Certification of Thermoplastic Sheet Butt Welding Machine

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Abstract:

The aim of this work was to argue whether the certification process used in Finland for butt welded products is sufficient for ensuring quality welds. This topic was approached by reviewing the plastic joining technical codes for butt welding in order to understand the correct butt welding process, the weld testing procedures and the common weld imperfections. To get an understanding of the certification process, the involved bodies were reviewed along with the functions of notified bodies, the roles of standards, and the function of certification markings.

For the practical part of this project a welding procedure test (WPT) was conducted with PRP-Plastic Oy on the Wegener SM 440 TPQ thermoplastic sheet butt welding machine. The procedure test required the creation of test samples for PP, PVC and PVDF sheets of various thicknesses, for which the technical codes were used as a guide. The samples were then sent to Häme UAS for tensile testing on their accredited testing machine. Afterwards, the results are sent to Inspecta, a notified body, along with the welding procedure specifications for certification. A bending test, independent to the WPT, was conducted on some of the samples to test the ductility of the welds.

It was noticed that the welding process for making the weld samples followed the guidelines of the technical codes very closely, while the welding procedure tests were much different to the codes. However, due to practical reasons and the vast amount of information that it provides, it is reasonable to use a tensile test as the sole evaluator for the welding procedure test.

Keywords:	Butt Welding, Certification, DVS Technical Codes, Notified Body, PRP-Plastic Oy, Tensile Testing, Thermoplastics
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Abbreviations

AppliGas	Appliances for Burning Gaseous Fuels
Atex	Equipment and Protective Systems Used in Potentially Explosive Atmospheres
CEN	European Committee for Standardization
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DT	Destructive Testing
DVS	Deutscher Verband für Schweissen (German Welding Association)
EC	European Commission
EEA	European Economic Area
EU	European Union
FINAS	Finnish Accreditation Service
HAMK	Hämeen ammattikorkeakoulu (Häme University of Applied Sciences)
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
MPa	Megapascal
MRA	Mutual Recognition Agreement
NDT	Non-Destructive Testing
PP	Polypropylene
PPE	Personal Protective Equipment
PVC (-U)	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
R&TTE	Radio Equipment & Telecommunications Terminal Equipment
SFS	Suomen Standardisoimisliitto (Finnish Standards Association)
TUKES	Turvallisuus- ja kemikaalivirasto (Finnish Safety and Chemicals Agency)
WPS	Welding Procedure Specification

FOREWORD

The reason why I wanted my degree thesis to be commissioned by a company was that I wanted it to be an opportunity to get introduced to the plastic industry in Finland better. During my studies at Arcada University of Applied Sciences I developed a special interest in composite materials. The search for a company in the composite industry nearby Helsinki, lead me to PRP-Plastic Oy. I was impressed by their glass fiber piping production facilities. From what I heard about their projects, I felt that this would be the type of company where I would be very interested in working in the future.

The topic in plastic welding arose from the company's need to certify their new thermoplastic sheet butt welding machine. Before the project I had very little knowledge about plastic welding and on how and why companies certify their machinery. I found it an interesting topic and a very good opportunity to learn something new.

I would like to thank the people at PRP-Plastic for their willingness to work with me for my Degree Thesis. I would especially like to thank Jarkko Räihä and Jukka Niemimäki for putting their time into organizing this project with me and helping on carrying it through. I would also like to thank Juha Räihä for initiating the co-operation with me, and Jari Pokkinen for the help to making the test samples.

A huge thank you to Valeria Poliakova for being my thesis supervisor. Thanks for the time and guidance that I received for getting this work done within the strict time period.

Helsinki, April 2015

Lauri Vesala

1 INTRODUCTION

For ensuring the safety of the public, companies are obligated to follow regulations that have been issued by the European Commission. Standards and directives help to ensure that the products in the market are safe, efficient and environmentally friendly. In the pipe industry it is especially important that the products are durable and resistant to chemical corrosion, mechanical stress, and temperature change, so that the potentially harmful content will not spill into the environment. One of the most common methods for making plastic pipe systems is the butt welding technique.

Butt welding works by melting the joining areas with a heat plate and pressing them together, which fuses the parts. The welding process results in different molecular orientation within the weld compared to the base material. The different orientation can result in unexpected mechanical properties of the joint, and therefore the weld section is a likely place for material failure. In order to reduce the failure risk, the welder must make sure that the joints are made according to standard. A failure in a pressurized or a toxic material containing container may result in severe consequences.

Products that are required to be produced according to certain specifications are often required to be certified. It might also be that instead of the product, the production process or the producer might be evaluated instead. A certified product implies to the customers and to the public that the product is reliable.

1.1 Objectives

The main aim of this work is to argue whether the certification process used in Finland for butt welded products is sufficient for ensuring quality. The claim will be discussed after approaching the four main objectives of this work:

- Identify how certification works in the industry.
- Identify how butt welding works, and the factors affecting weld quality.
- Produce test samples with the Wegener SM 440 TPQ Butt Welding Machine according to the DVS Technical Codes.

- Have the weld samples tested at HAMK with an accredited tensile testing machine. Analyze the results.

1.2 Approach

The certification process is reviewed by taking a look at the notified bodies, the accrediting bodies and their functions. The roles of standards, technical codes and directives and also the certification markings are looked at, and after getting a better understanding of how the certification process works, the butt welding process is reviewed. The proper butt welding technique is introduced by summarizing the DVS technical codes. The codes describe in detail the welding requirements, the correct welding method and parameters among other important information.

PRP-Plastic Oy, the company commissioning this thesis, has a new Wegener SM 440 TPQ thermoplastic sheet butt welding machine. The company wanted to perform a welding procedure test on the machine (*fin:* hitsauksen menetelmäkoe), so that the machine can be certified. The certificate can verify to their customers that the machine functions properly, and that a qualified welder can produce quality welds with the machine. The welding procedure test consisted of a tensile test done on the weld samples and the base material sample, base material being the sample without a weld.

Creating the test samples is the central focus of the practical part of this thesis. Additionally, the author designed a Welding Procedure Specification template for the samples, so that key information about the welding process could be recorded and sent to the Inspecta, the notified body, for certification. The welding procedure test was done testing was done at Hämeenlinna by HAMK with their accredited testing machine. Independently from the procedure test, the author carried out bending tests on the weld and base material samples at Arcada UAS in Helsinki, in order to study the bending properties of the welds.

2 LITERATURE REVIEW

2.1 Certification

2.1.1 Notified and Accrediting Bodies

One of the key functions of the European Union (EU) is to make international trading easier. Free trading within the EU would require for the products to meet the laws for all the countries, which is the reason for the Mutual Recognition Agreements (MRAs). By appreciating the MRAs, the products would meet the common requirements within the EU, making free trade possible. [1] To make sure that unsafe products do not enter the market, the EU requires conformity assessments for the new products. The assessments make sure that all the legislative requirements are met. The conformity assessments are carried out by notified bodies, which have been accredited by the member states of the EU. [2]

The national accrediting body is responsible for giving authority to the notified bodies. The purpose of the accrediting body is to accredit other organizations and to notify these to the European Commission (EC). The Finnish Accreditation Service (FINAS), defines accreditation as “giving formal recognition that a body or person is competent to carry out specific tasks.” [3] The notified bodies are then published by the EC, and are free to offer their conformity assessment services to any operator inside or outside of the EU. [4] This work will also talk about an “accredited” tensile testing machine. In this context, accredited means that the facilities using the machine are authorized to perform official tests in place of the certifying body.

The Finnish legislation assigned FINAS as the national accreditation body in Finland. FINAS is an independent department under the Finnish Safety and Chemical Agency (TUKES), who provide their services to all applicants. [5] In addition to accreditation, FINAS also provides training for assessors, and offers assessment services in various fields. [6]

There are several notified bodies in Finland, and some of the biggest ones are Contesta Oy, DNV Certification Oy, Inspecta Sertifiointi Oy, Suomen ympäristökeskus (SYKE) and VTT Expert Services Oy. [7] The bodies typically provide services in testing, certification and inspection. Inspecta is accredited for various directives, such as pressure equipment, lifts, measuring instruments and cranes among others. [8]

> **Certification:** Action by a third party, demonstrating that adequate confidence is provided that a duly identified product, process or service is in conformity with a specific standard or other normative document.
>
> **Inspection:** Examination of a product design, product, service, process or plant, and determination of their conformity with specific requirements or, on the basis of professional judgement, general requirements.
>
> **Testing:** Technical operation that consists of the determination of one or more characteristics of a given product, process or service according to a specified procedure.
>
> *Tasks of Notified Bodies* [3]

2.1.2 Standards, Technical Codes and Directives

Standards and technical codes are excellent quality references for the manufacturer and the certifying bodies. A standard is a document that states the common procedure for performing certain operations, as defined by the Finnish Standards Association (SFS). Standards typically function as recommendations, but authoritative bodies, such as notified bodies, may use them as procedure requirements. [9]

The standards are developed, issued and sold by standardization organizations, such as the International Organization for Standardization (ISO), the European Committee for Standardization (CEN), the German Institute for Standardization (DIN) or SFS. Standards that have already been confirmed on the international level by ISO can be confirmed by the European or a national organization. For example SFS can confirm an existing EN standard as the national standard, giving the standard the prefix SFS-EN. [9]

Technical codes are a set of practical information about correct processes, devices, applications quality assurance and testing. [10] They are usually based on standards and can also refer to other codes. The codes referred in this work are from the DVS Technical Codes on Plastics Joining Technologies, written by the German Welding Association (DVS). The DVS Technical Codes on Plastics Joining Technologies is a collection of the codes related to plastics joining, and they refer to the German DIN standards. The DVS codes are commonly used in the Finnish industry. [11]

In order to ensure product safety in the European market, the EU has set directives that state certain requirements for various product groups that the products must fulfill. Toys, machinery, electronics, safety devices and pressure equipment are products that fall under directives. One typical requirement stated in the directives is the CE-marking. The directives clearly define which products must be CE-marked and which are not allowed. [9]

2.1.3 Markings

After the certification, the notified body grants the certified body with a certificate and also possibly the permission to place a mark on the product. For example, Inspecta is accredited to grant the CE, FI and Nordic Poly Marks to products that fulfill the requirements for the marking. [12]

The European Conformity (CE-) marking is a required marking for products that are defined by directives that are sold within the European Economic Area (EEA). All other products are not allowed to be CE-marked. [13] The product groups requiring a CE-marking are: AppliGas, Cableway Installations to Carry Persons, Low Voltage Electrical Equipment, Construction Products, Atex, Explosives for Civil Uses, Hot Water Boilers, Lift, Machinery, Measuring Instruments, Medical Devices, Active Implantable Medical Devices, In Vitro Diagnostic Medical Devices, Non-automatic Weighing Instruments, R&TTE, PPE, Simple Pressure Vessels, Pressure Equipment, Recreational Crafts, Toys. (See Abbreviations for AppliGas, Atex, R&TTE and PPE) [14]

Unlike the CE-mark, the FI and Nordic Poly Marks are voluntary markings, meaning that they can be without any restriction to show the customers that the products meet certain quality standards. [15] Certain bodies however may require that the products meet the FI or the Nordic Poly Mark standards. This may for example ensure that the product meets additional requirements needed for the northern climate.

2.1.4 Welding Procedure Test

The welding procedure test is used to test the functionality of a method. Since the weld quality depends on the functionality of the welding equipment and the welding skills of the worker, both the equipment and the worker have to be certified. The workers are typically certified separately for each different type of weld. Additionally the welders can be certified for various destructive testing (DT) and non-destructive testing (NDT) methods. The focus of the welding procedure test in this work is the sheet butt welding procedure. [16]

2.2 Butt Welding

Butt welding, also called heated tool welding, is a technique for joining thermoplastic materials. The method is commonly used for joining individual pipe segments together to create a pipe system, or for joining individual plastic sheets to create a larger sheet. The welding machines can vary in size. The larger machines have to be kept inside workshops, but the smaller machines can be carried to the construction site. Unlike the other plastic welding techniques such as hot gas welding and extrusion welding, butt welding does not add material into the joint. Butt welding uses a heat plate to soften the material of the joint surfaces. The two parts are then pressed together in order to promote material fusion.

2.2.1 Thermoplastic Behavior

Three components play the major role in the quality of the weld: Temperature, pressure and time. With thermoplastics, the temperature plays the major role in how the material behaves: Hot material is soft and fluid and cold material is rigid. Thermoplastics are polymer molecules tangled amongst each other, not bonded by crosslinks. At lower temperatures the molecules are rigid and tangled, but once heat is added, the molecules become flexible and untangled. If the heat is lost, the chains become rigid and tangled once more, solidifying the plastic. [17]

In the welding process, pressure is used to promote molecular movement and fuse the two materials together when the material is hot and fluid. The pressure pushes the molecules from one surface deep into the other. Once the material is cooled, the molecules from the two surfaces materials will tangle and interlock the surfaces together. [17]

The heating and cooling times determine how well the joint surfaces are heated and how well the weld retains its shape. The heating time needs to be suitable so that the heat can penetrate into a certain length into the joint surface, so that enough material can be used to produce the proper joint. After joining, the material needs enough time to cool so that the material will be rigid enough so that the weld's shape is kept and the welded surfaces will not become misaligned. [17] Figure 1 illustrates the molecular behavior of polymers, in respect to heat. Table 1 shows how thermoplastics react to non-ideal welding parameters.

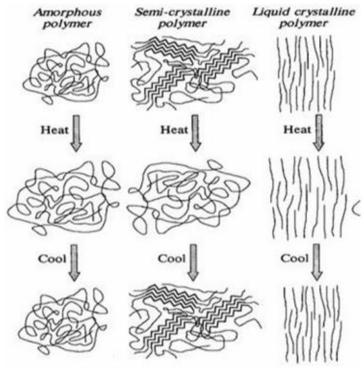


Figure 1: Polymer Molecules Reacting to Heat [18]

Temperature Too High	Molecules begin to oxidize and/or deteriorate.
Temperature Too Low	Molecules are not free enough to diffuse into the other surface.
Pressure Too High	Plastic melt escapes the joint as flash, and the solid plastic surfaces contact each other.
Pressure Too Low	Not enough diffusion of plastic melt between the surfaces.
Heating Time Too High	Material begins to oxidize and/or deteriorate. Too much material is melted.
Heating Time Too Low	Not enough material is melted.

Table 1: Excess Effects of Parameters on Butt Welding [17]

2.2.2 Butt Welding Process According to DVS

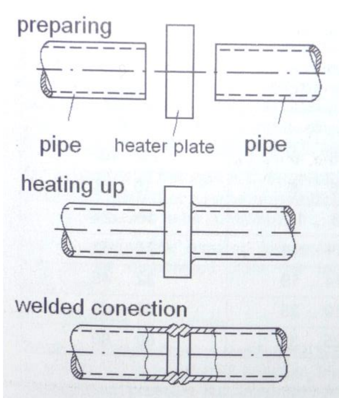
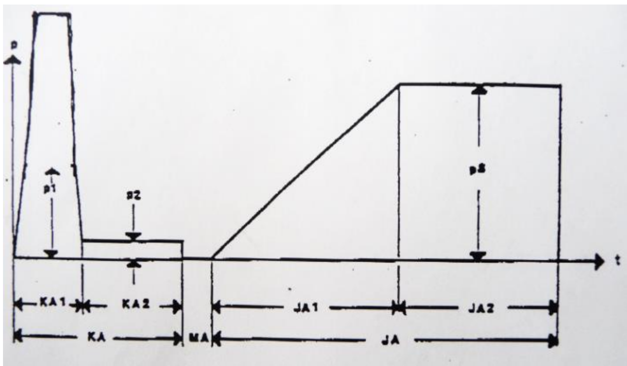


Figure 2: Schematic of the Butt Welding Process [19]



p- Pressure, p1- Alignment pressure,
p2- Heating Pressure,
ps- Welding pressure, t- Time,
KA1- Alignment time, KA2- Heating time,
KA- Heating period,
JA1- Period at full joining pressure,
JA- Cooling period,
MA- Changeover time

Figure 3: Pressure-Time Diagram of the Welding Process [20]

The following steps are taken from the *DVS Technical Code 2207-1: Welding of thermoplastics- Heat tool welding of pipes, pipeline components and sheets made of HDPE,* which is written according to the *DIN EN ISO 14632* standard. The code states that the welder has to be trained and possess a valid qualification certificate. [19] The butt welding process is illustrated in Figure 2, and the welding pressures during the process are illustrated in Figure 3.

1. **Cleaning:** The heated tool, the joining areas and other tools need to be clean and dry. The cleaning agent should be 100% vaporizing, such as ethanol. The cleaning cloth has to be clean, absorbent and non-fuzzy. [19]

2. **Welding Preparation:** The tool is heated to the welding temperature, and has to be cleaned before every operation. The parameters are either installed in the machine, or are obtained from the DVS. The parameters are then set into the machine.

   The joining areas from the two meeting parts must have matching wall thick nesses. The joining areas have to be planed with a clean tool directly before welding in order to remove any oxidized material. The gap between the two joining areas has to be of specific width, to prevent misalignment. [19]

3. **Alignment Phase:** The sheets are clamped to the machine. The welding is initiated by pressing the sheets against the heated tool (at weld temperature) at the alignment pressure. The pressure and the heat against the sheet results in the formation of a coplanar bead on the joining area. The step is finished once the bead has reached its required height. [19]

4. **Heating Phase:** The pressure is lowered to the heating-up pressure. This phase heats up the material further, while not increasing the bead height. [19]

5. **Changeover:** Once the heating phase is complete, the sheets are detached from the heated tool, the heated tool is removed, and the joining areas meet. This step has to be fast, in order to prevent the material from cooling. Cooled material results in a poor weld. [19]

6. **Joining Phase:** The joining areas should meet at slowly after which the joining pressure is built-up at a linear rate. The material is left to cool at joining pressure for the full duration of the cooling time. A uniform regular double-bead must appear after the joining. The ridge formed in the middle of the bead must be no deeper than the height of the bead. Once the full cooling time is reached, the sheet is unclamped and the bead may be removed. [19]

According to the PRP-Plastic welding manual, a quality weld always requires a machine. The manual also mentions that the welded thermoplastic materials should be from the same manufacturer. Different thermoplastics, for example PVC and PVDF, do not properly join together, and should not be welded. [20]

2.2.3 Welding Parameters According to DVS

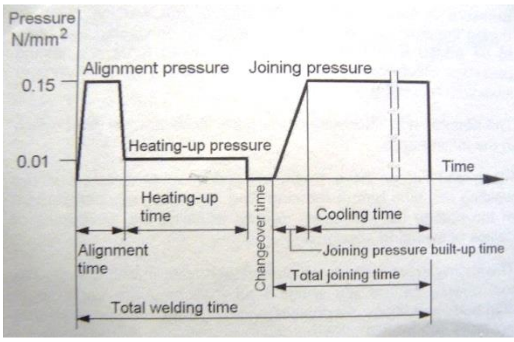


Figure 4: Pressure Chart for Butt Welding of HDPE Sheets [19]

The correct parameters that are required for the butt welding process can be found from the DVS technical codes. The alignment, the heating-up and the joining pressures can be found from the pressure chart (see Figure 4). As an example, the pressure chart above states that the alignment and the joining pressures for HDPE is 0.15MPa, while the heating-up pressure is 0.01MPa. The chart also shows the pressure buildup and decline rates, and it can be seen that at changeover, the pressure is zero. [19]

The heater tool temperature information can be found from the temperature chart. It can be seen that the heater plate temperature is chosen according to the wall thickness of the sheet or pipe. The heater plate temperature for a 10 millimeter thick HDPE sheet would be 213°C (see Figure 5). [19]

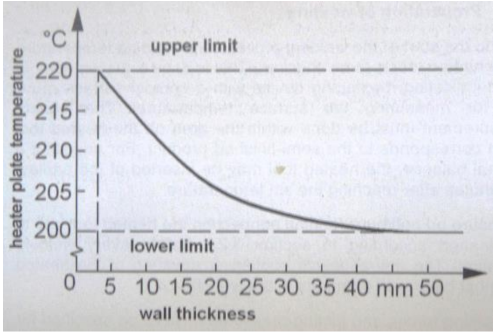


Figure 5: Heater Plate Temperature Chart for HDPE [19]

The information regarding the bead height, the heating-up time, changeover time, joining pressure build-up time and cooling time can be found from the parameter table (see Table 2). It can be seen that the parameters differ according to the wall thickness. [19]

1 Nominal wall thickness s	2 Alignment	3 Heating-up	4 Changeover	5 Joining	
	Heated tool temperature see figure 2				
	Bead height on heated tool on the end of the alignment time (alignment p = 0,15 N/mm²)	Heating-up time =10 x wall thickness p= ≤ 0,01 N/mm²)	Changeover time (Maximum time)	Joining pressure build-up time	Cooling time under joining pressure (minimum values) p = 0,15 N/mm² ± 0,01
mm	mm	s	s	s	min
up to 4,5	0,5	up to 45	5	5	6
4,5 ... 7	1,0	45 ... 70	5 ... 6	5 ... 6	6 ...10
7 ... 12	1,5	70 ... 120	6 ... 8	6 ... 8	10 ...16
12 ... 19	2,0	120 ... 190	8 ... 10	8 ... 11	16 ... 24
19 ... 26	2,5	190 ... 260	10 ... 12	11 ... 14	24 ... 32
26 ... 37	3,0	260 ... 370	12 ... 16	14 ... 19	32 ... 45
37 ... 50	3,5	370 ... 500	16 ... 20	19 ... 25	45 ... 60
50 ... 70	4,0	500 ... 700	20 ... 25	25 ... 35	60 ... 80

Table 2: Parameter Table for HDPE Sheet Butt Welding [19]

The parameters for each type of material are stated in different codes. The Technical code DVS 2207-1 is called *The Welding of thermoplastics: Heated tool welding of pipes, pipeline components and sheets made of HDPE,* while the corresponding code for PP is DVS 2207-11, for PVC-U it is 2207-12, and for PVDF it is DVS 2207-15.

2.2.4 Imperfections in Butt Welds According to DVS

This section goes over some typical faults that may occur if the welding is done incorrectly. A visual inspection is the quickest way to determine if a weld good quality. A good weld should always be correctly aligned and contain an even bead. Even so, the faults may be hidden inside the weld, and therefore other testing methods should be used for weld evaluation. The evaluation should be done by an experienced evaluator. Figure 6 illustrates some of more common imperfections that occur in butt welding. [21]

Even though an imperfection occurs in the weld, it may possibly be allowed if the fault is not severe. The DVS uses an Acceptance Level system to determine whether or not the imperfect weld may be used. Level I products have strict requirements concerning safety and load-bearing capability, allowing only very minor imperfections. Level II products have medium requirements, and Level III products have low requirements concerning the safety and load-bearing capability. To determine the acceptance level for the product, the product designer should make a hazard analysis for the product and consider the following aspects: Production site, hazards, requirements and regulations, the material behavior, operating conditions, and types of loads and stresses applied. [21]

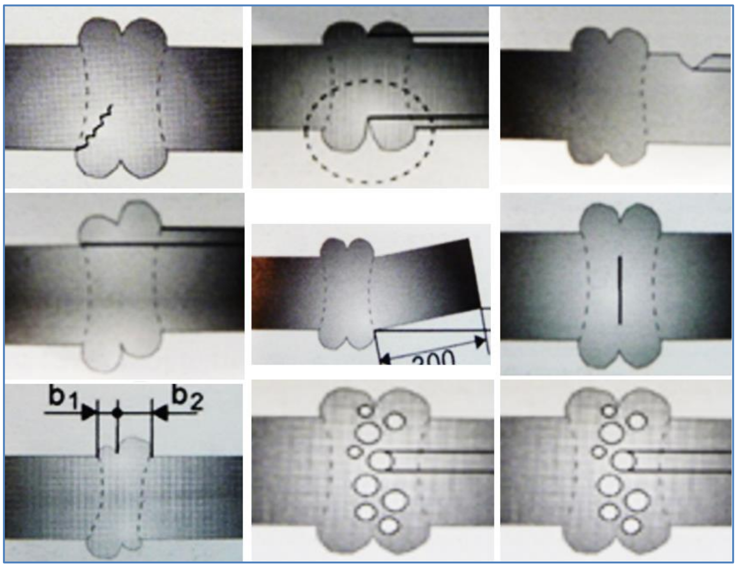


Figure 6: (Left to right, top to bottom) Cracks, Welding flash notches, Notches and score marks, Mismatch of joint faces, Angular mismatch of joint faces, Lack of fusion, Irregular weld bead width, Pores and foreign matter inclusions, Shrinkage cavities/pores [21]

Cracks: Cracks are not permitted. They may be found in the weld, in the base material or in the zone exposed to heating.

Welding Flash Notches: Welding flash notches are permitted only if the notch is no deeper than the height of the bead. They may result from insufficient joint pressure, heating-up time being too short, cooling time being too short, surfaces not being parallel, change of clamped work piece position during welding or mismatch.

Notches and Score Marks: Notches and score marks are allowed, and their allowed depth depends on the acceptance level. These may result from clamping tools, incorrect transportation or edge preparation faults.

Mismatch of Joint Faces: Joint face mismatch is allowed, and the allowed depth of the mismatch depends on the acceptance level. This results from incorrect alignment of the faces, or difference in thickness between the two faces.

Angular Mismatch of Joint Faces: Angular mismatch of joint faces is allowed, and the allowed angle depends on the acceptance level. This may result from a machine tool fault, a tool setup fault, non-permissible joining pressure, deformation or too short of a cooling time.

Lack of Fusion: None or incomplete fusion along the cross-section of the weld is not permitted. This may be caused by damp or wet surfaces, contaminated joint faces, oxidized joint faces, changeover time too long, wrong heated tool temperature or joint compression force too low.

Irregular Bead Weld Width: Irregular bead weld with is allowed, and the allowed width difference depends on the acceptance level. This may result from an angled heated tool, or a non-orthogonal joint face.

Pores and Foreign Material Inclusions: Pores and foreign material inclusions are allowed, and the allowed size of the pores and the allowed concentration of the pores depend on the acceptance level. This may result from evaporation during the welding or dirty heated tool.

Shrinkage Cavities/Pores: Shrinkage cavities and pores are allowed, and the allowed size of the pores and the allowed concentration of the pores depend on the acceptance level. This may result from the joint compression force being too low or the cooling time being too short. Shrinkage cavities are expected in high-crystallinity materials for physical reasons. [21]

The weld evaluator must be an experienced expert. If the imperfections are non-permissible, the evaluator must check for possible systematic faults in the assembly. The evaluator must request repairs or a new weld, and also give recommendations to solve the problem. [21]

2.2.5 Weld Testing According to DVS

DVS recommends a visual evaluation, radiographic/ X-ray test, a tensile test, a tensile creep test and technological bending test methods for the testing of butt welded sheets. The tests should be done by a qualified expert. [19]

Visual Inspection: During the visual inspection, the evaluator should check the external surfaces for imperfections (See section *Imperfections in Butt Welds According to DVS*). [21]

Radiographic or X-Ray Tests: The radiographic and X-ray tests can be used to non-destructively check the interior of the weld for voids or cracks. [19] The process is relatively more expensive, but can detect imperfections very accurately. However because of the gamma-ray and X-ray radiation, this procedure is potentially deadly. This technique is typically used only for ensuring high safety requirements, and is conducted by extremely qualified personnel. [16]

Tensile Test: DVS 2203-2 states the procedure for conducting a tensile test on a weld sample. The samples are not allowed to be heat treated or subjected to mechanical stresses, before the testing. The test sample can be made in three different shapes (see Figure 7). Six weld samples and six base material samples are to be tested. The tensile welding factor is calculated by dividing the maximum strength of the weld sample by the maximum strength of base material. The required welding factors are given by DVS 2203-1 Supplement 1 (see Table 3). The welding factor is the ratio of the weld strength to base material strength. [22]

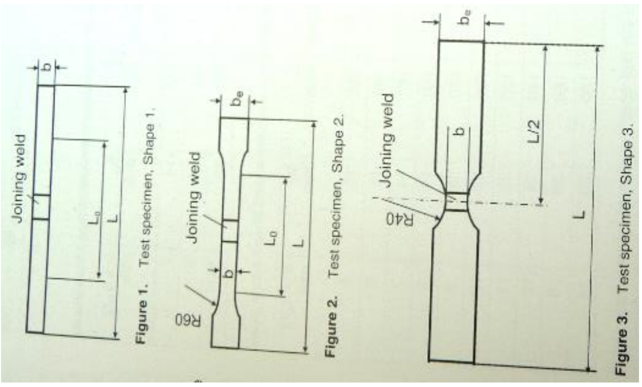


Figure 7: Shapes of Tensile Test Samples [22]

Material	PE	PP	PVC-U	PVC-C	PVDF
Tensile Welding Factor	0.9	0.9	0.9	0.8	0.9

Table 3: Minimum Required Tensile Welding Factor [23]

Creep Test: The test uses a machine that can apply a constant load on a sample at a constant temperature. It measures the time taken for the sample to fracture. The testing conditions of the sample should be similar to the application conditions of the part. The bead should be removed from the sample if it is not on the part. The test can be sped up at an elevated temperature and also with the use of ARKOPAL N-100 aqueous solution. The weld should withstand a minimum long term welding factor. [24]

Three Point Bending Test: The bending test uses a ram and two supports to bend the test sample and measures the applied force and the ram displacement. The ram displacement and the bend angle are the measured results that show the ductility of the weld. The sample dimensions are given in the Table 4.

Table 1. **Dimensions of the test arrangement and the test specimens.**

test specimen				distance between axes of rollers L_s [mm]	diameter of ram a [mm]
thickness s [mm] nominal value	width b [mm]		minimum length L_1 [mm]		
	pipe	plate			
$3 < s \leq 5$	$0.1 \times d$ [1)]	20	150	80	4
$5 < s \leq 10$	min.: 6	20	200	90	8
$10 < s \leq 15$	max.: 30	20	200	100	12.5
$15 < s \leq 20$		30	250	120	16
$20 < s \leq 30$		30	300	160	25

Table 4: Bending Test Dimensions [25]

No heat treatment is allowed, and the test is done at least 8 hours after the welding, and the beads have to be removed. The test is setup so that the sample is placed on the two supports, with the weld under the ram as seen in Figure 8. Six weld samples need to be tested, where three samples are tested per each side. [25]

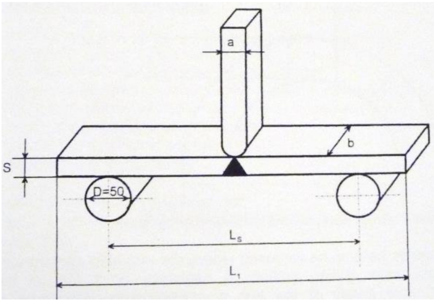


Figure 8: Bending Test Schematic [25]

2.2.6 Additional Method: Spark-Coil Testing

Spark-coil testing is a non-destructive method used for detecting cracks and pores inside a weld. The instrument's tip is run along the weld, where electricity is sent through the cross section to the metal ground. Porosity is indicated by visual sparks. The test uses high voltage, but if the voltage is too high the plastic begins to decompose which needs to be avoided. [26]

3 METHODS

The practical part of this work was to create the test samples, and to participate in the certification process by designing the WPS. The role of this section is to give better insight to the welding procedure, to how the company works, and to the requirements of the certification process. The comparison of the procedures used in making the samples and the procedures presented in the DVS technical codes can then be used to reinforce the main argument of this work.

3.1 Designing a WPS for Sheet Butt Welding

PRP-Plastics wanted the author to design a Welding Procedure Specification template for sheet butt welding. The WPS is used for providing the notified body, Inspecta, with information about the weld. The WPS is presented with the results of the tensile test to Inspecta, who will then decide whether or not to certify the welding machine. The following information was stated in the document:

- Standard
- Date of Weld
- Welding Machine
- Reference Number
- Location
- Welder
- Procedure
- Weld Joint Type
- Material
- Preparation and Cleaning
- Sheet Thickness
- Heated Tool Temperature
- Alignment Pressure
- Heating-up Pressure
- Joining Pressure
- Heating-up Time
- Changeover Time
- Cooling Time Under Joining Pressure
- Environmental Temperature
- Weld Schematic
- Inspections

The content of the WPS was based on the *DVS 2207-1 Protocol form for the heated tool butt welding of sheets* (see Appendix for the WPS document.) [19]

3.2 Creating the Test Samples

Figure 9: Sheet Butt Welding Machine Wegener SM 440 TPQ (Picture by Author)

The model of the welding machine was Wegener SM 440 TPQ, an automated sheet butt welding machine (see Figure 9). The machine has a Teflon coated heated tool, and it can weld 3 to 40 mm thick plastic sheets, with a maximum joint area-wise length of 4.04 meters. The machine's minimum welding force is 900N, meaning that it cannot apply any less welding force. Wegener states that the machine is designed to ensure faultless welds in accordance with DVS 2208-1: *Machines and devices for the heated tool welding of pipes, piping parts and panels*. After entering the material, the sheet thickness and the length, the machine determines the appropriate welding temperature, pressures and times based on the installed DVS parameters. [27]

3.2.1 Materials and Dimensions of the Samples

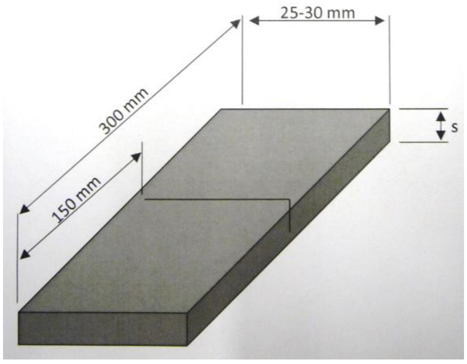


Figure 10: Dimensions of the Test Samples [28]

List of the made samples:

- PP 5mm: 3 Welds + 1 Base Material
- PP 15mm: 4 Welds + 2 Base Material
- PVC 5mm: 3 Welds + 1 Base Material
- PVC 12mm: 4 Welds + 2 Base Material
- PVDF 5mm: 3 Welds + 1 Base Material
- PVDF 15mm: 4 Welds + 2 Base Material

PRP-Plastic tested the Wegener SM 440 TPQ's welding performance for PP, PVC and PVDF sheets. 5mm thick PP, PVC and PVDF sheets, 12mm thick PVC sheets and 15mm thick PP and PVDF sheets were used. HAMK required a set of three weld samples and one base material sample for the tensile tests. The dimensions and the shape of the sample is shown in Figure 10. One set of each material and thickness was taken. The base material sample is a material sample not containing a welded joint. The base material sample was used as a reference for determining the quality of the joint.

The bending test required a set of one weld sample and one base material sample from the 15mm PP sheet, 12mm PVC sheet and 15mm PVDF sheet.

3.2.2 Welding and Making the Samples

Figure 11: PP Sheets Before and After Welding (Picture by Author)

The samples were made from long rectangular sheets, as seen in Figure 11, where the long side is welded. The machine's minimum table force requires the sheet to be long enough, so that the machine is applying the correct amount of pressure on the sheets. If the machine calculated the welding force to be too low, the length of the sheets needs to be increased (see Figure 12).

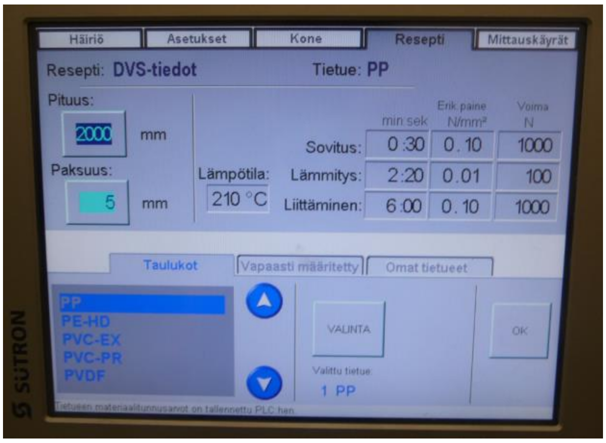


Figure 12: Machine's Display showing the Corresponding Welding Force, Tool Temperature and Duration for the Inserted Parameters (Picture by Author)

Preparation: The sheets were cut straight and even to their appropriate sizes with a band saw. The joining edge and the heated tool were cleaned with cloth and Sinol, an alcohol mixture. The parameters were inserted into the machine, and the tool was heated (see Table 5). The two sheets were placed on the opposite sides of the machine. They were aligned directly opposite of each other against an alignment plate, which ensured a correct distance between the edge of the clamp and the heat tool. After this, hydraulic clamps attached the sheets to the machine (see Figure 13).

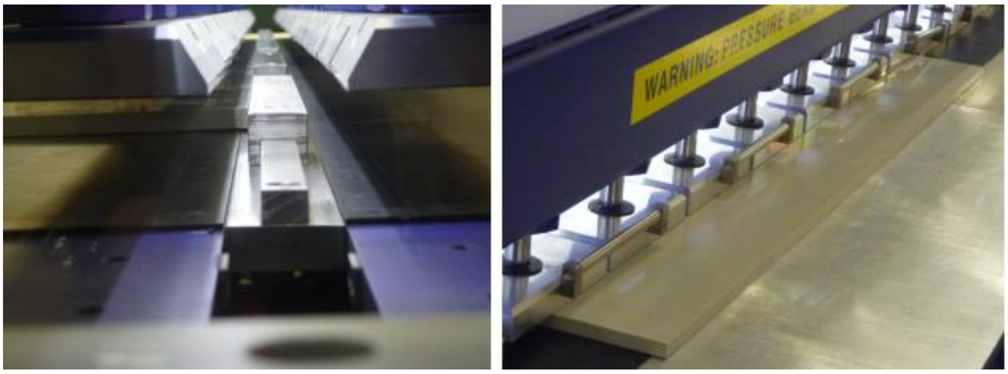


Figure 13: Alignment of the Sheets (Left). Clamping the Sheets (Right) (Picture by Author)

Welding: After the sheets were in place and the parameters were set into the machine, the welding process was initiated by pressing the start button. The process was fully automatic. During the process, the display showed which stage was in progress, the duration of the stage, the welding forces, the duration of the process, and the temperature of the tool (see Figures 14 and 15).

Figure 14: The Initiated Process at the Alignment Phase (Left). Process Completed (Right) (Picture by Author)

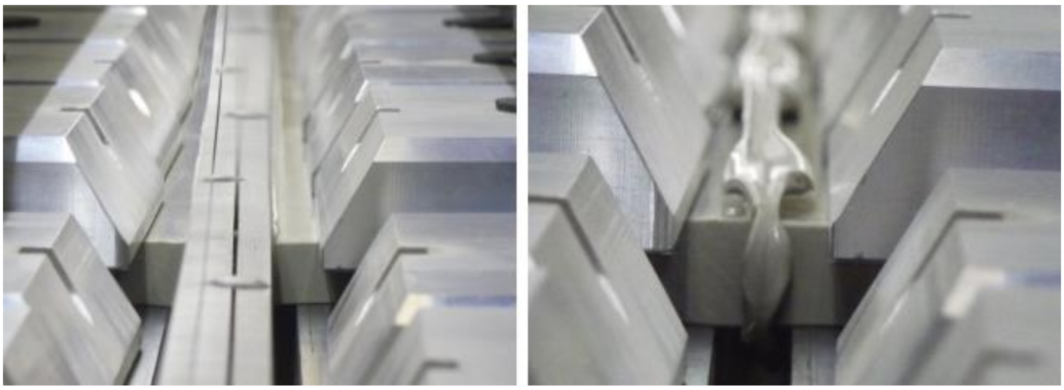


Figure 15: Bead is formed by pressing the Sheets against the Heated Tool (Left). The Sheets are pressed together and joined (Right) (Picture by Author)

After-Processing/ Making the Test Samples: After the sheets were joined, the beads were removed using a planer (see Figure 16). The sheets were then cut into samples with the band saw.

Figure 16: Sheet before Bead Removal (Left). Sheet after Bead Removal (Right) (Picture by Author)

	Units	DVS 2207-11		DVS 2207-12		DVS 2207-15	
		PP	PP	PVC-U	PVC-U	PVDF	PVDF
Nominal Wall Thickness	mm	5	15	5	12	5	15
Heat Tool Temperature	°C	210	210	230	230	240	240
Alignment/Joining Pressure	N/mm²	0.1	0.1	0.6	0.6	0.1	0.1
Heating-up Pressure	N/mm²	0.01	0.01	0.01	0.01	0.01	0.01
Alignment Time	s	30	120	-	95	-	60
Heating-up Time	s	140	280	75	180	90	190
Cooling Time	min	6	24	10	24	8	20

Table 5: Welding Parameters

3.3 Testing

3.3.1 Tensile Testing at HAMK

The tensile testing for the welding procedure test was done by HAMK. The testing machine was accredited, so HAMK had the authority to conduct the testing for Inspecta. The tests were performed with the Zwick/Roell Z050 tensile machine, which was calibrated two weeks prior to the tests by VTT (see Figure17). Its maximum pulling force was 50kN and the pulling speed was 10mm/min.

The three weld samples from each material-thickness set were tested and the average tensile strength was measured. The tensile welding factor would then be calculated by dividing the average weld strength with the tensile strength of the base material sample. The required welding factor for the tests was 0.8. The results were afterwards sent to PRP-Plastic, from where they would be sent to Inspecta along with the WPS for certification.

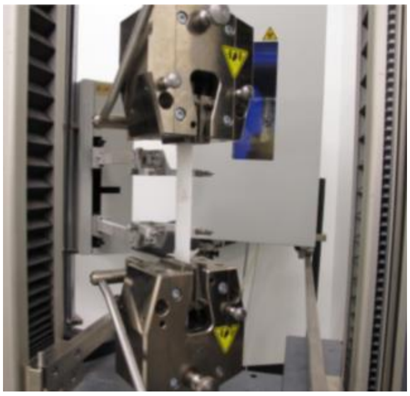


Figure 17: Sample Attached to the Zwick/ Roell Z050 Tensile Testing Machine [29]

3.3.2 Bend Testing at Arcada UAS

The three point bending test was completely independent to the welding procedure test and the certification of the welding machine. Its purpose was to study the bending properties of the welds. The tests were done at the Plastic Laboratory in the Department of Materials and Energy Technology in Arcada UAS by the author. The tests were performed with the Testometric M 350- 5CT, which can implement a maximum pulling force of 5kN.

One sample of each 12 and 15mm weld samples and base material samples were tested. The span between the supports was 120mm and the ram was located directly in the middle. The test setup was so that the weld was directly underneath the ram (see Figure 18).

The results of the bending tests were obtained in force/displacement; therefore the flexural strength had to be calculated by using Equation 1. The weld factor was then calculated to compare the flexural strengths between the weld sample and the base material sample.

Equation 1:

$$\sigma = \frac{3FL}{2bd^2}$$

Where σ is flexural strength, F is load, L is the length of the support span, b is width and d is thickness. [30]

Samples:

- 120x30x15mm PP weld sample + 120x30x15mm PP base material sample
- 120x30x12mm PVC weld sample+ 120x30x12mm PVC base material sample
- 120x30x15mm PVDF weld sample + 120x30x15mm PVDF base material sample

Figure 18: Bending Test Setup (Picture by Author)

4 RESULTS

4.1 HAMK Tensile Test

Table 6 shows the results of the tensile tests. The results show that the welds were barely weaker than the base material, with the exception of PVC. The welding factor of the 12mm PVC sheet was below 0.8, therefore not fulfilling the requirements.

Sample	Units	PP		PVC		PVDF	
		5mm	15mm	5mm	12mm	5mm	15mm
Base Material	MPa	31	32.7	50	45	50.9	51.2
Average Weld	MPa	30.4	31.8	45.5	32.4	49.8	51.1
Tensile Welding Factor		0.98	0.97	0.91	0.72	0.98	0.998

Table 6: Maximum Tensile Strength

Description of the Material Failure:

The PP samples fractured partly from the base material (see Figure 19). The joints were successful and the material fractured after reaching the maximum stress of the base material. [29]

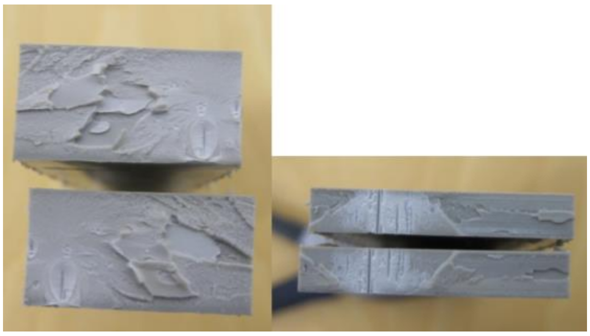


Figure 19: Fractured PP Samples (cross-sectional view) [29]

The PVDF samples fractured partly from the base material, but mainly from the joint (see Figure 20). The joints were successful and the material fractured after reaching the maximum stress of the base material. [29]

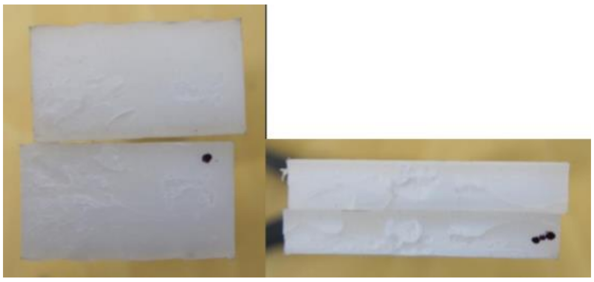


Figure 20: Fractured PVDF Samples (cross-sectional view) [29]

The PVC joint was successful only for the 5mm samples, where the material fractured clearly from the side of the base material (see Figure 21). The joint was unsuccessful for the 12mm samples. The fracture was brittle and the weld clearly contained pores. The fracture was significantly lower for the weld in comparison to the base material. [29]

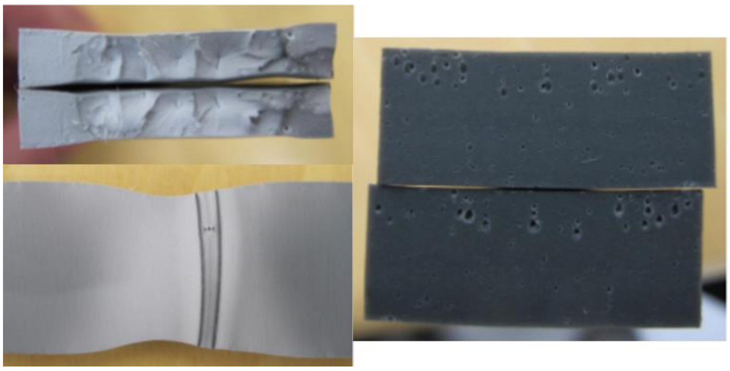


Figure 21: Fractured and Un-fractured PVC Sample (cross-sectional view) [29]

4.2 Arcada Three Point Bending Test

Table 7 shows the results of the three point bending test. The results show that all of the welds surpassed the 0.8 flexural welding factor. The 12mm PVC weld sample scored also the lowest welding factor in this test, reinforcing the conclusion that the 12mm PVC weld was of poor quality.

Sample	Units	PP 15mm	PVC 12 mm	PVDF 15mm
Base Material	MPa	74.8	88.7	123.9
Weld	MPa	72.5	78.4	119.6
Welding Factor		0.97	0.88	0.96

Table 7: Results of Tensile and Bending Tests

Description of the Material Failure:

The bending test showed that all of the base material samples were very ductile and none of them fractured during the testing. Figure 22 shows the condition of the base material samples after the testing.

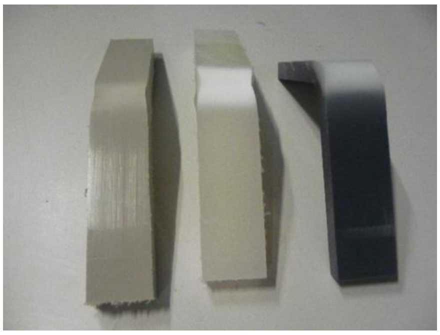


Figure 22: Base Material Samples after Testing (Picture by Author)

The PP weld sample did not fail during the test. Slight necking was seen at the top part of the weld, while the lower part showed very little deformation. The results show that the welded sample had a slightly lesser flexural strength than the base material sample, but the ductility of the two samples was very similar (see Figure 23).

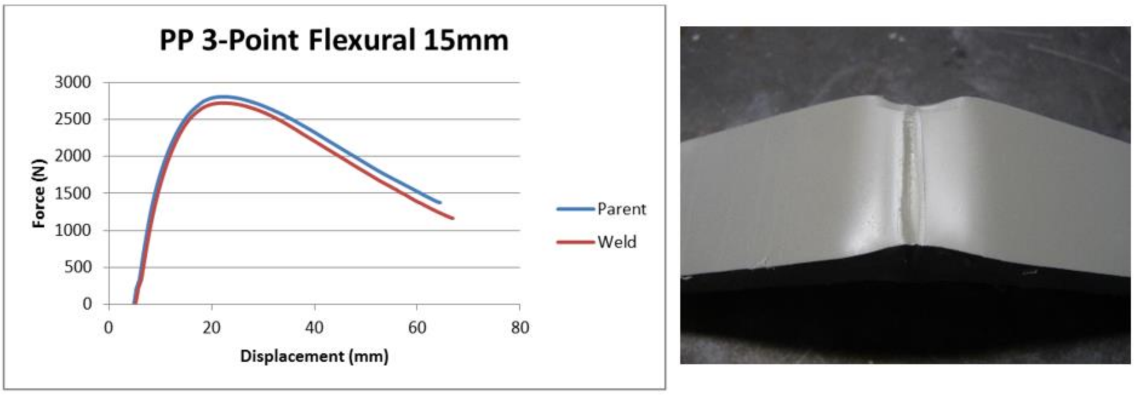


Figure 23: Bending Test Results of the PP Samples (Left) PP Weld Sample after Testing (top view) (Right) (Picture by Author)

The PVC weld sample failed violently during the test. The weld sample was significantly more brittle and weaker than the base material sample. The cross-section of the weld contained numerous pores (see Figure 24).

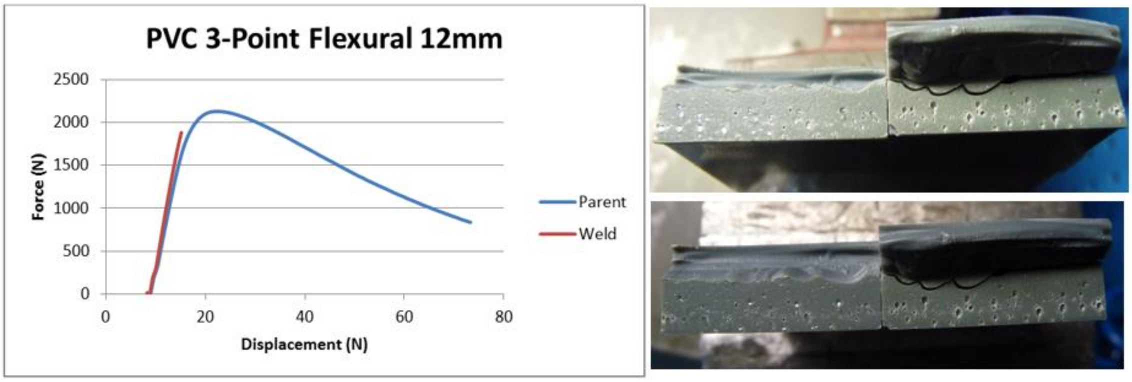


Figure 24: Bending Test Results of the PVC Samples (Left) PVC Weld Sample after Testing (cross-sectional view) (Right) (Picture by Author)

The PVDF weld sample failed violently during the test. The weld sample was significantly more brittle, but almost as strong in comparison to the base material sample. The cross-section of the weld contained no noticeable pores (see Figure 25).

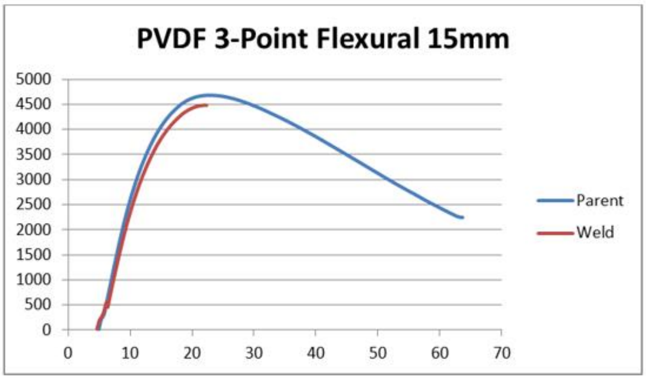


Figure 25: Bending Test Results of the PVDF Samples (Left) PVDF Weld Sample after Testing (cross-sectional view) (Right) (Picture by Author)

Result Summary:

From the weld samples, only the 12mm PVC sample failed. It is quite likely that Inspecta may request a new weld. The cross-section of the weld showed numerous pores, which may be shrinkage cavities due to cooling, or pores due to impurities on the joining area. The testers from HAMK suspected that the material was too cool during the joining phase of the welding.

5 DISCUSSION AND CONCLUSION

The purpose of this work was to study the certification process of a butt welding machine. The main aim was to understand how certification works and how it ensures weld quality. In this work the weld procedure testing was conducted on the Wegener SM 440 TPQ. It was noticed that the DVS technical codes were followed very closely for creating the test samples, but the test procedure itself was much more different than suggested in the DVS.

Even though the DVS technical codes presented a wide range of testing techniques, the testing process used in the welding procedure testing was simple. The welding procedure testing was done only with a tensile test that tested only 3 samples and required a tensile welding factor of 0.8, instead of the DVS recommendations of 6 samples and TWF of 0.9. Even though PRP-Plastics and likely many other companies around Finland use the DVS codes in their daily operations, why were the test techniques not followed as closely as the welding procedures? Why was the welding procedure test so simple in comparison to the recommendations, and why was the tensile test chosen over the testing methods?

In relation to the welding procedure test, the main function of the DVS codes was to be a guide for producing top quality welds. When it came to testing, the test method hardly played any role in the quality of the weld. It was therefore chosen that the tensile test would be used in the welding procedure test, because of its simplicity and the amount of information that it can provide the evaluator about the weld quality.

The tensile test gave information about the maximum strength of the sample, the elastic modulus, the ductility and the cross-sectional view of the sample’s fracture point for visual inspection. For conducting all of the mentioned radiography, X-ray, creep, tests, spark-coil, and bending tests, the parties would require equipment, time and samples. Most of this would be excessive for the purpose of verifying that a machine is able to perform correctly and produce quality welds.

The tensile and bending tests showed how the properties of welded sheets compare with homogeneous sheets. In general the weld only slightly reduced the strength of the sheets, which would not be a major issue for applications if the operation load of the joint has a good margin to the maximum strength. The bigger issue was that the welds in general were much more brittle than the base material. If the joint is kept below the maximum strength, the brittleness would not be a problem, but since weld quality can vary, the joint could fail without much warning. Working on this problem could lower the risk of joint failure. Two suggestions for this would be to use a filler material, or perhaps a post-welding procedure. It should be kept in mind that typically hot plate welding is suitable only for homogeneous polymers; therefore the filler material suggestion would require research.

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APPENDICES

Appendix 1: PRP-Plastic WPS for Butt Welding of Sheets (Document by Author)

PRP-Plastic
INDUTRADE GROUP

WPS- THERMOPLASTICS

BUTT WELDING- PP Sheet

DIN EN ISO 15013 | Date of Welding: | Machine: Wegener SM 400 TPQ

Reference NO: | Location: Mänsälä | Welder:

JOINT

Procedure: The work is performed according to the PRP-Plastic Oy manual: Sections 'puskuhitsaus'.

Weld Joint Type: Butt welding | Parent Material: Polypropylene

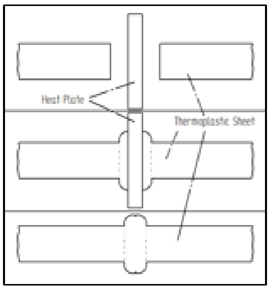
Class: Thermal fusion melt | Preparation and Cleaning Method:

WELD PREPARATION DETAILS

Sheet Thickness (mm)	
Checked Heated Tool Temperature (˚C min/max)	
Alignment Pressure (bar)	
Heating-up Pressure (bar)	
Joining Pressure (bar)	

Heating-up Time (s)	
Joining Pressure Build-up Time (s)	
Changeover Time (s)	
Cooling Time Under Joining Pressure (s)	
Environmental Temperature (˚C)	

Weld Schematic:



INSPECTIONS

- Macro-photography
- Tensile test. Three tests per weld type.
- Bending test. Three tests per weld type.
- Spark Inductor Inspection.

APPROVAL

Date: | Name: | Signature: