)	-	813 (810-816)	17	164	-40	277
Welded test pieces									
S355K2	11WT 1-2	12	-	439	584	22	45	-20	294
E350C	32WT 1-2	12	-	401	539	22	140	-20	246
E450BR	42WT 1-2	8	-	434	552	20	181	20	234
S690QL	21WT 1-2	8	653	-	812	11	31	-40	303

8.1 S355K2 and E350C

Material tests processed in this work shows that the mechanical properties of E350C meet the requirements of Indian IS 2062 and European EN 10025-2 material standards. Yield- and tensile strength of E350C is slightly lower than in S355K2, but it is within required values. Impact toughness and hardness values are quite equal, but the percentage elongation of E350C is noticeably higher.

The mechanical properties of welded material meet also the base material standard requirements. In tensile testing, the test pieces broke in the area of parent material, quite far away from the weld and heat affected zone with both steel grades. Noticeable difference in welded material is in impact toughness, with S355K2 it decreased nearly to half and with E350C impact toughness increased nearly 60 J/cm^2. Other mechanical properties did not have significant differences. Overall the mechanical properties of the tested E350C grade were good and based on these results, it could be used in place of S355K2.

In a macroscopic picture (picture 18) can be seen that there is lamellar tearing in E350C and E450BR materials, it shows as a straight line parallel to the plate surface in the middle of the material. It can be seen more clearly in the welded material but occurs also in base material. This lamellar tearing can also be seen in the tensile test piece fracture surface (picture 22), however this did not have effect on welded plate bend test where it could not be recognised.



PICTURE 22. Fracture surface of E350C tensile test piece (Paananen 2020.)

Worth mentioning with E350C and E450BR grade steels was also the flatness of the plates. Sample plates had a width of 300 mm and there was 1,5 mm distance between the points of contact of the straight edge and the plate. Flatness of E350C and E450BR was almost equal and can be seen in the picture 23. However, the European standard SFS-EN 10029 allows an 1 % difference in flatness for hot rolled steels with a specified minimum yield strength of ≤460 MPa, when using distance between the contact point of 300 mm to 1000 mm. (SFS-EN 10029, 2011 s. 12.) According to this the Indian steels meet the requirements of European dimension and shape standard, and these differences in flatness can be accepted.

PICTURE 23. Flatness of E350C and E450BR (Paananen 2020.)

8.2 E450BR

E450BR test results were quite different than with the E350C, when the E350C exceede the standard requirements well, the E450BR did not reach the requirements. Yield- and tensile strength stays below the IS 2062 standard requirements and the mechanical properties of S355K2 are clearly higher. However, percentage elongation is very high and the tensile strength even at -20 °C is good (131 J/cm^2), although the material standard required an impact test only at room temperature when the result was 157 J/cm^2. Welded E450BR mechanical properties were slightly better than with base material, also the hardness in the weld joint does not increase as much as with S355K2.

8.3 S690QL

The mechanical properties of S690QL were according to the standard requirements. The 0,2 % proof strength of welded S690QL had an average of 653 MPa which is slightly below the parent material requirement, although the filler material used was equally strong. In welded plate tensile test, the test piece broke from the interface of the heat affected zone and the parent material. Probably the strength of the weld joint could be increased by adjusting the weld parameters and heat input. Noticeable was also the decrease in the impact strength of a weld joint, when there was a 133 J/cm^2 difference compared to the base material.

9 FINAL TEST PROCESS

9.1 For base material

Based on the results of the tests processed in this work, it can be estimated what destructive testing processes are necessary when exploring properties of different steel grades. Tensile testing shows the most important steel properties, in this work it was made for series of five specimens from each material. A variance of the tensile test results is quite low and hence three test pieces should be enough to have reliable test results.

Charpy V- testing gives important information about impact toughness, it is usually made for set of three test pieces. The tests processed in this work show that there might be a lot of differences in impact strength and it should be always tested. With structural steels it is not necessary to test the hardness of the material, alltough when there is need for abrasion resistant steels, hardness of the material is an important feature and it can be tested.

9.2 For weld joint

When testing and approving new high strength steels to production, it would be good to sort out the weldability and the effect of the weld on steel. With high strength steels, there might be more differences in the weldability and in the mechanical properties of welded material than with a normal structural steel.
The tensile test piece made from butt welded plate gives results, where the weld effect to steel can be clearly seen. The weld might also have notable effect on the impact toughness of the steel, and it should be tested with Charpy V- impact test. If there are significant differences between welded plate and parent material, testing can be continued with bend test and macroscopic examination. Macroscopic examination shows faults in weld joint and base material, and for example lamellar tearing can be found out.
I think that the microscopic examination does not give much information for this kind of testing process, and probably there is no need for it. Weld joint and testing of weld could be done according to the welding procedure test that is described in the standard EN ISO 15614-1 by using destructive testing methods that are required for testing level 2.

10 SUMMARY

The aim of this thesis was to find differences between different steel grades and to develop a testing process that is suitable for testing and approving new steel grades for the production of Normet machines. In different parts of the world, steels are manufactured according to different standards, with a testing process it is possible to compare different steel grade properties and find the material meeting the requirements.

The work was started by searching information about different material testing methods and choosing the right tests for the work. Sample plates of two steel grades manufactured in India were ordered to Finland, also sample plates of steels used in Finland were ordered from two different steel grades. The material testing was made for steels used in Finland, to have results that can be compared to Indian steels, although there are already versatile results in the material test reports. There were difficulties in finding the corresponding steel from India in the strength grade S690QL, hence other tested Indian manufactured steel grade was E450BR according to the Indian material standard IS 2062. Another Indian manufactured steel tested was E350C whose mechanical properties were compared to the European steel grade S355K2.

Material testing methods used were tensile- impact- hardness- bend and microscopic examination tests. Weld joints were also made for steel plates, to see differences in the weldability. Plates were welded with a welding robot to have similar weld joints for all tested steels. Manufacturing of the test pieces and the material tests were performed in the laboratories of Savonia University of Applied Sciences. The results of the material tests demonstrated a good example of differences of the mechanical properties between different steels. Based on these results, the necessary testing methods were chosen.

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12 APPENDICES

APPENDIX 1. Tensile test report (1/28)

SAVONIA

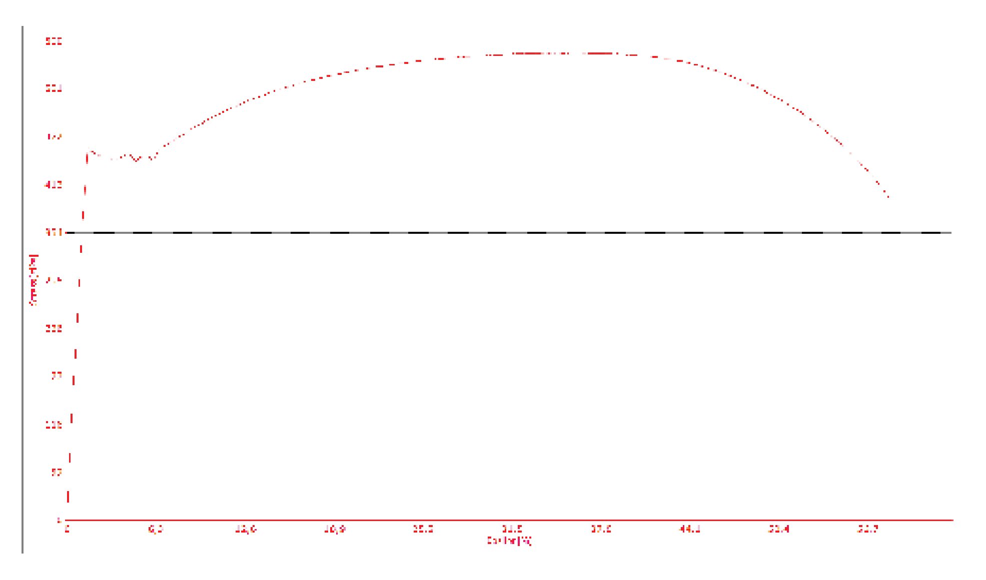
Test Report

Order Number: 11T1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: 1, S355K2+N
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_opinnäytetyö Series - 1 /

Remarks:

Description		Result	
Thickness x Width	ao x bo	12,250 x 25,000	mm
Start Section	S_0	306,250	mm²
Modulus of Elasticity	E	32	GPa
Upper yield strenght	R_{eH}	459	MPa
Lower yield strength	R_{eL}	442	MPa
0,020% / 0,200% Proof Strength, Plastic Extension	Rp	347 / 456	MPa
Tensile Strength	R_m	576	MPa
Percentage Total Extension at Fracture	A	58,21	%
Elongation A5	A	25,000	%
Percentage Reduction of Area	Z	100,00	%
Maximum Force	Fm	176,35	kN



APPENDIX 2. Tensile test report (2/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

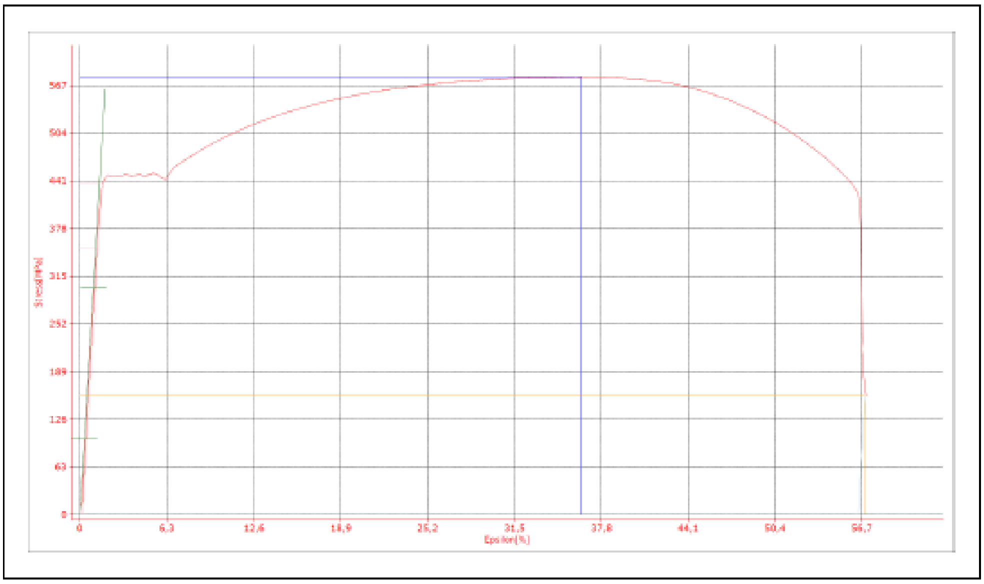
Test Report

Order Number: 11T2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: 1, S355K2+N
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_opinnäytetyö Series - 2 /

Remarks:

Description		Result
Thickness x Width	a0 x b0	12,250 x 25,000 mm
Start Section	S_0	306,250 mm²
Modulus of Elasticity	E	31 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	353 / 439 MPa
Tensile Strength	R_m	579 MPa
Percentage Total Extension at Fracture	A	56,86 %
Elongation A5	A	24,500 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	177,25 kN



APPENDIX 3. Tensile test report (3/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

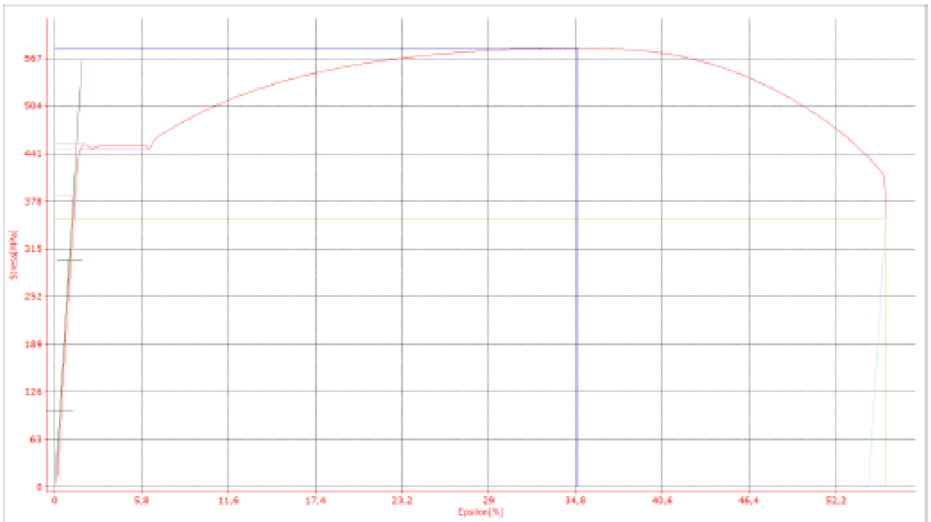
Test Report

Order Number: 11T3
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: 1, S355K2+N
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_opinnäytetyö Series - 3 /

Remarks:

Description		Result
Thickness x Width	a_0 x b_0	12,250 x 25,000 mm
Start Section	S_0	306,250 mm²
Modulus of Elasticity	E	31 GPa
Upper yield strenght	R_{eH}	454 MPa
Lower yield strength	R_{eL}	447 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	386 / 447 MPa
Tensile Strength	R_m	581 MPa
Percentage Total Extension at Fracture	A	55,46 %
Elongation A5	A	24,500 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	178,05 kN



APPENDIX 4. Tensile test report (4/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

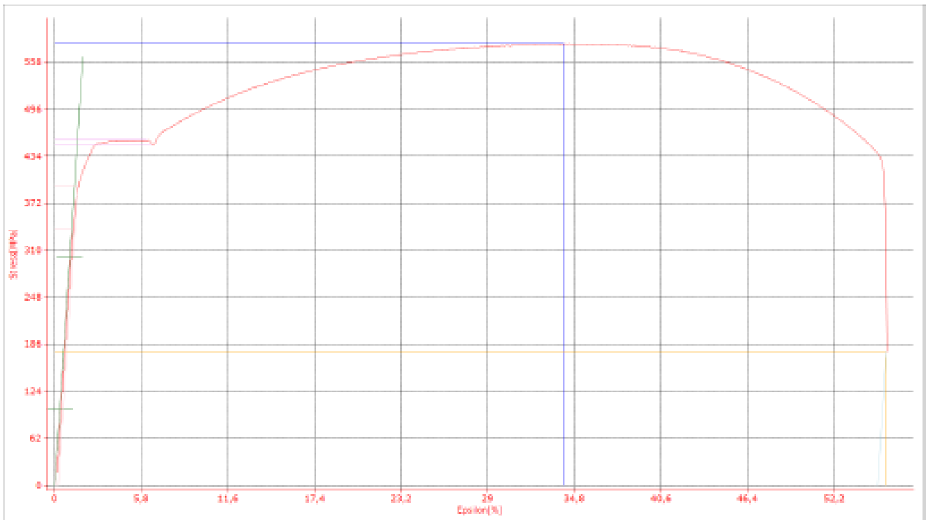
Test Report

Order Number: 11T4
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: 1, S355K2+N
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_opinnäytetyö Series - 4 /

Remarks:

Description		Result
Thickness x Width	ao x bo	12,250 x 25,000 mm
Start Section	S_0	306,250 mm²
Modulus of Elasticity	E	30 GPa
Upper yield strenght	R_{eH}	455 MPa
Lower yield strength	R_{eL}	448 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	339 / 396 MPa
Tensile Strength	R_m	583 MPa
Percentage Total Extension at Fracture	A	55,62 %
Elongation A5	A	24,500 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	178,48 kN



APPENDIX 5. Tensile test report (5/28)

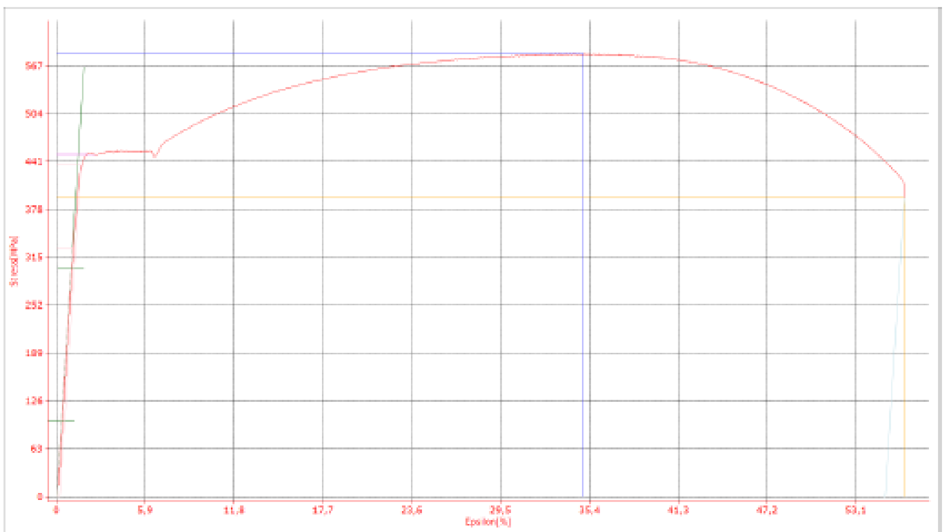
SAVONIA
UNIVERSITY OF APPLIED SCIENCES

Test Report

Order Number:	11T5	Material Info:	1, S355K2+N
Operator:	TP	Batch Number:	
Customer:	Normet Oy	Date of Test:	03.02.2020
Supplier:		Sample Group:	
Welder:		ID:	SFS-ISO EN 6892-1 B 03022020_opinnäytetyö Series - 5 /

Remarks:

Description		Result
Thickness x Width	ao x bo	12,250 x 25,000 mm
Start Section	S_0	306,250 mm²
Modulus of Elasticity	E	31 GPa
Upper yield strenght	R_{eH}	453 MPa
Lower yield strength	R_{eL}	450 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	328 / 437 MPa
Tensile Strength	R_m	583 MPa
Percentage Total Extension at Fracture	A	56,23 %
Elongation A5	A	24,500 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	178,54 kN



APPENDIX 6. Tensile test report (6/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

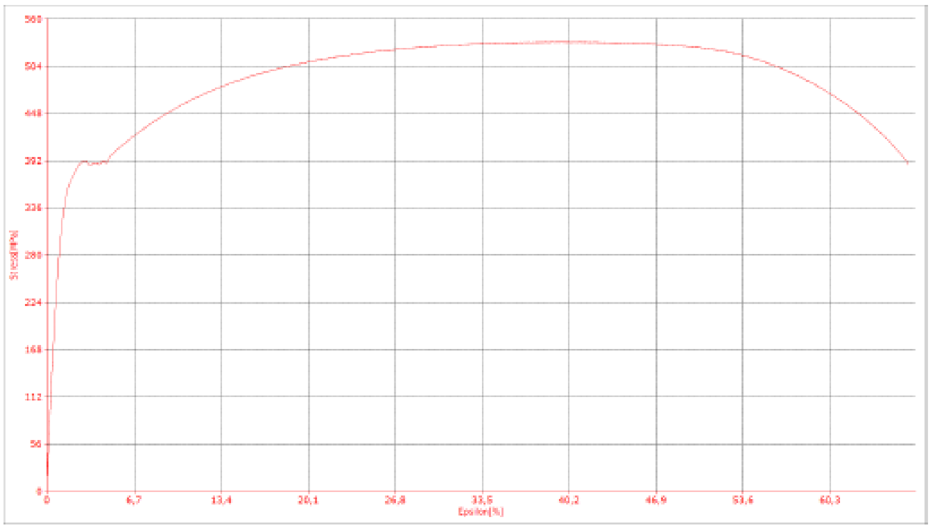
Test Report

Order Number: 32T1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07032020_3opinäyt. Series - 1 / 154

Remarks:

Description		Result
Thickness x Width	ao x bo	12,000 x 25,000 mm
Start Section	S_0	300,000 mm²
Modulus of Elasticity	E	26 GPa
Upper yield strenght	R_{eH}	391 MPa
Lower yield strength	R_{eL}	388 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	283 / 338 MPa
Tensile Strength	R_m	533 MPa
Percentage Total Extension at Fracture	A	66,20 %
Elongation A5	A	29,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	159,91 kN



APPENDIX 7. Tensile test report (7/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

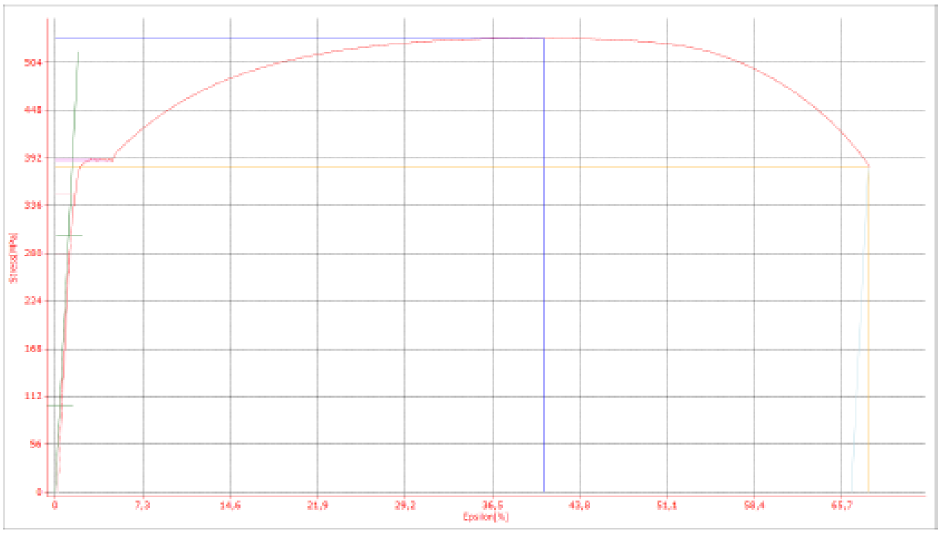
Test Report

Order Number: 32T2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07032020_3opinäyt. Series - 2 / 154

Remarks:

Description		Result
Thickness x Width	ao x bo	12,000 x 25,000 mm
Start Section	S_0	300,000 mm²
Modulus of Elasticity	E	27 GPa
Upper yield strenght	R_{eH}	390 MPa
Lower yield strength	R_{eL}	388 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	279 / 349 MPa
Tensile Strength	R_m	533 MPa
Percentage Total Extension at Fracture	A	67,74 %
Elongation A5	A	29,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	159,83 kN



APPENDIX 8. Tensile test report (8/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

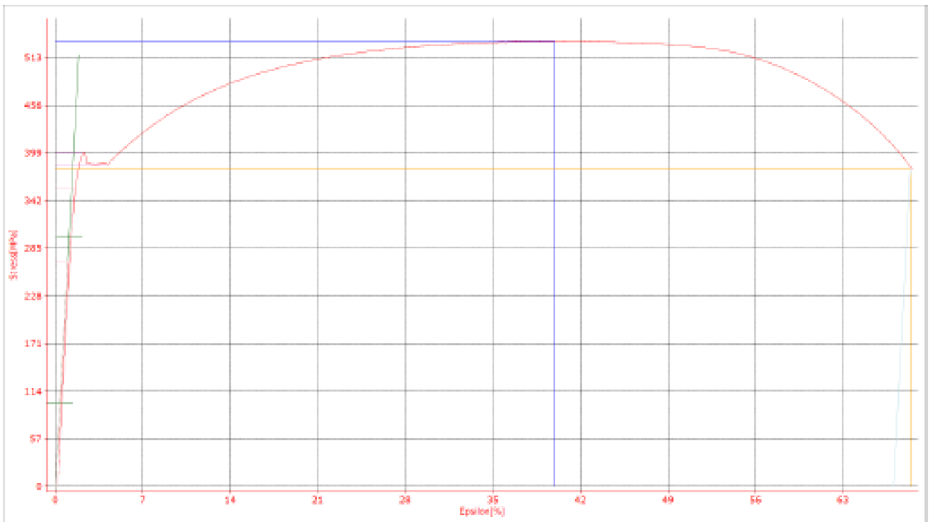
Test Report

Order Number: 32T3
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07032020_3opinäyt. Series - 3 / 154

Remarks:

Description		Result
Thickness x Width	ao x bo	12,000 x 25,000 mm
Start Section	S_0	300,000 mm²
Modulus of Elasticity	E	27 GPa
Upper yield strenght	R_{eH}	400 MPa
Lower yield strength	R_{eL}	385 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	270 / 357 MPa
Tensile Strength	R_m	533 MPa
Percentage Total Extension at Fracture	A	68,25 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	159,88 kN



APPENDIX 9. Tensile test report (9/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

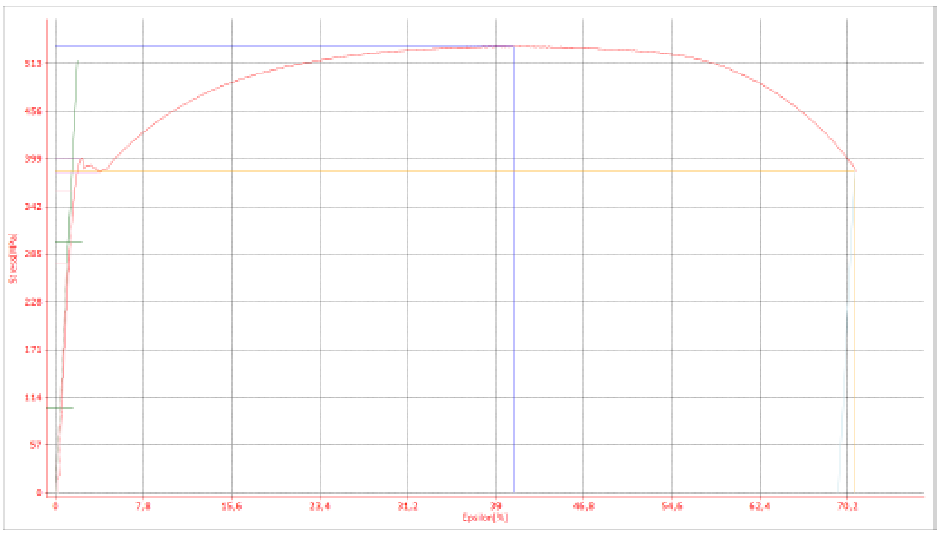
Test Report

Order Number: 32T4
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07032020_3opinäyt. Series - 4 / 154

Remarks:

Description		Result
Thickness x Width	ao x bo	12,000 x 25,000 mm
Start Section	S_0	300,000 mm²
Modulus of Elasticity	E	27 GPa
Upper yield strenght	R_{eH}	400 MPa
Lower yield strength	R_{eL}	383 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	274 / 360 MPa
Tensile Strength	R_m	533 MPa
Percentage Total Extension at Fracture	A	70,63 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	159,93 kN



APPENDIX 10. Tensile test report (10/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

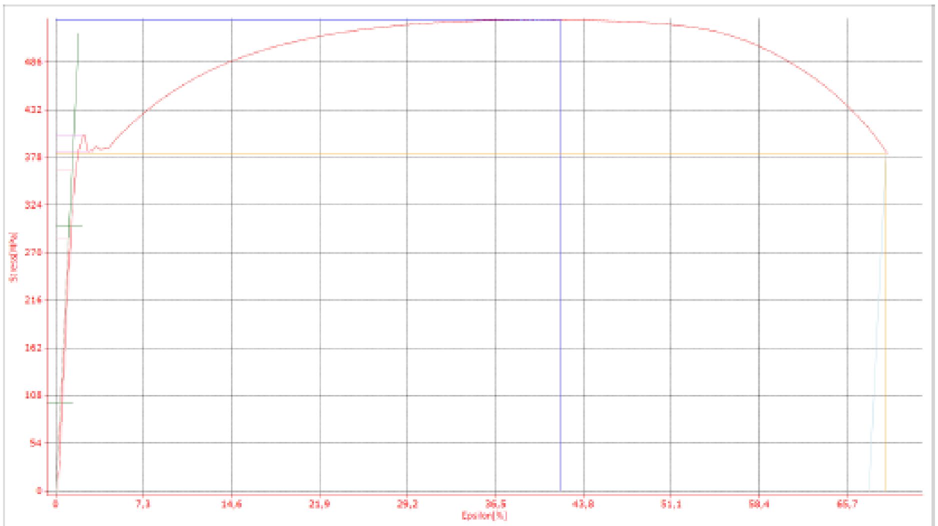
Test Report

Order Number: 32T5
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07032020_3opinäyt. Series - 5 / 154

Remarks:

Description		Result
Thickness x Width	a_0 x b_0	12,000 x 25,000 mm
Start Section	S_0	300,000 mm²
Modulus of Elasticity	E	27 GPa
Upper yield strenght	R_{eH}	403 MPa
Lower yield strength	R_{eL}	385 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	286 / 363 MPa
Tensile Strength	R_m	534 MPa
Percentage Total Extension at Fracture	A	68,79 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	160,34 kN



APPENDIX 11. Tensile test report (11/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

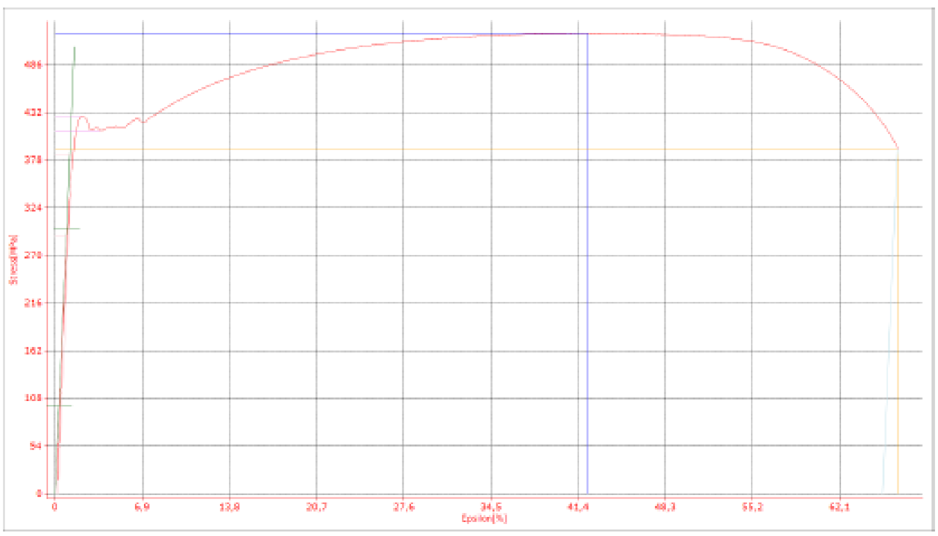
Test Report

Order Number: 42T1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä4opnnäyt. Series - 1 /

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	34 GPa
Upper yield strenght	R_{eH}	428 MPa
Lower yield strength	R_{eL}	411 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	293 / 384 MPa
Tensile Strength	R_m	522 MPa
Percentage Total Extension at Fracture	A	66,56 %
Elongation A5	A	31,250 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	104,38 kN



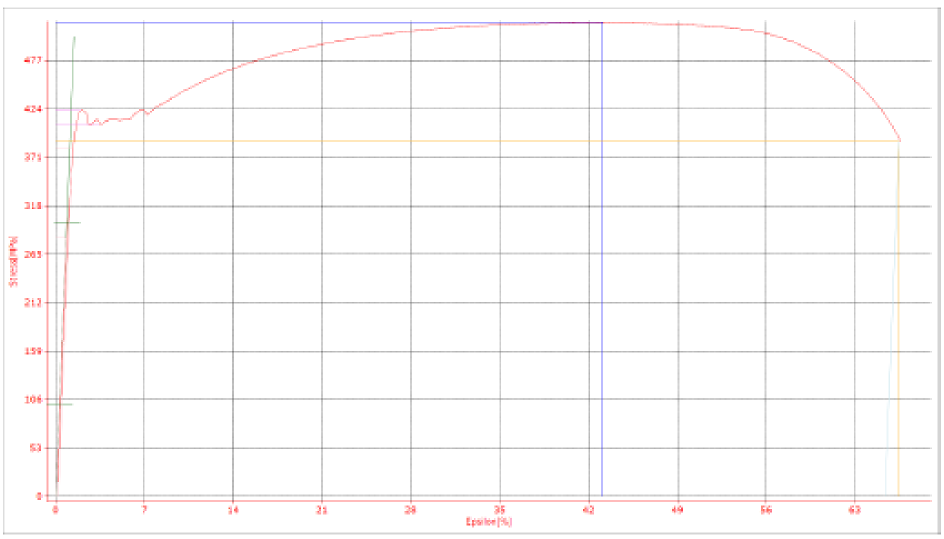
APPENDIX 12. Tensile test report (12/28)

Test Report

Order Number:	42T2	Material Info:	E450
Operator:	TP	Batch Number:	
Customer:	Normet Oy	Date of Test:	07.04.2020
Supplier:		Sample Group:	
Welder:		ID:	SFS-ISO EN 6892-1 B 07042020_erä4opnnäyt. Series - 2 /

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	34 GPa
Upper yield strenght	R_{eH}	423 MPa
Lower yield strength	R_{eL}	407 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	282 / 381 MPa
Tensile Strength	R_m	519 MPa
Percentage Total Extension at Fracture	A	66,39 %
Elongation A5	A	31,250 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	103,77 kN



APPENDIX 13. Tensile test report (13/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

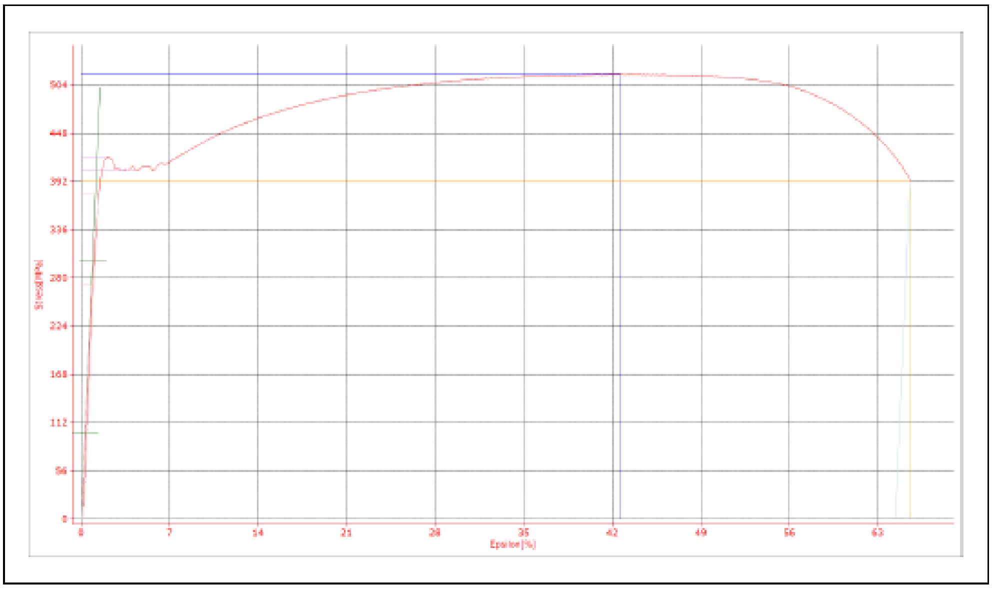
Test Report

Order Number: 42T3
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä4opnnäyt. Series - 3 /

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	33 GPa
Upper yield strenght	R_{eH}	420 MPa
Lower yield strength	R_{eL}	405 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	272 / 378 MPa
Tensile Strength	R_m	516 MPa
Percentage Total Extension at Fracture	A	65,44 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	103,30 kN



APPENDIX 14. Tensile test report (14/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

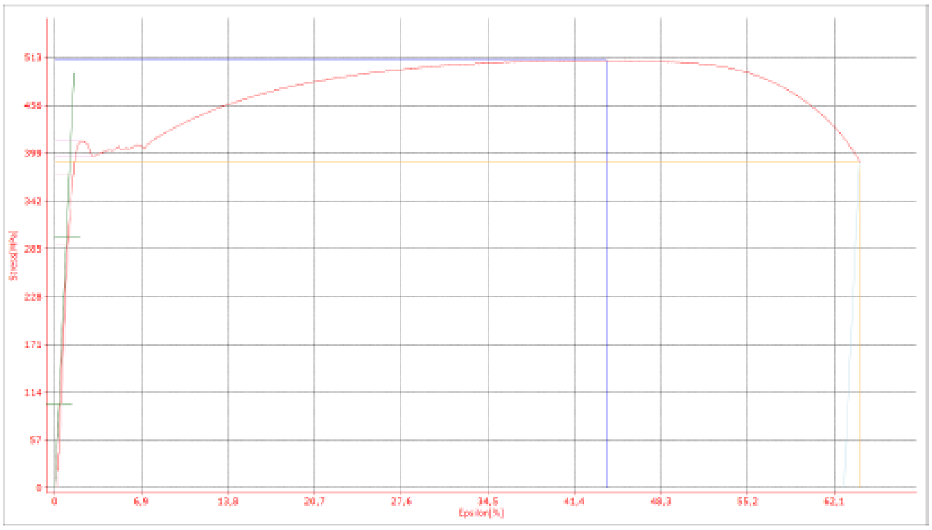
Test Report

Order Number: 42T4
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä4opnnäyt. Series - 4 /

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	33 GPa
Upper yield strenght	R_{eH}	414 MPa
Lower yield strength	R_{eL}	396 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	290 / 374 MPa
Tensile Strength	R_m	510 MPa
Percentage Total Extension at Fracture	A	63,95 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	102,07 kN



APPENDIX 15. Tensile test report (15/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

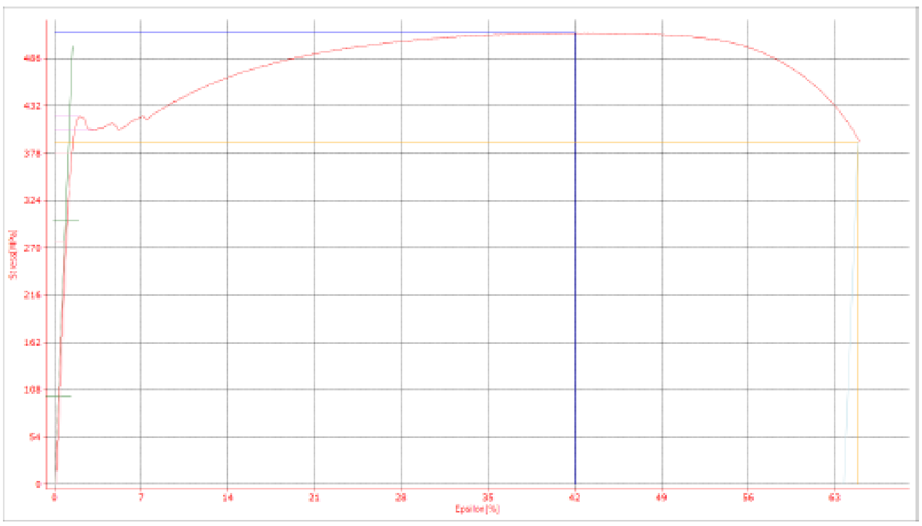
Test Report

Order Number: 42T5
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä4opnnäyt. Series - 5 /

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	34 GPa
Upper yield strenght	R_{eH}	420 MPa
Lower yield strength	R_{eL}	404 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	277 / 378 MPa
Tensile Strength	R_m	516 MPa
Percentage Total Extension at Fracture	A	64,77 %
Elongation A5	A	30,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	103,11 kN



APPENDIX 16. Tensile test report (16/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

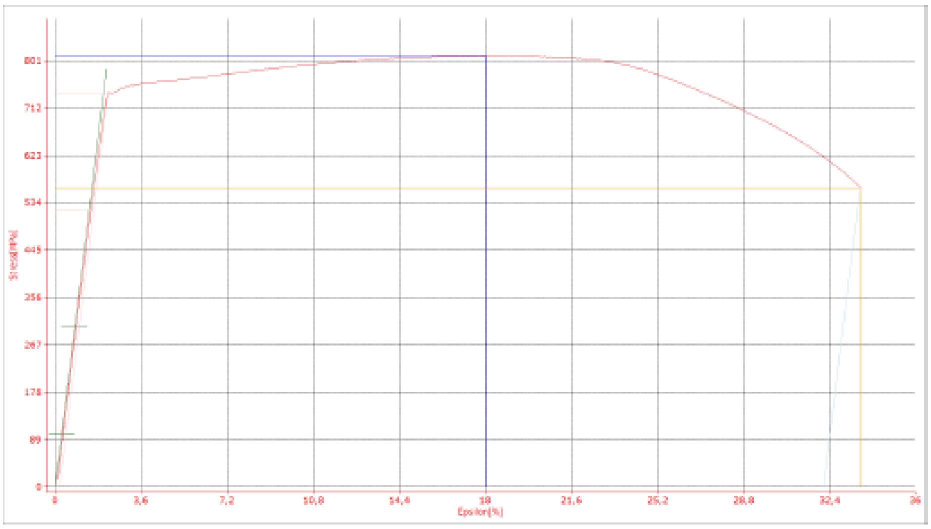
Test Report

Order Number: 21T1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_erä2opinnäytetyö Series

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	37 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	519 / 741 MPa
Tensile Strength	R_m	810 MPa
Percentage Total Extension at Fracture	A	33,61 %
Elongation A5	A	19,375 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	162,01 kN



APPENDIX 17. Tensile test report (17/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

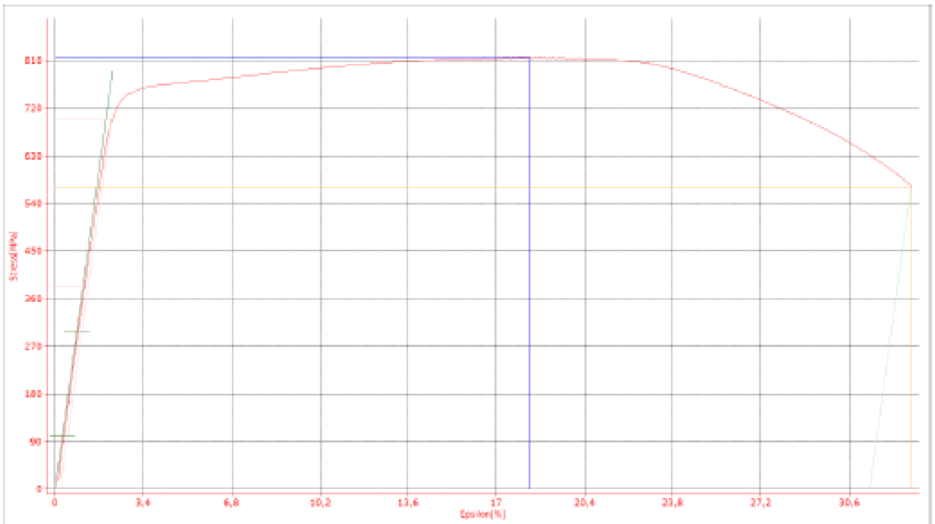
Test Report

Order Number: 21T2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_erä2opinnäytetyö Series

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	36 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	385 / 698 MPa
Tensile Strength	R_m	815 MPa
Percentage Total Extension at Fracture	A	32,93 %
Elongation A5	A	16,250 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	163,08 kN



APPENDIX 18. Tensile test report (18/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

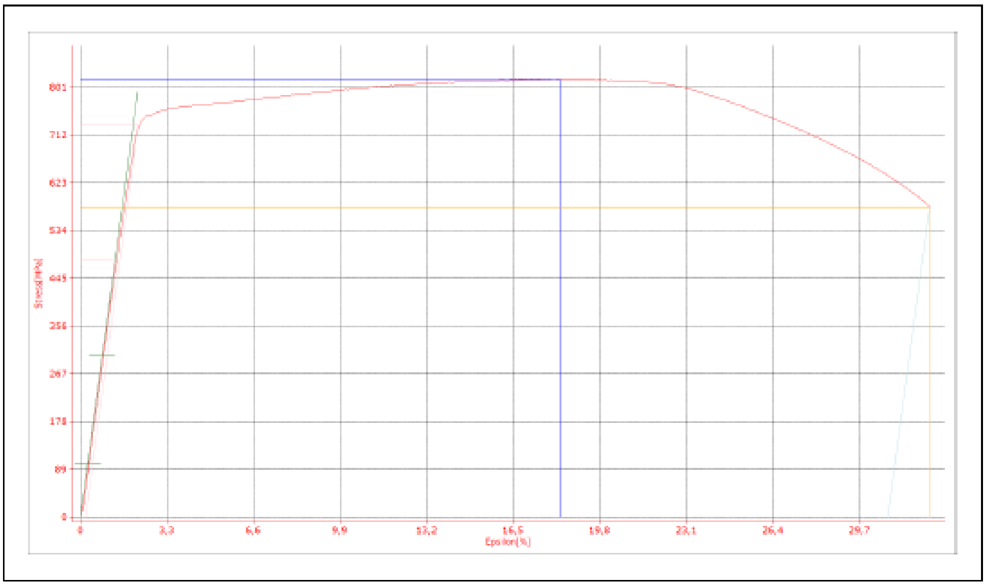
Test Report

Order Number: 21T3
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_erä2opinnäytetyö Series

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	36 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	478 / 730 MPa
Tensile Strength	R_m	816 MPa
Percentage Total Extension at Fracture	A	32,33 %
Elongation A5	A	16,250 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	163,11 kN



APPENDIX 19. Tensile test report (19/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

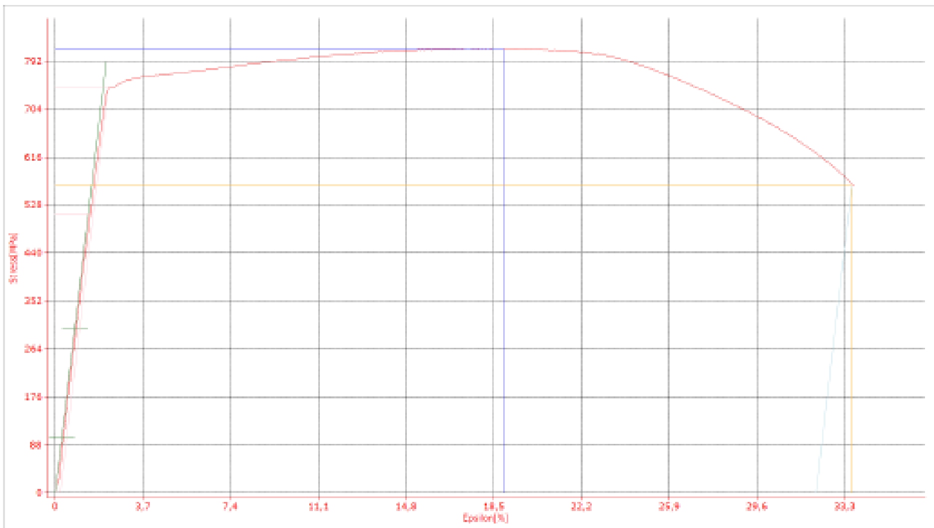
Test Report

Order Number: 21T4
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_erä2opinnäytetyö Series

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	37 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	512 / 743 MPa
Tensile Strength	R_m	815 MPa
Percentage Total Extension at Fracture	A	33,56 %
Elongation A5	A	18,125 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	162,98 kN



APPENDIX 20. Tensile test report (20/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

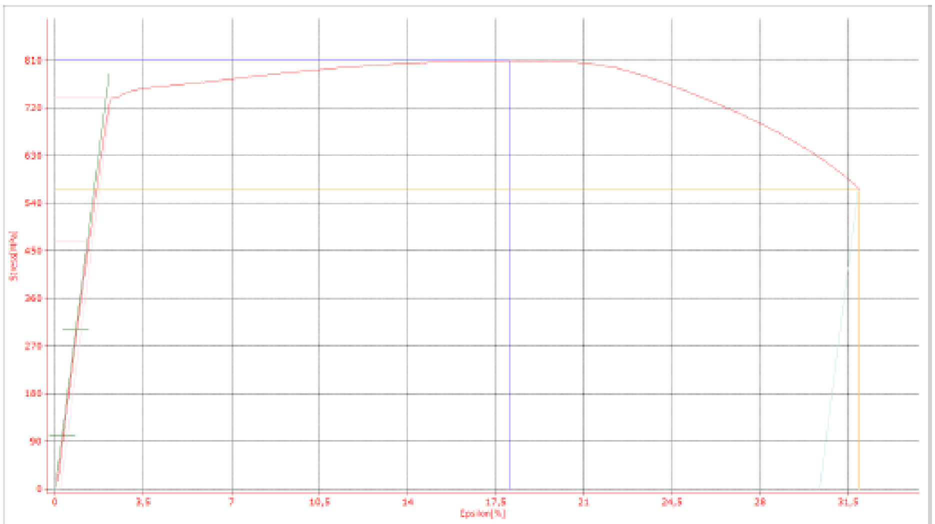
Test Report

Order Number: 21T5
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 03.02.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 03022020_erä2opinnäytetyö Series

Remarks:

Description		Result
Thickness x Width	ao x bo	8,000 x 25,000 mm
Start Section	S_0	200,000 mm²
Modulus of Elasticity	E	37 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	469 / 738 MPa
Tensile Strength	R_m	810 MPa
Percentage Total Extension at Fracture	A	31,86 %
Elongation A5	A	16,250 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	161,91 kN



APPENDIX 21. Tensile test report (21/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

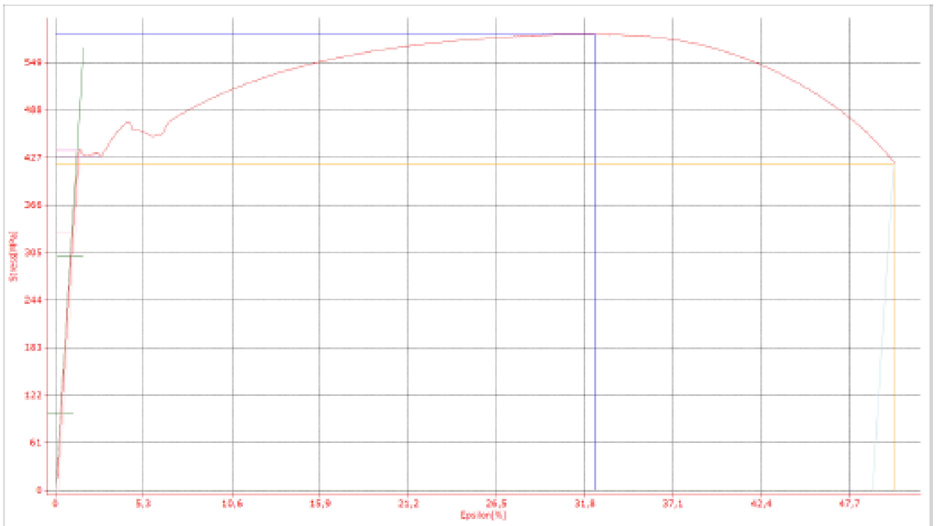
Test Report

Order Number: 11WT1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S355K2
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 1 /

Remarks:

Description		Result
Thickness x Width	ao x bo	10,250 x 25,000 mm
Start Section	S_0	256,250 mm²
Modulus of Elasticity	E	33 GPa
Upper yield strenght	R_{eH}	438 MPa
Lower yield strength	R_{eL}	429 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	331 / 434 MPa
Tensile Strength	R_m	586 MPa
Percentage Total Extension at Fracture	A	50,27 %
Elongation A5	A	21,111 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	150,04 kN



APPENDIX 22. Tensile test report (22/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

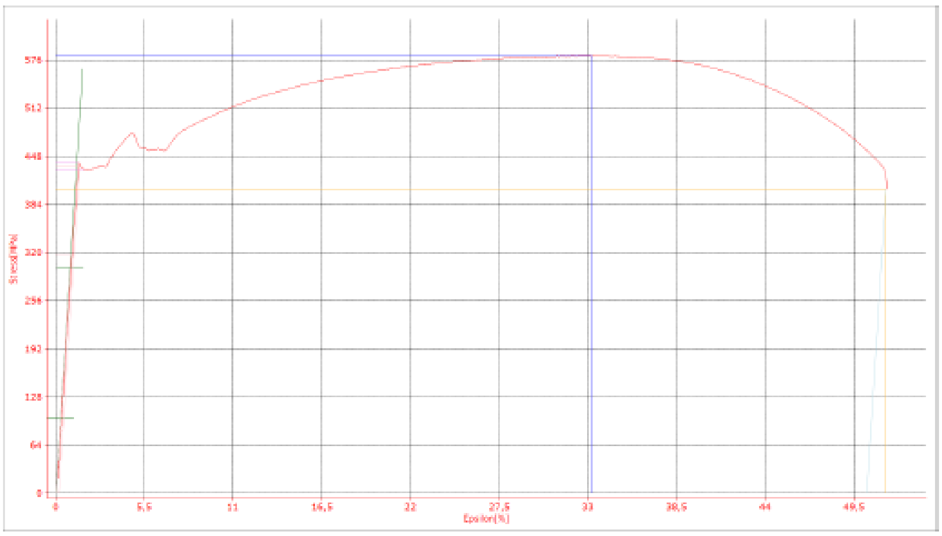
Test Report

Order Number: 11WT2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S355K2
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 2 /

Remarks:

Description		Result
Thickness x Width	ao x bo	10,600 x 25,000 mm
Start Section	S_0	265,000 mm²
Modulus of Elasticity	E	34 GPa
Upper yield strenght	R_{eH}	440 MPa
Lower yield strength	R_{eL}	430 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	318 / 435 MPa
Tensile Strength	R_m	582 MPa
Percentage Total Extension at Fracture	A	51,40 %
Elongation A5	A	22,222 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	154,22 kN



APPENDIX 23. Tensile test report (23/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

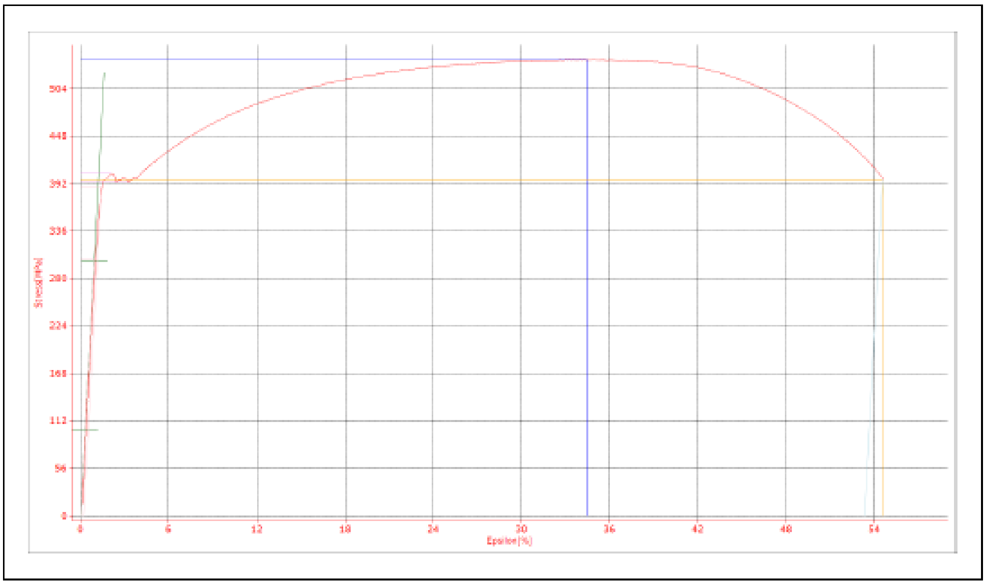
Test Report

Order Number: 32WT1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E350
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 3 /

Remarks:

Description		Result
Thickness x Width	ao x bo	11,150 x 25,000 mm
Start Section	S_0	278,750 mm²
Modulus of Elasticity	E	32 GPa
Upper yield strenght	R_{eH}	404 MPa
Lower yield strength	R_{eL}	394 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	302 / 389 MPa
Tensile Strength	R_m	538 MPa
Percentage Total Extension at Fracture	A	54,50 %
Elongation A5	A	22,222 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	150,09 kN



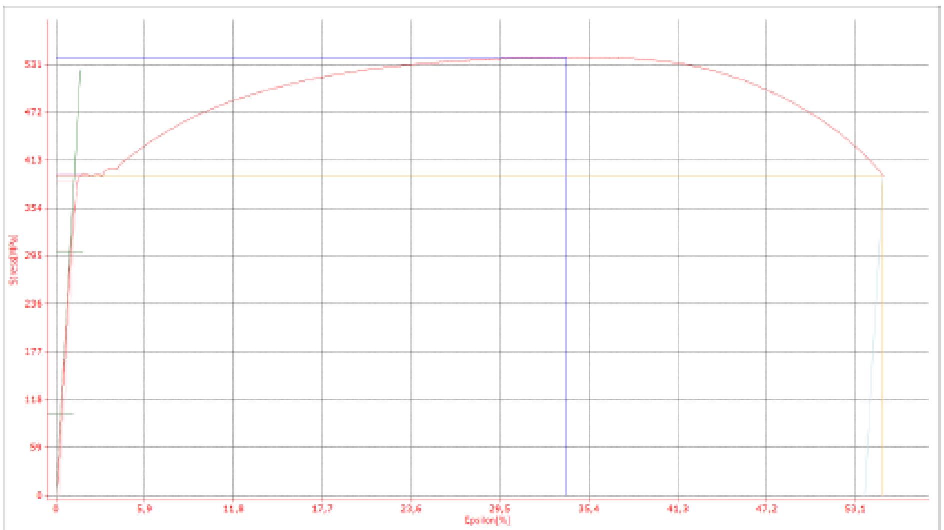
APPENDIX 24. Tensile test report (24/28)

Test Report

Order Number:	32WT2	Material Info:	E350
Operator:	TP	Batch Number:	
Customer:	Normet Oy	Date of Test:	07.04.2020
Supplier:		Sample Group:	
Welder:		ID:	SFS-ISO EN 6892-1 B 07042020_eräšopnnäyt. Series - 4 /

Remarks:

Description		Result
Thickness x Width	ao x bo	11,100 x 25,000 mm
Start Section	S_0	277,500 mm²
Modulus of Elasticity	E	32 GPa
Upper yield strenght	R_{eH}	397 MPa
Lower yield strength	R_{eL}	393 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	302 / 388 MPa
Tensile Strength	R_m	540 MPa
Percentage Total Extension at Fracture	A	54,87 %
Elongation A5	A	22,222 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	149,81 kN



APPENDIX 25. Tensile test report (25/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

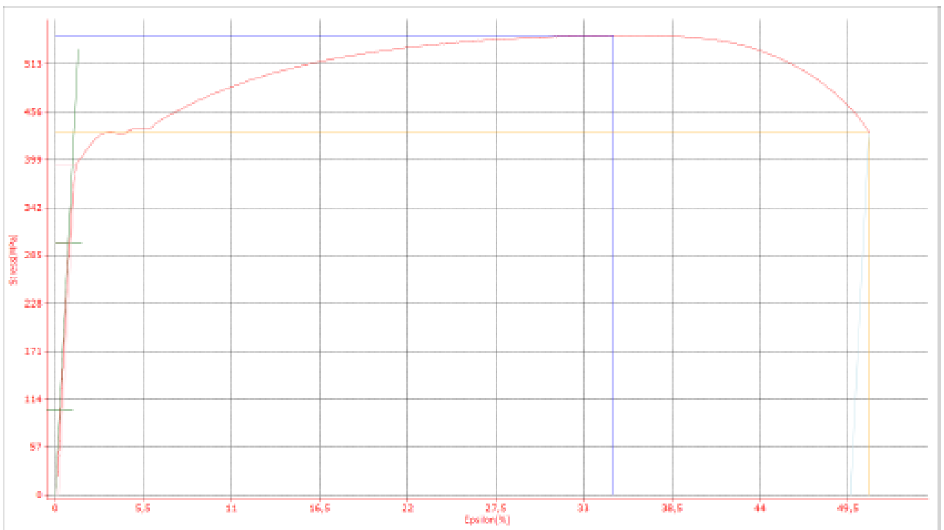
Test Report

Order Number: 42WT1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_eräSopnnäyt. Series - 7 /

Remarks:

Description		Result
Thickness x Width	ao x bo	7,000 x 25,000 mm
Start Section	S_0	175,000 mm²
Modulus of Elasticity	E	38 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	300 / 394 MPa
Tensile Strength	R_m	547 MPa
Percentage Total Extension at Fracture	A	50,71 %
Elongation A5	A	20,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	95,76 kN



APPENDIX 26. Tensile test report (26/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

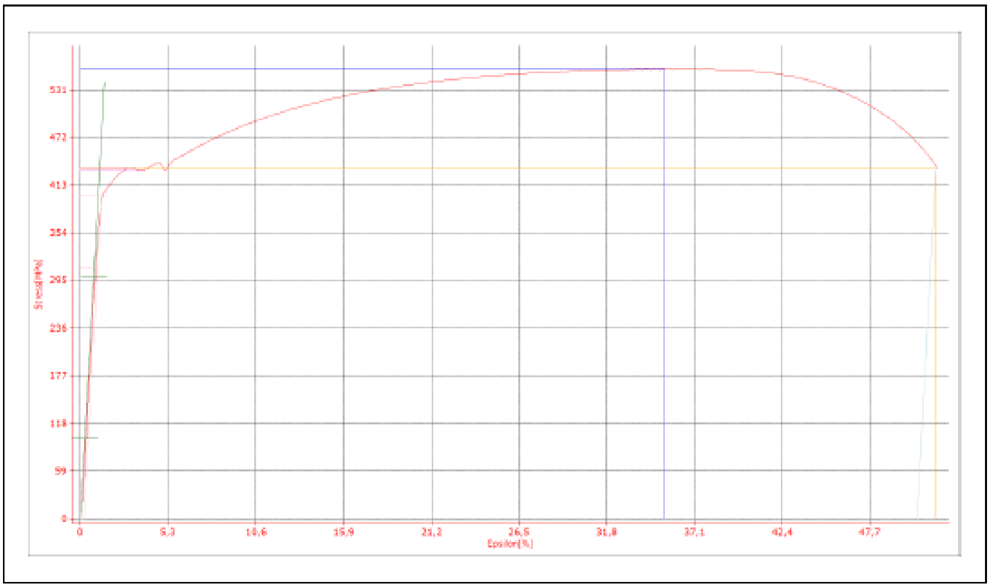
Test Report

Order Number: 42WT2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: E450
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 8 /

Remarks:

Description		Result
Thickness x Width	ao x bo	7,000 x 25,000 mm
Start Section	S_0	175,000 mm²
Modulus of Elasticity	E	38 GPa
Upper yield strenght	R_{eH}	434 MPa
Lower yield strength	R_{eL}	431 MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	310 / 399 MPa
Tensile Strength	R_m	557 MPa
Percentage Total Extension at Fracture	A	51,63 %
Elongation A5	A	20,000 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	97,48 kN



APPENDIX 27. Tensile test report (27/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

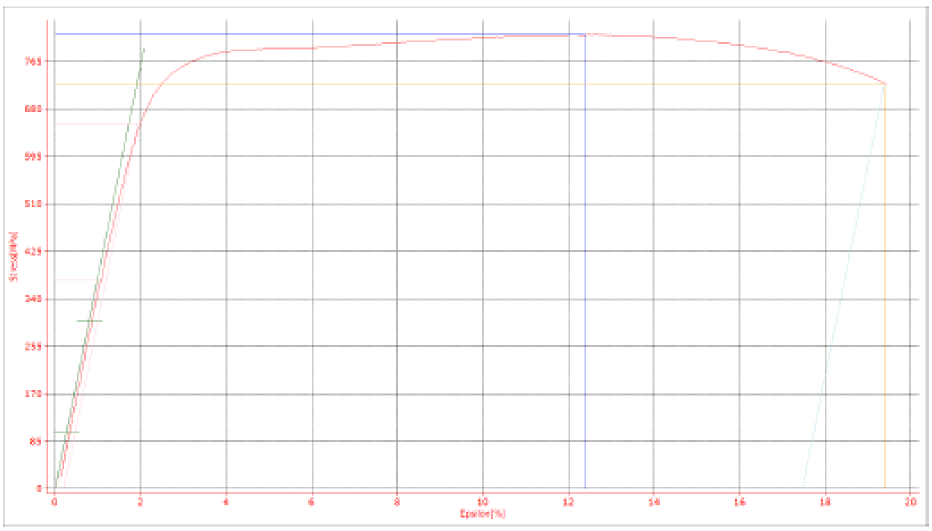
Test Report

Order Number: 21WT1
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 5 /

Remarks:

Description		Result
Thickness x Width	ao x bo	7,050 x 25,000 mm
Start Section	S_0	176,250 mm²
Modulus of Elasticity	E	38 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	375 / 655 MPa
Tensile Strength	R_m	814 MPa
Percentage Total Extension at Fracture	A	19,31 %
Elongation A5	A	10,667 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	143,46 kN



APPENDIX 28. Tensile test report (28/28)

SAVONIA
UNIVERSITY OF APPLIED SCIENCES

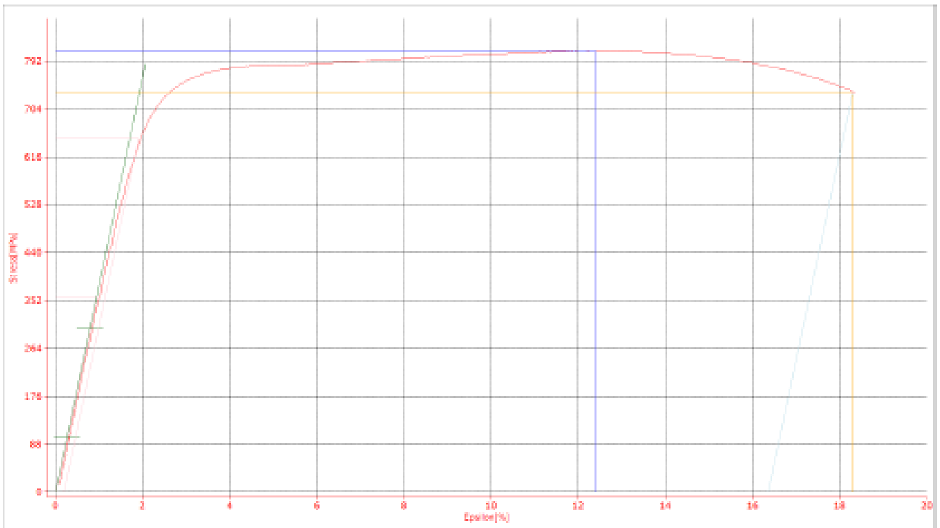
Test Report

Order Number: 21WT2
Operator: TP
Customer: Normet Oy
Supplier:
Welder:

Material Info: S690QL
Batch Number:
Date of Test: 07.04.2020
Sample Group:
ID: SFS-ISO EN 6892-1 B 07042020_erä5opnnäyt. Series - 6 /

Remarks:

Description		Result
Thickness x Width	ao x bo	6,900 x 25,000 mm
Start Section	S_0	172,500 mm²
Modulus of Elasticity	E	38 GPa
Upper yield strenght	R_{eH}	--- MPa
Lower yield strength	R_{eL}	--- MPa
0,020% / 0,200% Proof Strength, Plastic Extension	R_p	359 / 650 MPa
Tensile Strength	R_m	810 MPa
Percentage Total Extension at Fracture	A	18,24 %
Elongation A5	A	10,667 %
Percentage Reduction of Area	Z	100,00 %
Maximum Force	Fm	139,80 kN



Other appendices are not available in public version.