KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINNERING AND DESIGN

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INVESTIGATION OF WELDING PROCESS AND QUALITY OF WELDED JOINTS

Final Project for Master's degree

Supervisor
Assoc. prof. dr. Saulius Baskutis

KAUNAS, 2016

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINNERING AND DESIGN
DEPARTMENT OF PRODUCTION ENGINEERING

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Final Project for Master's degree
Industrial engineering and management (code 621H77003)

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KAUNAS, 2016

KAUNAS UNIVERSITY OF TECHNOLOGY

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(Title of study programme, code)

INVESTIGATION OF WELDING PROCESS AND QUALITY OF WELDED JOINTS

DECLARATION OF ACADEMIC INTEGRITY

I confirm that the final project of mine, **Algirdas Sriubas**, on the subject "Investigation of welding process and quality of welded joints" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources; all direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

I fully and completely understand that any discovery of any facts of dishonesty inevitably results in me incurring a penalty under procedure effective at Kaunas University of Technology.

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Production engineering
Department

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(Signature, date)

Kazimieras Juzėnas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

INVESTIGATION OF WELDING PROCESS AND QUALITY OF WELDED JOINTS

Approved by the Dean Order No.V25-11-7, 3 May 2016

2. Aim of the project

The main aim of the Master‘s degree final project is to obtain appropriate variations between mechanical parameters of structural steel S235JR welded with three different welding methods and quality of seams, with minimum amount of defects

3. Structure of the project

INTRODUCTION, LITERATURE REVIEW, EXPERIMENTAL SETUPS AND PROCEDURES, RESULTS AND DISCUSSIONS, CONCLUSIONS, APPENDICES

4. Requirements and conditions

1. To analyze welding’s impact to materials mechanical properties.

2. To determine strongest welding method.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 20__ ________ __st.

Given to the student
____

Task Assignment received ______________________________ ________________________
(*Name, Surname of the Student)* (*Signature, date*)

Supervisor ______________________________ ______________________
(*Position, Name, Surname)* (*Signature, date*)

Sriubas, Algirdas. *INVESTIGATION of WELDING PROCESS and QUALITY of WELDED JOINTS* Master‘s thesis / supervisor assoc. prof. Saulius Baskutis. The Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study area and field: Production and Manufacturing Engineering, Technological Sciences

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Kaunas, 2016. 60p.

SUMMARY

A weld is made when separate pieces of material needs to be joined and form one piece while are heated to a temperature high enough to cause softening or melting. Additional filler material is typically added to strengthen the joint. Welding is a dependable, efficient and economic method for permanently joining similar metals. The most common used processes are manual metal arc welding (MMAW), fluxed core arc welding (FCAW) and gas tungsten arc welding (GTAW or TIG). All of these methods employ an electric power supply to create an arc which melts the base metal(s) to form a molten pool.

The investigation of welding structural steel S235JR with these 3 different types of the welding has been done with the help of company "Marbusta". After the welding these specimens were tested with tensile test in Kaunas university of technology laboratories to find out how every type of the welding affects materials mechanical properties as tensile, yield strength and elongation. Results were analysed using function F=f (Δl) curves. Company „Metesta" helped on investigation of quality in welded joints. Using radiography test method (RT) photos with defects were acquired and analysed according to ISO standard. The hardness distribution along the fusion, heat affected and parent metal zones is presented.

All results received during the investigation are analysed and discussed in this project.

Sriubas, Algirdas. SUVIRINIMO PROCESO IR SUVIRINTŲ SUJUNGIMŲ KOKYBĖS TYRIMAS. Magistro baigiamasis projektas / vadovas doc. dr. Saulius Baskutis; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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Reikšminiai žodžiai: *suvirinimas, sujungimas, tempimas, kietumas, radiografija.*

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SANTRAUKA

Suvirinimo siūlė yra gaunama, kai atskiros medžiagos dalys, kurios bus sujungtos, yra šildomos iki pakankamai didelės tempartūros, kol atsiranda lydymosi efektas. Pridetinė medžiaga paprastai naudojama sujungimui sustiprinti. Suvirinimas yra patikimas, veiksmingas ir ekonomiškas būdas ilgalaikiui medžiagų sujungimui. Dažniausiai vartojami procesai yra rankinis lankinis suvirinimas elektrodais (MMAW), suvirinimas pusautomačiu naudojant miltelinę vielą (FCAW) ir suvirinimas nelydžiu volframo elektrodu inertinėse dujose (GTAW arba TIG). Visi šie būdai naudoja elektros srovę, kad sukurtu elektros lanką, kuris lydo pagrindinį metalą ir sukuria lydymosi baseiną.

Tyrimas, suvirinant bandinius šiais trimis skirtingais būdas, įvykdytas padedant įmonei UAB „Marbusta“. Po suvirinimo šie pavyzdžiai buvo išbandyti tempimo bandymu Kauno technologijos universiteto laboratorijoje siekiant išsiaiškinti, kokią įtaką turi suvirinimas medžiagų mechaninėms savybėms, tokioms kaip takumo ir stiprumo ribai, bei pailgėjimui. Rezultatai buvo analizuojami naudojant gautas funkcijos F =f(Δl) kreives. UAB „Metesta“padėjo atliekant suvirintų sujungimų kokybės tyrimą. Naudojant radiografinį prašvietimo bandymo metodą (RT), nuotraukos su defektais buvo gautos ir analizuotos pagal ISO standartą. Kietumo pasiskirstymas suvirinimo siūlėje, šilumos paveiktoje ir pagrindinio metalo zonose taip pat pateikiamas.

Visi tyrimo metu gauti rezultatai yra pateikiami ir analizuojami šioje ataskaitoje.

Gratitude

I would like to express my gratitude to the supervisor S. Baskutis, for help in my master‘s thesis investigation.

Table of content

INTRODUCTION

The number of different welding processes has grown in recent years. These processes differ greatly in the manner in which heat and pressure (when used) are applied, and in the type of equipment used. There are currently over 50 different types of welding processes; we'll focus on 3 examples of electric arc welding, which is the most common form of welding.

The most popular processes in industry are manual metal arc welding (MMAW), flux cored arc welding (FCAW) and tungsten inert gas welding (TIG). All there types uses some type of gas or flux to create inert environment in which weld pool could solidify without oxidizing.

During welding material is affected by huge amount of heat which can have impact to materials physical properties and chemical composition in the fusion zone may be changed due to filler metal melting. Investigation of tensile and hardness tests of butt welds with different welding methods were done. The hardness distribution on the cross-section of the welded joints is presented. Quality tests of welded joints were done using radiography test method (RT).

The main aim of the Master‘s degree final project is to obtain appropriate variations between mechanical parameters of structural steel S235JR welded with three different welding methods and quality of seams with minimum amount of defects.

The thesis aims to achieve the following objectives:

- to determine how different welding methods affects materials mechanical and physical properties;
- to estimate hardness variations in fusion, heat affected and parent metal zones;
- to examine the specimen with non-destructive (NDT) method to test the quality of the weld;
- to determine which welding process should be used in order to achieve strongest weld beads.

1. LITERATURE REVIEW

1.1 About the company

While working in steel constructions manufacturing company, topic for master thesis was thinked out, and company agreed to help on my investigation. Marbusta Ltd main strongest activities are pipe welding, installation, reconstruction and repairing of all kinds of metals. Company is a subcontractor with the biggest Lithuanian and foreign petrochemical, food industrial, pharmaceutical, construction and shipping companies [1]. It has skilled personnel, equipment and technologies which are necessary for works . They appreciate the professionalism and willingness to succeed of their employees. The company has 2500 m^2 workshop for manufacturing different metal constructions, which includes shot blasting room, painting room, warehouse and machinery area. Activities of the company are:

- The rent of qualified workers for short or long term (welders, assemblers, pipe fitters, lockshmiths);
- Engineering services (3D designing, project documentation, quality control,);
- Production and instalation (construction parts, different types of tanks, containers, reservoirs);
- Welding (111 Metal-arc welding with covered electrode, 131 MIG welding: metal-arc inert gas welding, 135 MAG welding: metal-arc active gas welding, 136 Flux-cored wire metal-arc welding with active gas shield, 141 TIG root layer / 135 MAG overlay layers combined welding process, Plastic Fusion pre-heating and post-welding heat treatment);
- Transportation, shipping (world wide transportation by containers, lorries and ships).

The company agreed to help in my investigation of welding processes and provided all required equipment, materials and staff.

Fig. 1.1 Company logo [1]

1.2 Metal preparation for welding

In this chapter how important metal preparation for welding is discussed. Types and notes how properly prepare metal for welding are described in below topics as well.

1.2.1 Surface preparation

Preparation of surfaces before joining is a critical operation in ensuring the integrity of a joint. It is necessary to ensure that the surfaces in and around the joint are clean, free from scale and other heavy oxide coatings, dry and free from organic materials. Properly cleaning the metal takes time, but it is worth the effort to insure that your welds are of the best quality and integrity. Below are some steps to follow in order to properly clean the metal which will be welded [2].

- Metal surface has to be checked before welding. If there is any rusts, coatings or dusts, it is important to remove it.
- To remove rusts a grinder or steel wool may be used.
- To remove a bad weld and make new is better than try to fix old one. Starting with a clean slate means that you can create a weld that will be strong.
- Edges of join should be machined with angle grinder. Clean edges are necessary that the weld would be strong and solid.
- Doing surface preparation process, pair of glasses should be worn to protect eyes.

Various methods and grades of cleanliness are applied in surface preparation. It can be done by hand cleaning, power tool or abrasive blast cleaning. Surface preparation is a most important step in a corrosion protection system

Hand and power tool cleaning

Surface cleaning by hand tools such as scrapers and wire brushes is relatively ineffective in removing mill scale or adherent rust. Power tools offer a slight improvement over manual methods and these methods can be approximately 30% to 50% effective, but are not usually utilised for new steelwork fabrications [2]. Sometimes it is not possible to clean by abrasive blasting and hand and power tool methods may be the only acceptable alternative methods. Modern power tooling has been developed not only to achieve a good standard of surface cleanliness and profile, but also to gather and to help workers avoid all dust and debris generated.

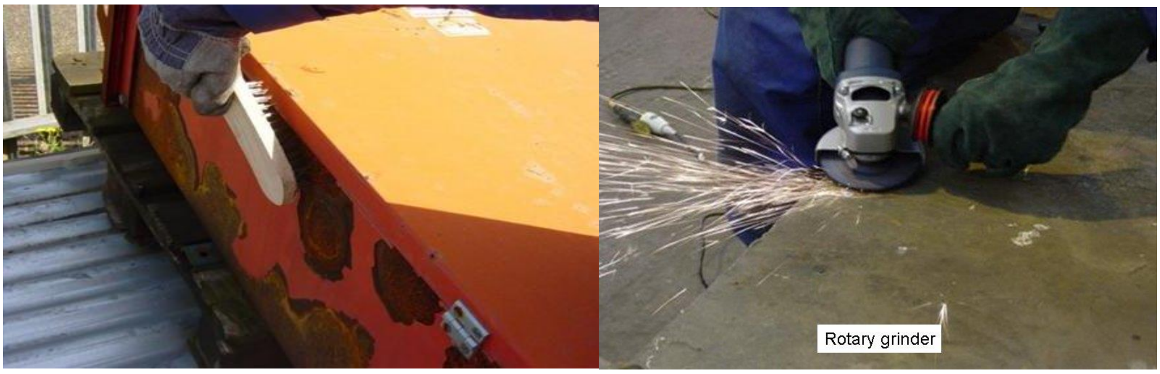


Fig. 1.2 Surface cleaning with hand and power tool [2]

Abrasive blast cleaning

By far the most significant and important method used for the thorough cleaning of mill-scaled and rusted surfaces is abrasive blast cleaning. This method involves mechanical cleaning by the continuous impact of abrasive particles at high velocities on to the steel surface either in a jet stream of compressed air or by centrifugal impellers [2]. The latter method requires large stationary equipment fitted with radial bladed wheels onto which the abrasive is fed. As the wheels spins at high speed, the abrasive is thrown onto the steel surface, the force of impact being determined by the size of the wheels and their radial velocity. The abrasives are recycled with separator screens to remove fine particles. This process can be 100% efficient in the removal of mill scale and rust.

Fig. 1.3 Surface cleaning with abrasive blast [2]

1.2.2 Joint preparation

The type of joint selected for any welding job may materially affect the quality and strength of the weld; the cost of labor and materials; the time and expense involved in preparing, jigging, and positioning the work; and other factors of like importance. The selection of joint type depends from thickness and material, sizes, accessibility to weld, available equipment etc. There are many types of butt welds, but all are divided into these categories: single welded butt joints, double welded butt joint, and open or closed butt joints. A single welded butt joint is the name for a joint that has only been welded from one side. A double welded butt joint is created when the weld has been welded from both sides. With double welding, the depths of each weld can vary slightl [5]. A closed weld is a type of joint in which the two pieces that will be joined are touching during the welding process. An open weld is the joint type where a gap between to pieces is left during welding process.

V – joints

Single-V butt welds are similar to a bevel joint, difference is only that both sides are beveled. In thick metals, and when welding can be performed from both sides of the work piece, a double-V joint is used. When welding thicker metals, a double-V joint requires less filler material because there are two narrower V-joints compared to a wider single-V joint. Also the double-V joint helps compensate for warping forces. With a single-V joint, stress tends to warp the piece in one direction when the V-joint is filled, but with a double-V-joint, there are welds on both sides of the material, having opposing stresses, straightening the material [9].

J – joints

Single-J butt welds are when one piece of the weld is in the shape of a *J* that easily accepts filler material and the other piece is square. A J-groove is formed either with special cutting machinery or by grinding the joint edge into the form of a J. Although a J-groove is more difficult and costly to prepare than a V-groove, a single J-groove on metal between a half an inch and three quarters of an inch thick provides a stronger weld that requires less filler material. Double-J butt welds have one piece that has a *J* shape from both directions and the other piece is square [9].

U – joints

Single-U butt welds are welds that have both edges of the weld surface shaped like a *J*, but when they are joined together, they form a U. Double-U joints have a *U* formation on both sides.

.

Table 1. Workpiece thickness limits per joint type[3]

Joint type	Thickness
Square joint	Up to 6.35 mm
Single-bevel joint	4.76–9.53 mm
Double-bevel joint	Up to 9.53 mm
Single-V joint	Up to 19.05 mm
Double-V joint	Over 19.05 mm
Single-J joint	12.70–19.05 mm
Double-J joint	Over 19.05 mm
Single-U joint	Up to 19.05 mm
Double-U joint	Over 19.05 mm
Flange (edge of corner)	Sheet metals less than 2.657 mm
Flare groove	All thickness

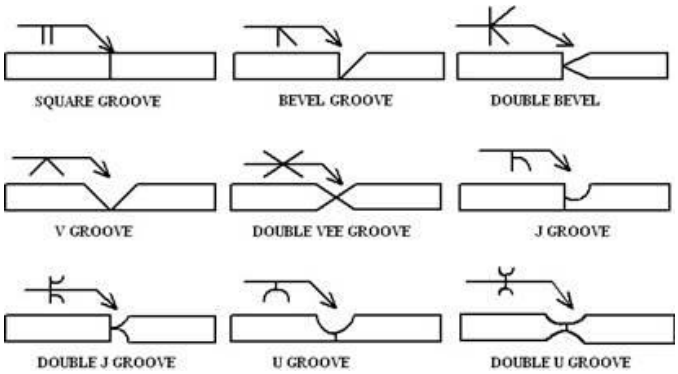


Fig. 1.4 Butt joints geometries [3]

Above are listed preferable joint thicknesses for the various types of butt welding joints. When the thickness of a butt weld is defined it is measured at the thinner part and does not compensate for the weld reinforcement

1.3 Welding types

1.3.1 Shielded metal arc welding or manual metal arc welding (111 MMAW or SMAW)

MMAW (Manual Metal Arc welding) or SMAW (Shielded Metal Arc Welding) is:

- Metals are melted by the heat impact;
- The heat comes from an electric arc that is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded;
- Has to be done with a consumable electrode, with solid metal sheath and coated in flux to lay the weld;
- Arc striking influenced by short cutting;
- Can be done inside or on the open air;

The consumable electrode:

1. It protects the solidifying weld metal from atmospheric contamination
2. It prevents the weld metal cooling too rapidly;
3. It controls the contour of completed weld

As the weld is laid, the flux coating of the electrode evaporates giving off vapours a layer of slag. The flux provides molten slag witch covers the filler metal as it travels from the electrode to the weld pool. Once part of the weld pool is formed, the slag floats to the surface and protects the weld from atmospheric contamination as it solidifies. Once hardened, it should be chipped away to reveal the finished weld. The process is shown in the Fig. 1.6.

DCEN (Direct Current Electrode Negative): Causes heat to build up in the electrode, increasing the electrode melting rate and decreasing the depth of the weld [4].

Applications:

- Maintenance and repair industries;
- Ship industry;
- Pipes;

Advantages:

- Equipment cheap, simple and portable;
- Welding is possible in any position;
- Can be done inside and in the open air.

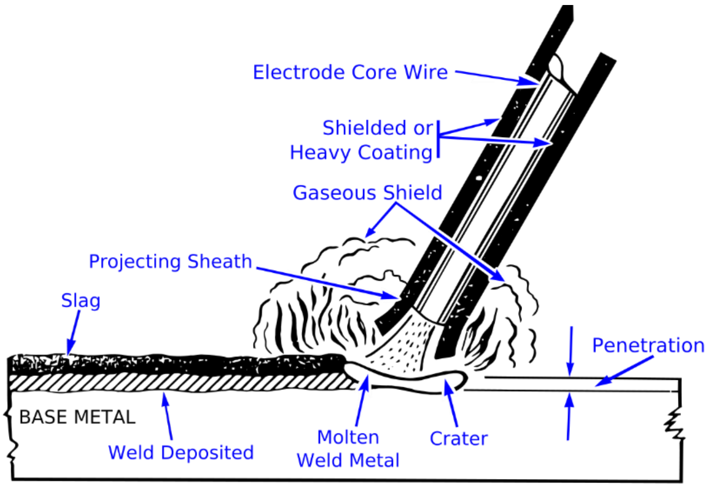


Fig. 1.6 Shielded metal arc welding weld area [4]

Disadvantages:

- Smokes prejudicial to health;
- Electrode type choice is crucial;
- Hydroscopic electrodes;
- Need to remove slag immediately due inclusions problems;
- Quality depends welder skills;

1.3.2 Metal-arc inert gas and metal-arc active gas welding (131 MIG, 135 MAG)

Metal Inert Gas Welding (Gas Metal Arc Welding) is a arc welding process, in which the weld is shielded by an external gas (Argon, helium, CO_2, argon+Oxygen or other gas mixtures). Consumable electrode wire, having chemical composition similar to that of the parent material, is continuously fed from a spool to the arc zone. The arc heats and melts both the work pieces edges and the electrode wire. The fused electrode material is supplied to the surfaces of the work pieces, fills the weld pool and forms joint. As feeding of the filling wire (electrode) the process is called as a semi-automatic. The welder controls only the torch positioning and speed.

Advantages of Metal Inert/Active Gas Welding (MIG, MAG):

- Welding with no interruptions can be produced;
- Not skilled labour can do it;
- No slag;

Disadvantages of Metal Inert/Active Gas Welding (MIG, MAG):

- Expensive and non-portable equipment is required;
- Outdoor application are limited because of effect of wind, dispersing the shielding gas.

Metal-arc active gas welding (135 MAG).

Gas-shielded metal arc welding is an arc welding process where an endless wire electrode melts under a shielding-gas cover which protects the welding zone against environmental influences. This process is characterised by high versatility with respect to the material, the degree of mechanisation and the welding position. Gas-shielded metal arc welding can be used for almost all weldable materials. Unalloyed and alloyed steels are preferably welded with active gases, e.g. carbon dioxide. This variety is called metal active gas welding, in short MAG welding.

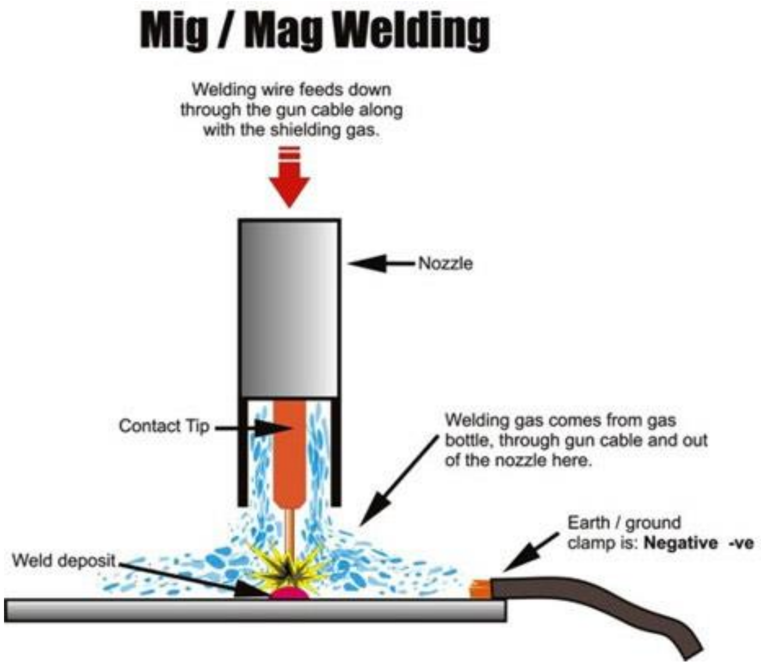


Fig. 1.7 MIG/MAG weld area [5]

1.3.3 Flux-cored arc welding (136 FCAW)

Flux-cored arc welding (FCAW or FCA) is an arc welding process that uses ac arc between a continuous filler metal electrode and the weld pool. FCAW requires a continuously-fed consumable tubular electrode containing a flux and a constant-voltage or, less commonly, a constant-current welding power supply. The process is used with shielding gas from a flux contained within the tubular electrode with or without additional shielding from an externally supplied gas [5]. This process is widely used in construction because of its high welding speed and portability. The advantage of FCAW over SMAW is that the use of the stick electrodes used in SMAW is unnecessary. This helped FCAW to overcome many of the restrictions associated with SMAW. Process is shown in Fig. 1.8.

Advantages:

- FCAW may be an "all-position" process with the right filler metals (the consumable electrode);
- No shielding gas needed with some wires, so it can be used for outdoor welding and/or windy conditions;
- A high-deposition rate process (speed at which the filler metal is applied);
- Can be automotive;
- As compared to SMAW and GTAW, there is less skill required for operators;
- Less precleaning of metal required;
- Metallurgical benefits from the flux such as the weld metal being protected initially from external factors until the slag is chipped away.

Applications:

- Mild and low alloy steels;
- Stainless steels;
- Some high nickel alloys;
- Some wearfacing/surfacing alloys;
- Porosity chances very low.

Disadvantages:

- Porosity – the gases (specifically those from the flux-core) don't escape the welded area before the metal hardens, leaving holes in the welded metal;
- More costly filler material/wire as compared to GMAW;
- The equipment is less mobile and more expensive as compared to SMAW or GTAW.

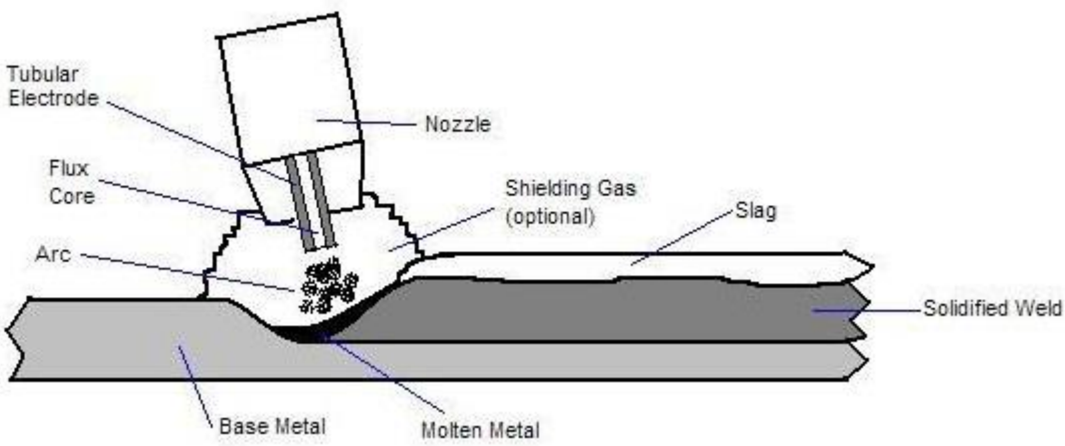


Fig. 1.8 FCAW weld area [6]

1.3.4 Gas tungsten arc welding (141 TIG, GTAW)

Gas Tungsten Arc Welding is and arc welding process that uses arc between a tungsten electrode (non-consumable) and the weld pool (Fig. 1.9). The electrode, the arc, and the area surrounding the molten weld puddle are protected from the atmosphere by an inert gas shield. A filler metal is necessary if thinner materials, edge joints and flange joints are welded. For thicker materials an externally fed or cold filler rod is generally used [5]. Gas tungsten arc welding produces most clean welds with no slag, the chance inclusions in the weld metal is and the finished weld requires virtually no cleaning. Argon and Helium, the primary shielding gases employed, are inert gases. Inert gases do not chemically combine with other elements and therefore, are used to exclude the reactive gases, such as oxygen and nitrogen, which can get in from outside.

Applications

Gas tungsten arc welding is widely used for joining thin wall tubing and for making root passes in pipe joints. It is an all-position welding process. Full penetration without an excessively high inside bead is important in the root pass, and due to the ease of current control of this process, it lends itself to control of back-bead size. For high quality welds, it is usually necessary to provide an inert shielding gas inside the pipe to prevent oxidation of the inside weld bead.

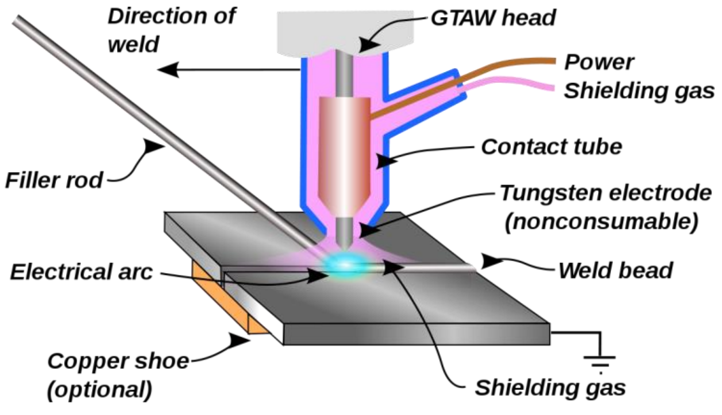


Fig. 1.9 TIG welding weld area [7]

Advantages of TIG welding:

- Produces high quality welds in almost all metals and alloys;
- The weld is automatically protected by the inner gas during the welding process;
- Very little, if any, post weld cleaning is required;
- Can be done in all-positions.

Disadvantages of TIG welding;

- Slow process;
- Requires highly skilled labour;
- Welder is exposed to huge intensities of light;
- More expensive than MIG/MAG.

1.4 Welded seams quality inspection types

In this paragraph non-destructive quality inspection types are discussed and explained in the below chapters.

1.4.1 Visual inspection (VT)

Visual inspection is the most widely used non-destructive testing technique. It is extremely effective and the least expensive inspection method. The welding inspector can use visual inspection throughout the entire production cycle of a weldment, It is an effective quality control method that will ensure procedure conformity and will catch errors at early stages [6].

1.4.2 Radiographic inspection (RT)

Radiography (X-ray) is one of the most important, versatile and widely accepted of all the non-destructive examination methods. X-ray is used to determine the internal soundness of welds. The term 'X-ray quality," widely used to indicate high quality in welds, arises from this inspection method. -rays are produced by high-voltage generators. As the high voltage applied to an X-ray tube is increased, the wavelength of the emitted X-ray becomes shorter, providing more penetrating power. Gamma rays are produced by the atomic disintegration of radioisotopes. The radioactive isotopes most widely used in industrial radiography are Cobalt 60 and Iridium 192. This allows them to penetrate to greater depths than X-rays of the same power, however, exposure times are considerably longer due to the lower intensity [10]. The amount of energy absorbed by a material depends on its thickness and density. Thus a thinner part will absorb less energy than a thick part. Energy not absorbed by the material will cause exposure of the radiographic film and there areas will be dark. Areas of the film exposed to less energy remain lighter. Therefore, areas of the material where the thickness has been changed by discontinuities, such as porosity or cracs, will appear as dark outlines on the film.

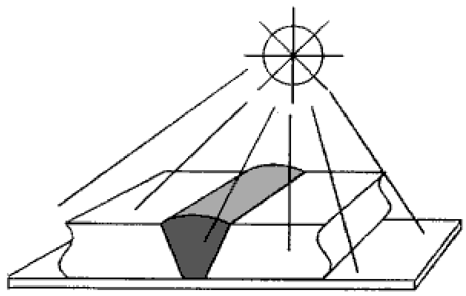


Fig. 1.10 Radiography is one of the most widely accepted examinations method [8]

1.4.3 Liquid penetrant inspection (PT)

Liquid-penetrant examination (PT) is a highly sensitive, non-destructive method for detecting minute discontinuities (flaws) such as cracks, pores, and porosity, which are open to the surface of the materials being inspected. Although there are several types of penetrants and developers of them [6]. A liquid penetrant is applied to the surface of the part to be inspected. The penetrant is dawn into the surface opening by capillary action. The high contrast between the fluorescent material and the object makes it possible to detect minute traces of penetrant that indicate surface defects. Dye penetrant inspection is similar, except that vividly coloured dyes visible under ordinary light are used. The part to be inspected must be dry and clean, because any foreign matter could close the cracks and exclude the penetrant. Penetrants can be applied by dipping, spraying or brushing, but sufficient time must be allowed for the liquid to be fully absorbed into the discontinuities. This may take a hour or more. This type of inspection is widely used to locate leaks in welds and can be applied with austenitic steles and nonferrous materials [10].

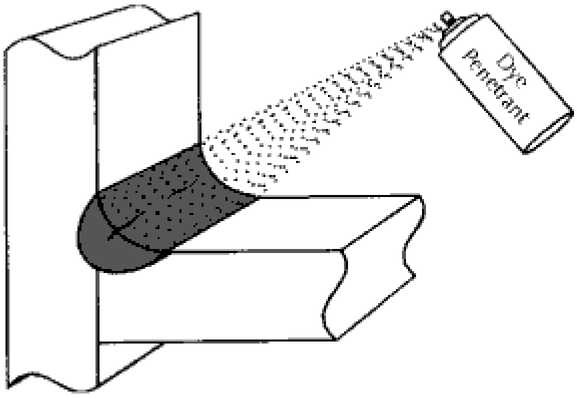


Fig. 1.11 Liquid penetrant inspection method [8]

1.5 Tensile test

One of the simplest tests for determining mechanical properties of a material is the tensile test. In this test, a load is applied along the longitudinal axis of a test specimen. The applied load and the resulting elongation of the member are measured. Load-deformation data obtained from tensile and/or compressive tests do not give a direct indication of the material behaviour, because they depend on the specimen geometry. Loads and deformations may be converted to stresses and strains.

Stress: $\sigma = \frac{F}{A_0}$; (1)

Strains: $= \frac{\Delta l}{l}$; (2)

Elongation: $\delta = \frac{\Delta l - L}{L} * 100\%$; (3)

Modulus of elasticity: $E = \frac{\sigma}{\varepsilon}$ or $E = \frac{F * l}{\Delta l * A}$ (4)

Where:

σ = normal stress on a plane perpendicular to the longitudinal axis of the specimen (MPa); F = applied load (N); A_0 = original cross sectional area (m^2); ε = normal strain in the longitudinal direction (m/m); δ = change in the specimen's gage length (%); L = original gage length (m); Δl = length after tensile test (m); E = Modulus of elasticity (GPa).

The resulting stress-strain curve or diagram gives a direct indication of the material properties.

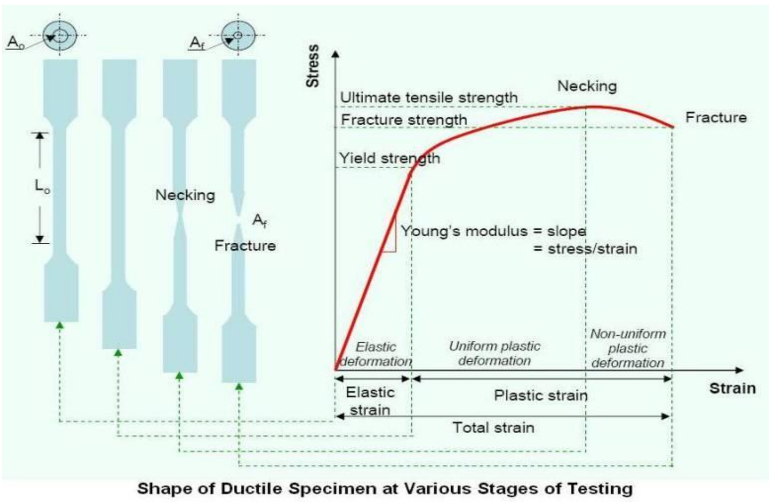


Fig. 1.12 Tensile test stress-strain diagram [9]

1.6 Hardness test

The hardness can be defined as „the resistance the metal exhibits to permanent deformation by penetration of other harder material“. Within materials science, typically four different hardness testing methods are available: Vickers, Knoop, Brinell and Rockwell. The Vickers Hardness (HV) is calculated by measuring the diagonal lengths of an indent left by introducing a diamond pyramid indenter with a given load into the test material. Vickers has wide range of use and can be applied to many situations.

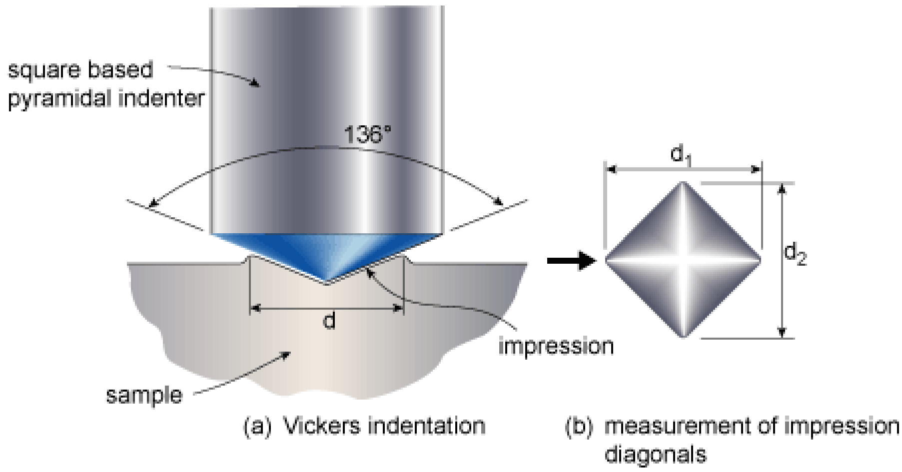


Fig. 1.13 Vickers hardness test method [10]

2. EXPERIMENTAL SETUPS AND PROCEDURES

In this section are featured investigation of experimental procedure, equipment overview and mechanical properties analysis. The main goal was to find out which welding type is strongest on stretching. The plates were prepared in „Marbusta Ltd" workshop and experiment was accomplished in the laboratories at Kaunas University of Technology.

2.1 Experiment procedures

Plasma jet cutting. As all plates were cut with plasma jet cutter (description in chapter 2.2), first of all G codes for CNC laser cutting machine were created. For that purpose FastCAM software (description in chapter 2.2) was used. G codes for plate counter are demonstrated in figure 2.1. 12 similar plates in same conditions were cut out from 4 mm thickness S235JR material (description in chapter 2.3) steel sheet, dimensions and real example is shown in figure 2.3. Process is indicated in figure 2.2.

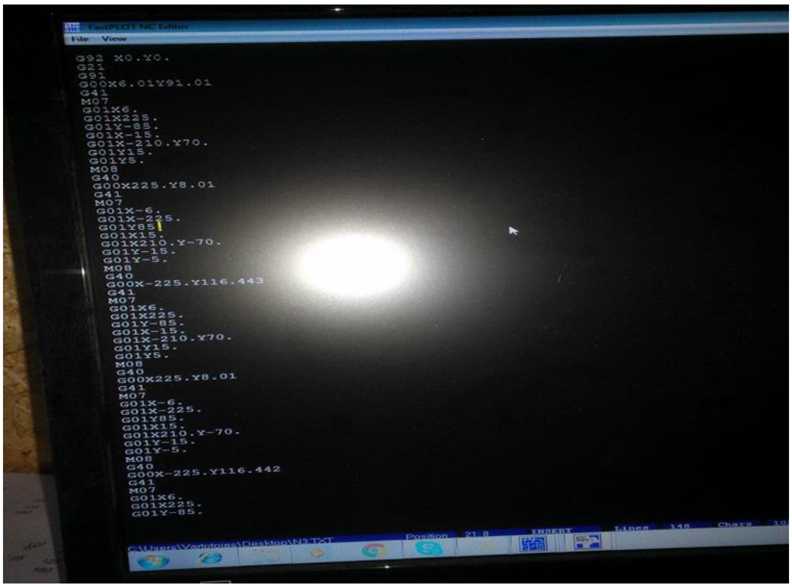


Fig 2.1 G codes were generated using FastCAM software

Fig 2.2 CNC plasma jet cutting

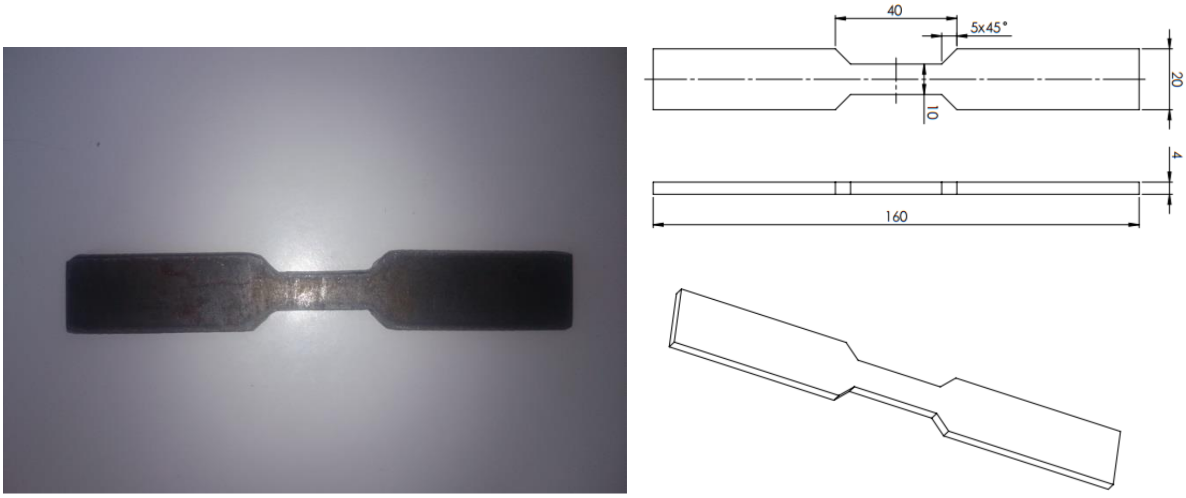


Fig. 2.3 Cutted plate and dimensions of it

Joint type and preparation. Single bevel groove joint was selected as most suitable joint for that kind of welding. As plates edges after plasma jet cutting were not completely clean, they were cleaned using angle grinder. The same angle grinder was used to cut plates into 2 pieces and prepare joint for welding. Groove angle is 30±3°. Root opening – 1 mm. Edges were prepared according to LST EN ISO 9692-1:2004 standard. Plates surfaces quality was good enough, so nothing more to improve it was necessary. Joint type and real example are shown in figures 2.4 and 2.5.

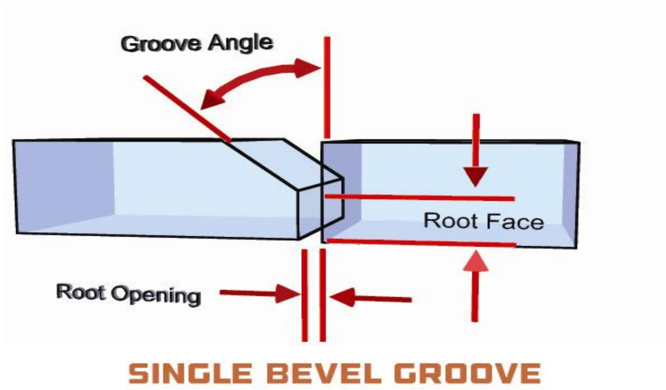


Fig. 2.4 Joint type – single bevel groove

Fig. 2.5 Real example of joint type – single bevel groove

Welding types and parameters. Totally 9 plates were welded. Three of them using manual metal arc welding (111, MMAW), three using flux-cored arc welding (136, FCAW) and three using gas tungsten arc welding (141, TIG). Three plates left not welded to compare results. All plates were with the same joints, welded by the same welder in the same conditions. For gas tungsten arc weldig argon inert gas was used as shielding gas, while for flux-cored arc welding carbonic acid gas was used. Type of the weld – butt weld according to LST EN ISO 17659. Welding process and how specimens looked after the welding is shown in figures 2.6 and 2.7 respectively. Welding process specifications for every type of the welding are attached in the Annexes 1.

Fig. 2.6 Welding process

Fig. 2.7 Plates after welding. PA – 136 type, EL- 111 type, AR – 141 type.

Tensile test. Tensile properties show how the material reacts to forces being applied. For that reason a prepared specimen is loaded in universal elektromechanical test machine (description is presented in chapter 2.2). Then they were stretching slowly increasing stretching power till they were interrupted and applied load and the elongation of specimen were measured (figure 2.8). All tests were done under the laboratory environment at room temperature 20±2 ^{o}C and 55±5 % relative humidity. During this experiment power needed to interrupt plates welded in different types was obtained also using displacement sensor and software (description is presented in chapter 2.2). All data from test machine and displacement sensor was sent to computer and using HBM software (description is presented in chapter 2.2) excel files were created. Tensile test is used to determine the modulus of elasticity, elongation, tensile strength, and yield strength.

The main product of a tensile test is a load versus elongation curve, which can be converted into stress vesus strain curve. Each material has its own unique stress-strain curve.

Fig. 2.8 Interrupted plate after stretching experiment

Fig 2.9 Displacement sensor attached to plate in order to measure displacements during stretching

Hardness test. Another important mechanical property of material is hardness. Reaserch aim is to measure hardness in different welded specimen's areas (welded zone, heat-affected zone (HAZ), parent metal) and compare if welding type has impact to measured results. In order to do that, breaked plates had to be mechanically cutted into small pieces (Fig. 2.10) and layied into special forms using polyester resin and Ø40 diameter tube. After 1 hour, when epoxy stagnated, samples were polished with different roughness abrasives to acquire right surface for microhardness testing (Fig. 2.11). Using microhardness tester VMHT (description is presented in chapter 2.2) indentations every 0.5 mm were made to find out how welding area were affected during the welding. Acquired data is shown and analyzed in charts in the chapter 3.3.

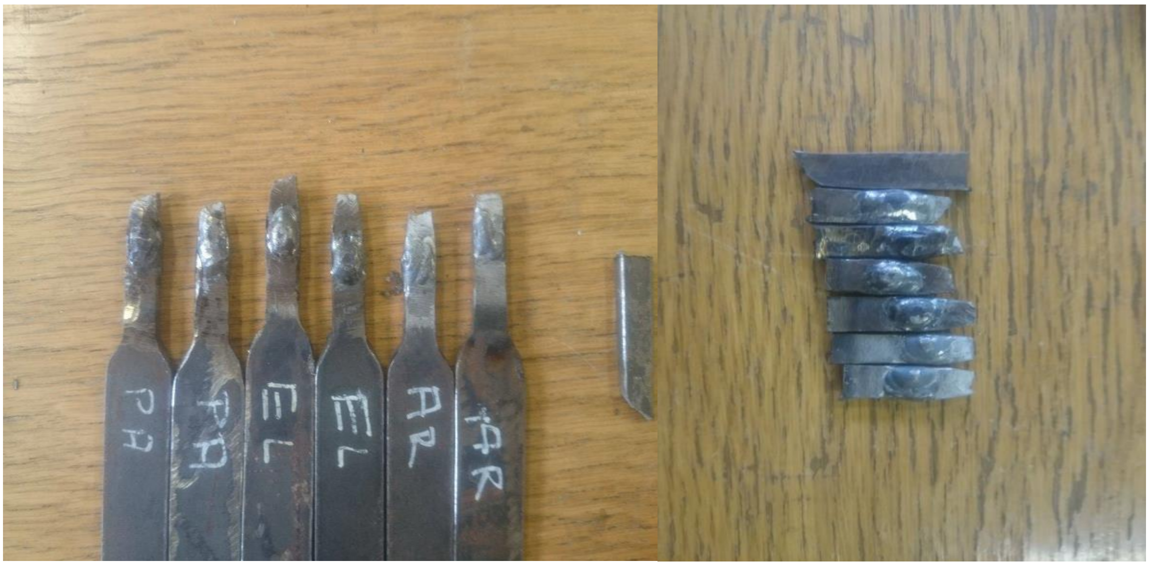


Fig. 2.10 After the tensile test, broken plates were cutted into the smaller pieces

Fig. 2.11 Prepared macrographs for microhardness test

2.2 Equipment used in reaserch

1)Lincoln CNC plasma jet cutter with water table

The Tomahawk® 1538 Plasma cutting machines are built to cut different width metal sheets. Cutting with plasma max – 40mm, with gas mas – 140mm. Technical specifications are listed below.

Product	Item Number	Primary Voltage (50-60Hz)	Rated Output	Cutting Capacity (mm)	Flow Rate	Inlet Pressure	Output Range (A)	Weight (kg)	Dimensions HxWxD (mm)
Tomahawk® 1025	K12048-1	400V/3Ph	60A/40% 40A/100%	25	130l/min+/-20%@5.0bar	6.0 bar	20-60	22	389 x 247 x 489
Tomahawk® 1538	K12039-1		100A/40% 60A/100%	40	180l/min+/-0%@5.0bar	7.0 bar	20-100	36	455 x 301 x 618

Fig.2.12 Lincoln Tomahawk 1538 technical specifications [11]

Fig. 2.13 Lincoln Tomahawk 1538

2) FastCAM software

CAD CAM CNC Software Series created for integrated 2D drawing, tool pathing, true shape nesting, code verification & NC generation for CNC machines. User friendly and free download available.

3) Kemppi masterTIG MLS 2000

Kemppi MASTERTIG MLS™ 2000 is a TIG welding system especially designed for industrial use and for welding. The equipment consists of a power source, panel and TIG-welding torch. The power source is a multifunctional and can be used for MMA welding also, only welding torch need to be changed. The welding torch is cooled with gas.

Fig. 2.14 For TIG and MMAW welding KEMPPI masterTIG MLS2000 were used

MasterTig MLS™		2000
Connection voltage	50/60 Hz	1~, 230 V -10 % ... +10 %
Rated power at max current	TIG	6.5 kVA
	MMA	7.1 kVA
Connection cable	HO7RN-F	3G2.5 (3.3 m)
Fuse, delayed		16 A
Load capacity 40° C	30 % ED TIG	200 A/18 V
	60 % ED TIG	150 A/16 V
	100 % ED TIG	130 A/15.2 V
	35 % ED MMA	160 A/26.4 V
	40 % ED MMA	-
	60 % ED MMA	140 A/25.6 V
	100 % ED MMA	120 A/24.8 V
Welding range	TIG	5 A/10 V– 200 A/18 V
	MMA	10 A/20.5 V– 160 A/26.4 V
Open circuit voltage		80 V DC
Power factor at max current		0.75
Efficiency at maximum current		80 %
Stick electrode	ø mm	1.5…4.0
External dimensions	L x W x H, mm	410 x 180 x 390
Weight	kg	15

Fig. 2.15 Technical speicifcation of MasterTIG 2000 [12]

4) Jasic MIG350

The Jasic MIG 350 Compact is equipped with powerful IGBT components, digital A/V display, 4-roll wire feed and multi process capabilities. The inverter is made for excellent welding characteristics and perfect performance for highly demanding and repetitive weld cycles is guaranteed. This high quality three-phase machine delivers best conditions for medium to heavy duty fabrication work.

Fig. 2.16 For FCAW Jasic MIG350 welder were used

Technical Data

Input Voltage (3 Phase)	AC 400V - 50/60 Hz
Input Power (kVA)	15
Current Range (A)	MMA - 20 - 350 MIG - 50 - 350
MIG Voltage Range (V)	15 - 38
No-Load Voltage (V)	65
Duty Cycle @ 40℃	350A @ 40%
Wire Spool Size	ø 300mm
Efficiency (%)	85
Power Factor	0.93
Protection/ Insulation Class	IP21S/F
Dimensions (mm)	900 x 400 x 670
Weight (Kg)	54

Fig. 2.17 Jasic MIG350 technical specification [13]

5) Universal elektromechanical test machine

The machine designed to be used in laboratories for quality control and research on metals. The machine is composed by a strong base containing the transmission components and the hardware control instruments. The main body is made from two columns that guide the cross-bar; they are made of high resistance steel with ground hard chrome surfacing. The system is suitable to make both tests: with single direction or dual direction. Maximum load capacity – 50kN.

Fig. 2.18 Universal elektromechanical test machine. Maximum load capacity – 50 kN

6) HBM displacement sensor U5

The U5 force transducer is convincing not simply from the measuring point of view, but also can be fitted easily for example in test benches, press-fit devices, presses and test devices, just as in other industrial applications. Because mounting the U5 is extremely easy to use: for pressure and tension measurements without an adapter, directly on the structural element. In this case it was used to measure tensile tests displacements.

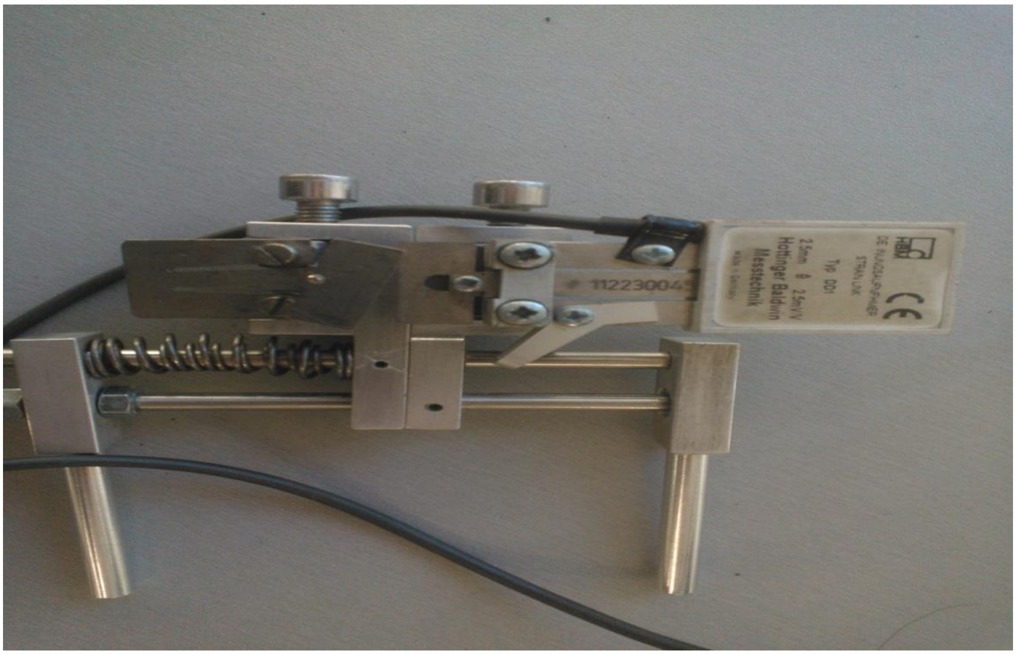


Fig. 2.19 HBM displacement sensor type U5

7) HBM software

Special software developed to receive test results from displacement sensors, helps to analyse and visualize acquired results.

Fig. 2.20 HBM software Spider 8

8) Micro hardness tester VMHT

The micro hardness testers of the UHL VMHT series provide semi or fully-automatic low-load Vickers or Knoop hardness testing from 1 g to 2 kg. Using brilliant Leica optics and a high valuable load mechanism with fixed weights to apply the test force, repeatable and long time stable results are achieved.

Fig. 2.21 VMHT micro hardness tester

2.3 Material

All experiments were performed from non-alloy structural steel S235JR (standard: EN 10025 – 2:2004, European standard for hot-rolled structural steel). The chemical composition and the mechanical and physical properties of used material are provided in tables 2.1 and 2.2, respectively. All plates were machined by plasma jet cutting as discussed in chapter 2.1. After cutting plates were cooled in room temperature water.

Table 2.1. Mechanical properties of steel S235JR [14]

	Minimum yield strength Reh MPa	Tensile strength Rm MPa	Minimum elongation - A Lo = 5,65 * √So (%)				Notch impact test	
Steel grade	Nominal thickness mm	Nominal thickness mm	Nominal thickness mm				Temperature	Min. absorbed energy
	≤16	>3 ≤100	>3 ≤40	>40 ≤63	>63 ≤100	>100 ≤125	°C	J
S235JR	235	360-510	26	25	24	22	+20	27

Table 2.2. Chemical composition of steel S235JR [14]

Steel grade	C max. %			Mn max. %	Si max. %	P max. %	S max. %	N max. %	Cu max. %
	Nominal thickness mm								
	≤16	>16 ≤40	>40						
S235JR	0,17	0,17	0,20	0.48	0.01	0.018	0,040	0,004	0,03

3. RESULTS AND DISCUSSIONS

In this chapter results are shown received from different procedures such as tensile test and radiography inspection. The data was processed with the spreadsheet software Microsoft Excel. Calculations of stress, strain, modulus of elasticity and change in the specimen's gage length (%) are calculated in order to compare results.

3.1 Tensile test analysis

During tensile test plates welded with different types were tested. The data of force variation and plate displacements were received in Excel files. Charts representing results and calculations are shown and compared below. Function: F=f(Δl).

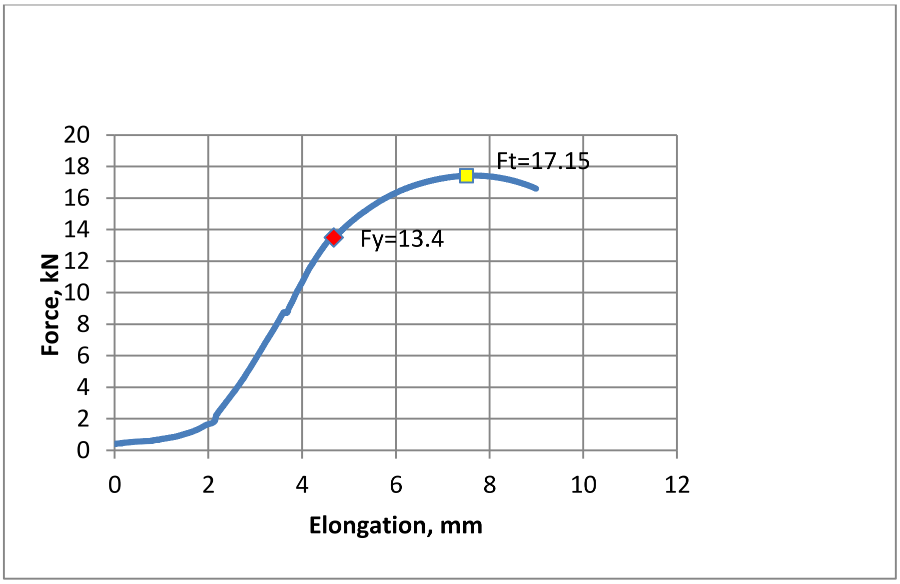


Fig 3.1 Stress-strain chart of plate welded with 111 type

Yield strength is a minimum relative stress at which the sample elongates without increasing the load and is equal to load divided by cross-sectional area. Some materials as high strength steels does not have clearly noticeable yield strength point, so offset equal to $\sigma_{0.2}$ plastic strain is used to define it.

$$\sigma_{0.2} = \frac{F_y}{A_0}; \text{ then } \sigma_{0.2} = \frac{13400N}{0{,}00004m^2} = 335MPa:$$

A_0 – cross-sectional area (m^2);

Tensile strength is a properties which shows what maximum stress material can withstand before breaking. In stress-strain it is a highest point and is calculated maximum load dividing by cross-sectional area.

$\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{17150N}{0,00004m^2} = 428.750MPa$:

Change in the sample's length gauge is equal to length before test minus length after tensile test divided by length before test expressed in procents.

$\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{170.3-160}{160}$ = 6,5%:

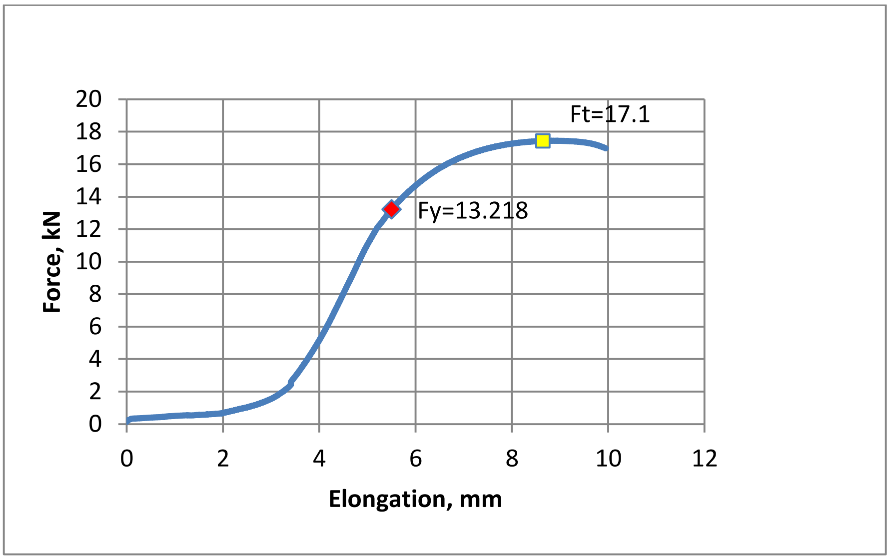


Fig. 3.2 Stress-strain chart of second plate welded with 111

Yield strength: $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{13218N}{0,00004m^2} = 330,450MPa$;

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{17100N}{0,00004m^2} = 425.750MPa$;

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{170.9-160}{160}$ = 6,8%

Second experiment was made with plates welded with 136 FCAW type. Stress-strain chart from results and calculations are showed below.

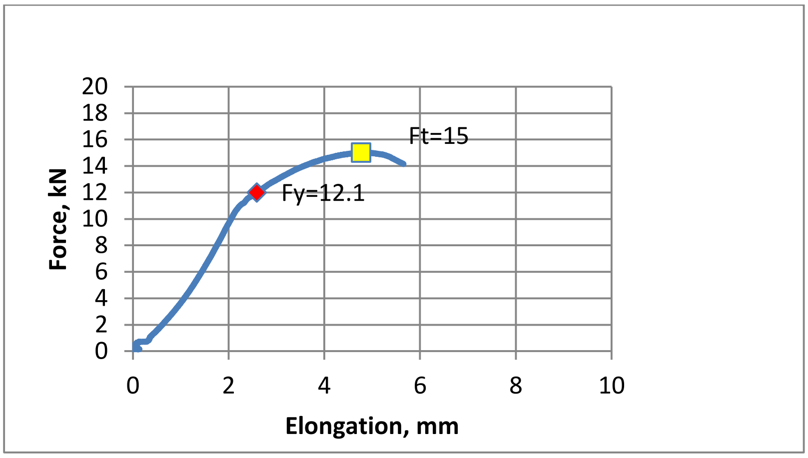


Fig.3.4 Stress-strain chart of first plate welded with 136

Yield strength: $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{12100N}{0{,}00004m^2} = 302{,}500MPa$;

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{15000N}{0{,}00004m^2} = 375MPa$;

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{165.7-160}{160}$ = 3,6%

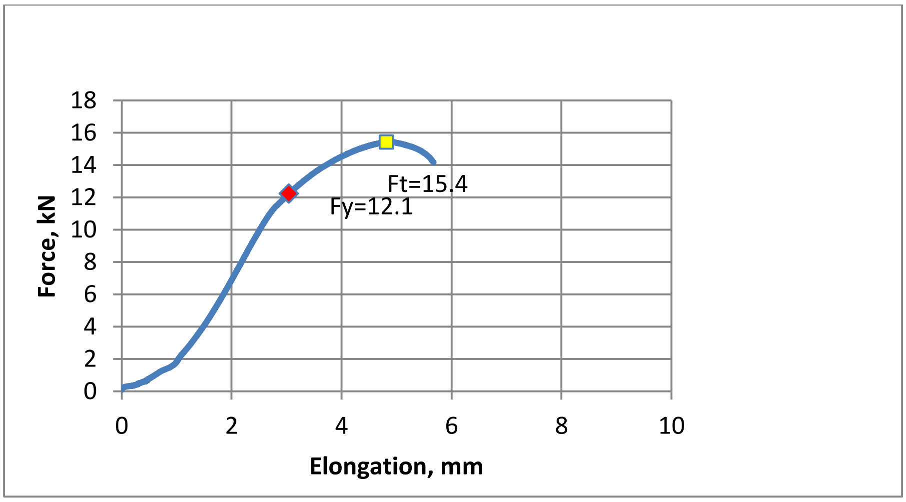


Fig.3.5 Stress-strain chart of second plate welded with 136

Yield strength : $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{12100N}{0{,}00004m^2} = 302{,}500MPa$;

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{15400N}{0{,}00004m^2} = 385MPa$;

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{165.7-160}{160}$ = 3,6%

Third experiment was made with plates welded with 141 TIG type. Stress-strain chart from results and calculations are showed below.

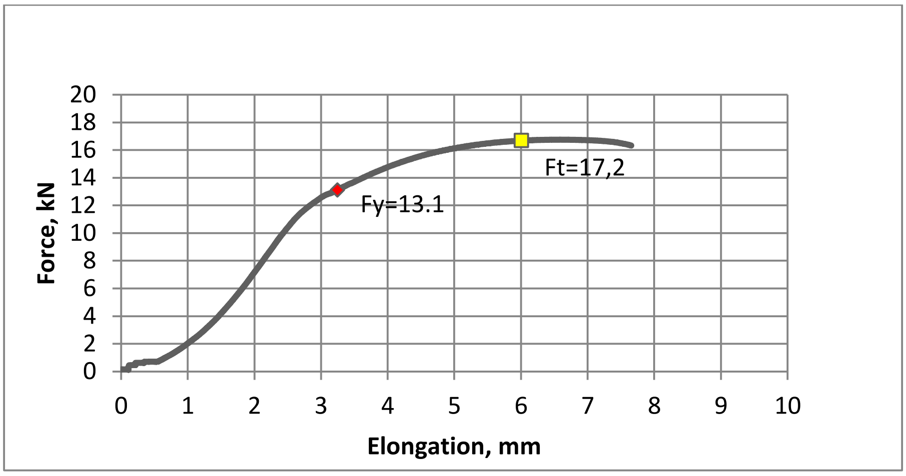


Fig.3.6 Stress-strain chart of first plate welded with 141

Yield strength : $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{13100N}{0,00004m^2} = 327,500\ MPa$;

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{17200N}{0,00004m^2} = 430\ MPa$;

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{167.7-160}{160}$ = 4,8%

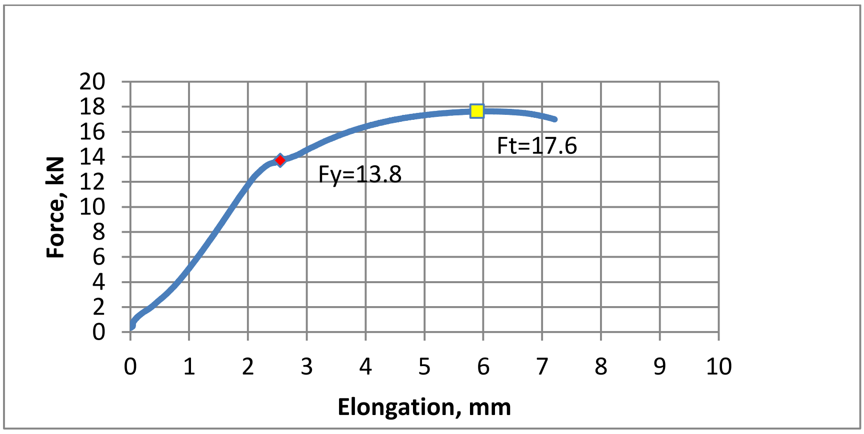


Fig.3.7 Stress-strain chart of second plate welded with 141

Yield strength : $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{13800N}{0,00004m^2} = 345\ MPa$;

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{17600N}{0,00004m^2} = 440\ MPa$;

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{167.3-160}{160}$ = 4,6

The last experiment was completed with solid plate (not welded), which one properties will be compared with welded plates. Summary chart and conclusions are listed below.

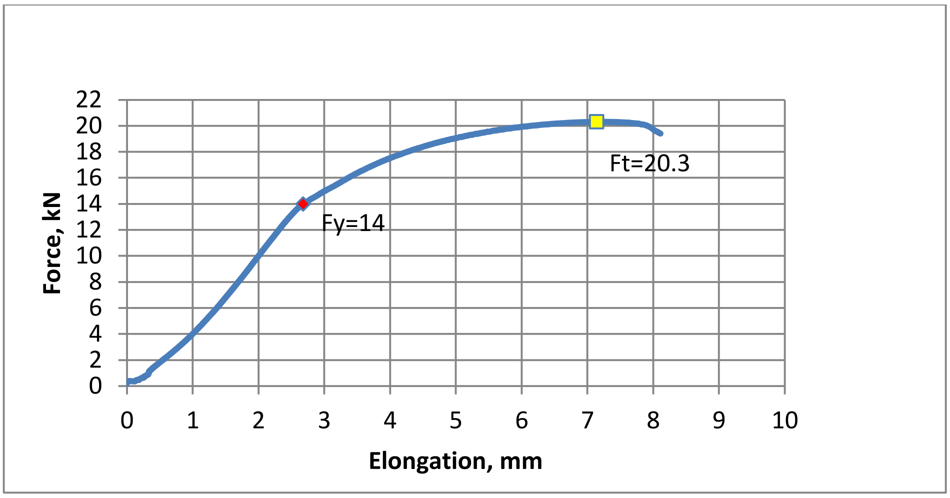


Fig.3.8 Stress-strain chart of not welded plate

Yield strength : $\sigma_{0.2} = \frac{F_y}{A_0}$; then $\sigma_{0.2} = \frac{14000N}{0,00004m^2} = 350\ MPa;$

Tensile strength: $\sigma_u = \frac{F_u}{A_0}$; then $\sigma_u = \frac{20300N}{0,00004m^2} = 507.500\ MPa;$

Change in the length: $\delta = \frac{\Delta l - L}{L}$*100%; then $\delta = \frac{167.3-160}{160}$ = 4,6%

In order to summarize and make conclusions of results, the chart with all results is shown in figure 3.9.

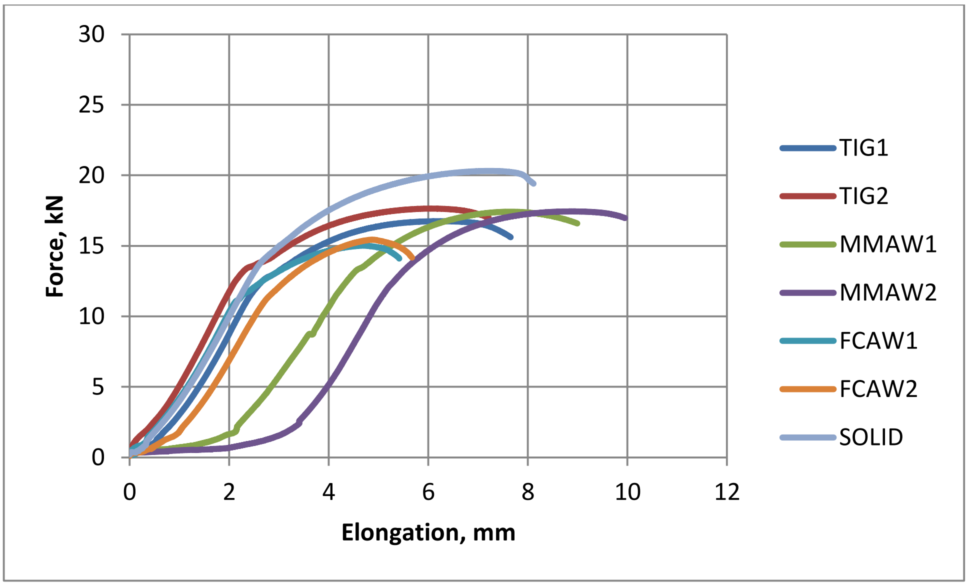


Fig.3.9 Summary chart of all tensile test results

Reviewing all tensile test results it is noticable that welding has impact on specimens strength as not welded one had largest tensile strength equal to 507.500 MPa and elongaded up to 7.3 mm, however the elongation of not welded plate it is not best. Plates with worst tensile parameters were welded with

FCAW type and achieved tensile strength equal to 375 MPa. Most closely to solid plate were plates welded with TIG with tensile strength of 440 MPa. According to this experiment, it is noticeable, that if product should sustain large tensile loads it should be welded with tungsten inert gas, bus this type of welding is most expensive and requires the skilled worker. MMAW is still not bad selection as its tensile strength is almost 430 MPa. In order to compare uniaxial tensile test results more easily, summary table is shown below.

Table 3.1 Tensile test results

Type	**Yield strength (ReH), MPa**	**Tensile strength (Rm), MPa**	**Elongation, %**
MMAW1	335	428,750	6.5
MMAW2	330.450	425.750	6.8
FCAW1	302	375.5	3.2
FCAW2	302.5	385	3.5
TIG1	327.5	430	4.8
TIG2	345	440	4.6
Solid	305	507.5	4.6

It was noted by the tensile tests that fracture of the welded specimens mostly is occurring in the HAZ (Fig. 3.10). In this zone precipitate coarsening [24] is causing the decrease of the mechanical properties of the welds.

Fig. 3.10 Specimen’s after tensile test

3.2 Quality inspection results

As welding's can have a lot of different imperfections, these specimens were tested using radiographic (RT) inspection. Test was made with help of certified company "Metesta Ltd", which is accredited to determine defects of all groups and provides all types of NDT (non – destructive testing) to industry more than 10 years. Classification and explanation of imperfections is made according to EN ISO 6520 – 1:2007 . Imperfections are classified into 6 main groups: cracks, cavities, solid inclusions, lack of fusion and penetration, imperfect shape and dimension, miscellaneous imperfections. Results and photo of RT are presented in table 3.2 and figure 3.11 respectively.

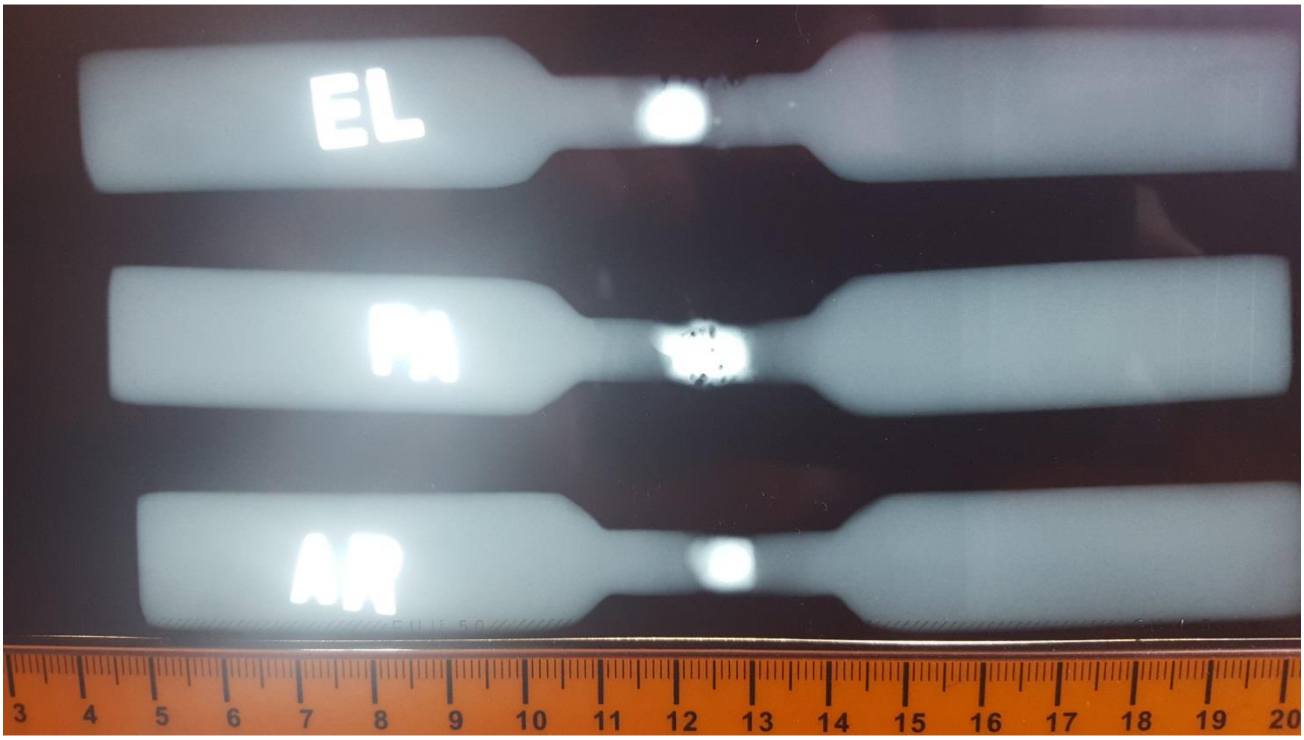


Fig. 3.11 Photo with welding imperfections acquired during RT inspection

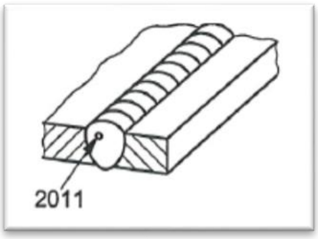
It was observed that small cracks appeared in the HAZ at or near the fusion line where the zone of lower values of hardness is located.

Table 3.2. Radiographic test results

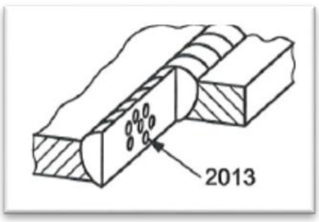
Weld No.	Dimensions (mm)	Defect interpretation	Evaluation		Welding type
			Yes	No	
Test plate AR	t-4	2011	x		141
Test plate PA	t-4	4011,2013		x	135
Test Plate EL	t-4	2013		x	111

Classification, pictures and explanation of imperfections are done according to LST EN ISO 6520 – 1:2007.

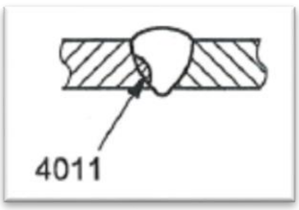
2011 – Group No. 2 – Cavities. Gas pore;



2013 – Group No. 2 – Group of gas pores having a random geometric distribution;



4011 – Group No. 4 Lack of fusion and penetration. Lack of side-wall fusion;



The porosity in weld bead might be found, because of atmosphere contamination, excessively oxidized work piece surface or foreign matter. Porosity is a weld defect that is fairly common, but also fairly easy to fix. Incomplete root fusion is when the weld fails to fuse one side of the joint in the root. This may be cause of too small root gap, misplaced welds or too small bevel angle.

3.3 Hardness test results

In this chapter results acquired from micro hardness test are shown and discussed below. Indentations were done every 0.5 mm to measure hardness in all three different zones (welded or fusion zone, heat affected zone, parent metal) on both sides from the laser weld centre.

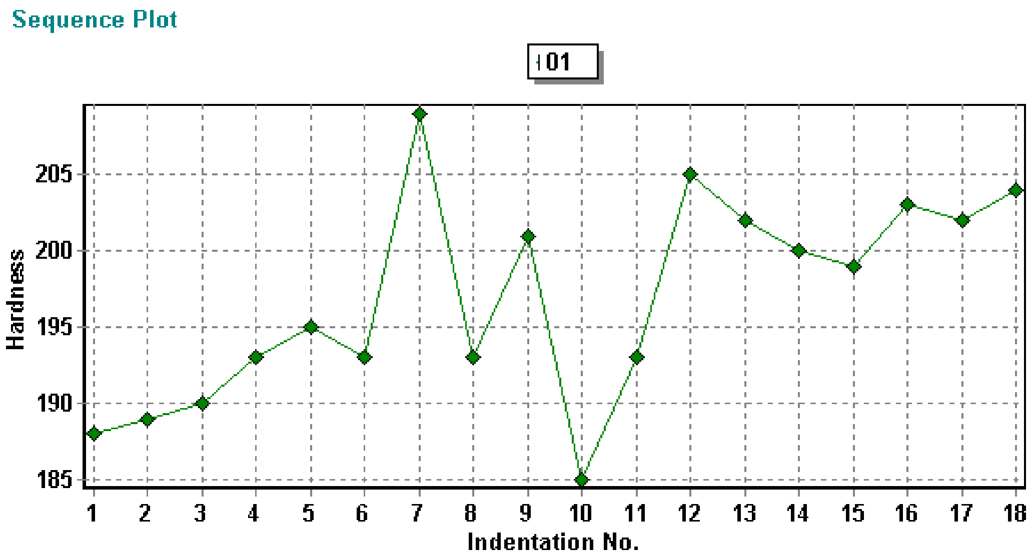


Fig. 3.12 Hardness test results MMAW

From the chart it is noticeable that hardness in the welded zone (indentation No. 1 to 6) is softer ~193 HV than hardness in parent metal ~203 HV (indentation No. 12 to 18). Reason of this is that fusion zone is welded with the metal, which is softer than parent. Starting from indentation No. 7, the heat affected zone is located, where areas microstructure is changed. This is the result of heat input and penetration of fusion metal impact and that causes hardness results variation in this area.

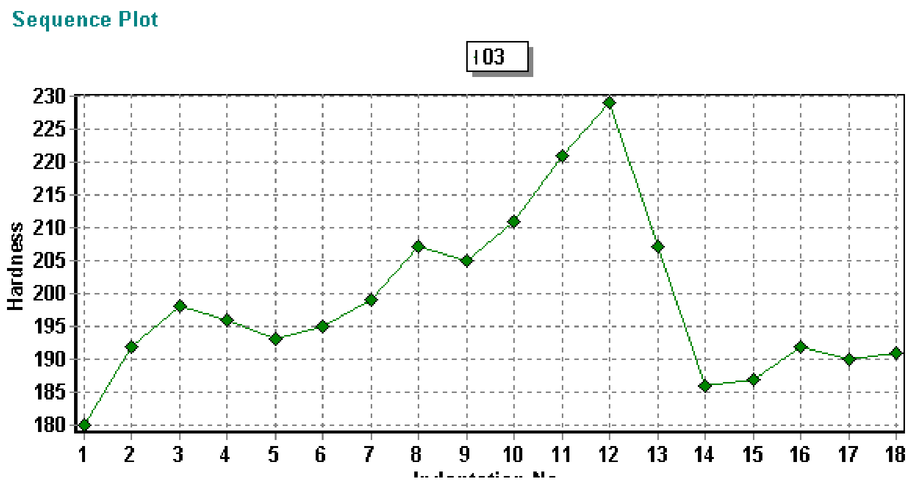


Fig. 3.13 Hardness test results FCAW

From the second chart reviewing results of micro hardness test, where plates were welded with FCAW, it is noticeable that fusion zone hardness ~195HV (indentation No. 1 to 7) is even harder than parent metal ~190HV (indentation No. 14 to 18). That maybe impacted by penetration of electrodes metal and higher temperature in the welding zone. Starting from indentation No. 8 up to 13 is visibly seen heat affected zone, where hardness increase and than falls down because of heat impact to parent metal and penetration of fusion metal.

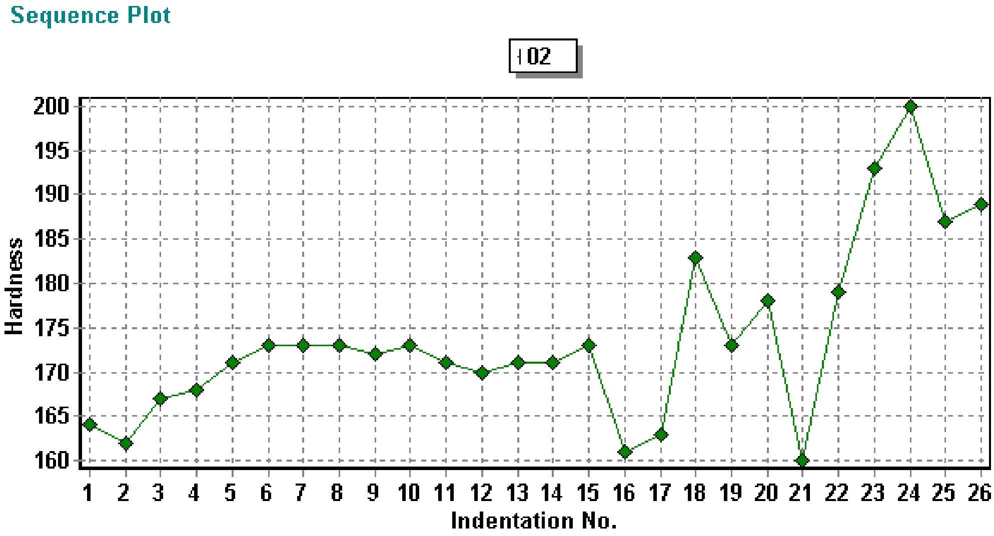


Fig. 3.14 Hardness test results TIG

Analysing third chart of micro hardness test, where plate were welded with TIG, up to indentation No. 15 no significant changes of hardness values were not found, so the measurements were continued in the right side from the centreline of the weld. There the heat affected zone was obtained starting from indentation No. 18 up to No. 24. Then measurements entered into parent metal where hardness values were more or less constant ~187 HV.

Comparing all three acquired results it is seen, that in most cases when entering from fusion zone to the parent metal, heat affected zone is located, where significant variation of hardness values is noticeable. In addition, the hardness values in fusion zone are less than in parent metal, except of FCAW welding type. That may be the influence of welding wire and electrodes chemical composition.

4. CONCLUSIONS

In this study the investigation of three different welding types in order to determine the impact on mechanical properties and quality of the welds of steel S235JR has been done. It was discussed and analysed: specification, advantages and disadvantages of welding’s done by manual metal arc welding (MMAW), fluxed core arc welding (FCAW) and tungsten inert gas welding (TIG), specimen examination with non–destructive test method, specimen’s tensile test and Vickers’s hardness test results. The following conclusions were obtained from experiments:

1. Totally seven plates were tested on tensile test. Reduction in tensile strength is noticeable on all welded specimens. Comparing achieved results, welding with TIG (Rm = 440 MPa), appears as strongest welding process as the testing results were closest to not welded specimens results (Rm= 507.5 MPa). The reduction in tensile strength appears due to filler metal addition and high heat impact. Increase in yield strength in most cases could be achieved because of doping elements in the welding area and change of microstructure.
2. Analysing hardness results achieved on Vickers’s test is noticeable that highest hardness is in the fusion zone by using welding with FCAW (195 HV). Variations in HAZ may be result of heat input and cooling after welding as well as local tempering. Welding strongly affects materials microstructure which leads to hardness variations. It was observed that the hardness of fusion zone is closely related to the strength and elongation of welded joints.
3. Analysing results acquired from radiography test (RT), some defects and not allowed failures were noticed. Using MMAW method the occurrence of weld porosity was observed. This is the result of environmental impact and oxidizing process in the weld area. On FCAW specimens the lack of fusion and gas pores were found. Gas pores is referred to as cavities in the weld due to gas entrapment. Incorrect welding parameters caused the lack of fusion in the joint. Only plate with TIG, which one requires most skilful welder, passed the test.
4. Calculated tensile strength of all welded plates showed, that if steel constructions has to sustain heavy loads, it should be welded using tungsten inert gas welding, as the strength of welded plate by TIG method is equal 440 MPa.

5. PICTURES, TABLES AND LITERATURE REFERENCES

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APPENDICES

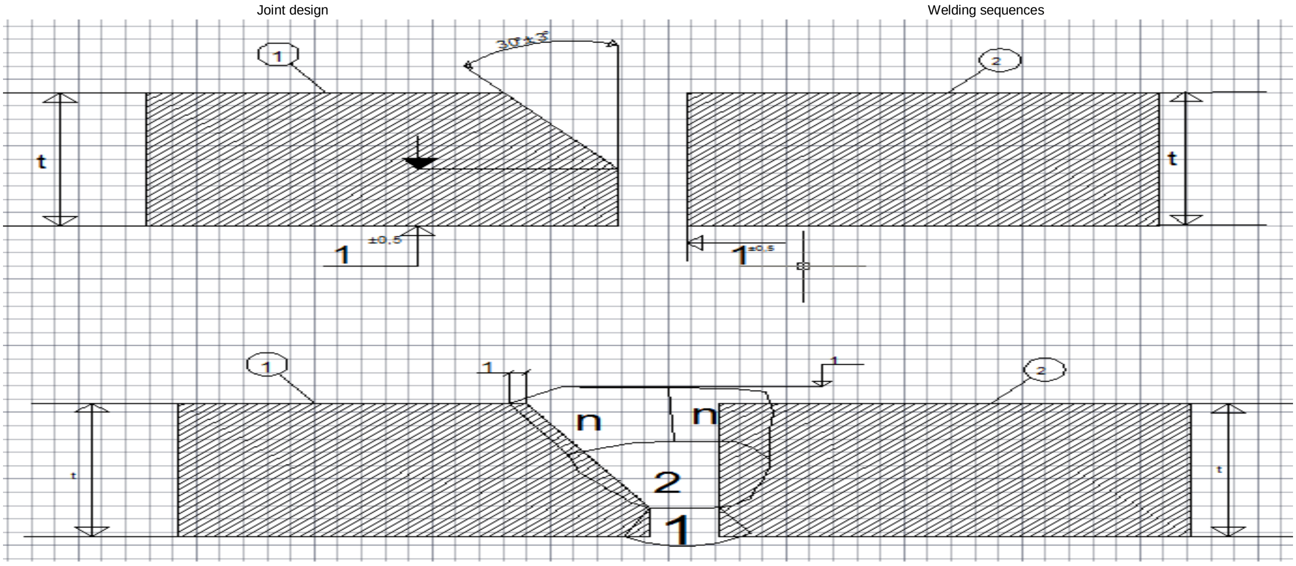
kauno technologijos universitetas (ktu 1922)	# Suvirinimo procedūrų aprašas Welding procedure specification (pSPA sudarytas pagal LST EN ISO 15609-1)	**SPA Nr.** WPS No. 13.08-34 **SPPP Nr.** WPQR No. TPT 11/09 **Data** Date 2016 – 05 - 12

Gamintojas Manufacturer	A.Sriubas	**Objektas** Object	Specimen's welding
Užsakovas Customer			

Elementų matmenys Elements measurement	**Metalas** Metal	**Grupė** Group	**Elementų matmenys** Elements measurement	**Metalas** Metal	**Grupė** Group
1 t_1 - 2.87…5.2 Lakštas	Structural steel S235JR (EN 10025 – 2:2004)	1.1; 1,2	2 t - 2.87…5.2 Lakštas	Structural steel S235JR (EN 10025 – 2:2004)	1.1; 1,2

Jungties tipas Type of joint	Single butt	According to LST EN ISO 17659	**Suvirinimo būdas** Welding process	111
Siūlės tipas Type of weld	BW	According to LST EN ISO 17659	**Apsauginės dujos** Shielding gas	------
Suvirinimo padėtis Welding position	PC, PH.	According to LST EN ISO 6947	**Volframo elektrodas** Type of tungsten electrode	------

Jungties paruošimas Joint design — **Suvirinimo eiliškumas ir siūlės forma** Welding sequences



Joint preparation: according to - LST EN ISO 9692-1:2004

Pridėtinis metalas
The filler metal

Indeksas Index	**Pavadinimas** Name	**Gamintojas** Manufacturer	**Klasifikacija** Classification	**Standartas** Standard	**Iškaitinimas** Preheating	**Laikymas** Keep in thermos
E1	P 48 P	ELGA	E 46 2 B 12 H5	LST EN 499-95		

Suvirinimo parametrai
Parameters of welding

Ėjimas Run	**Procesas** Welding process	**Pridėtinis metalas** The filler metal		**Srovė** Current		**Suvirinimo greitis, cm/min** Welding speed	**Vielos pastūmos greitis, m/min** Wire feed speed	**Dujų debitas, l/min** Gas debit	
		Indeksas Index	**∅, mm**	**A**	**Tipas/poliškumas** Type/poliarity			**Apsauginių** Shielding	**Padėklo** Back
1+2+n	111	E1	2,5	100-140	DC/+	-	-	-	-

Aplinkos temperatūra Ambient temperature	≥ -20° C
Pašildymo temperatūra Preheating temperature	
Tarpėjiminė temperatūra Interpass temperature	
Temperatūros kontrolės priemonės Equipment of temperature measurement	
Pašildymo priemonės Preheating equipment	
Papildomos priemonės Additional equipment	
Terminis apdorojimas Post weld heat treatment	
Pastaba Note	Welding area must be protected from drafts and atmospheric precipitation. After welding, the welded areas must be cleaned to remove any residue, slag, spatter, and so on.

SPA sudarė WPS made	**SPA patikrino** WPS check	**Užsakovo atstovas** Customer
Algirdas Sriubas		

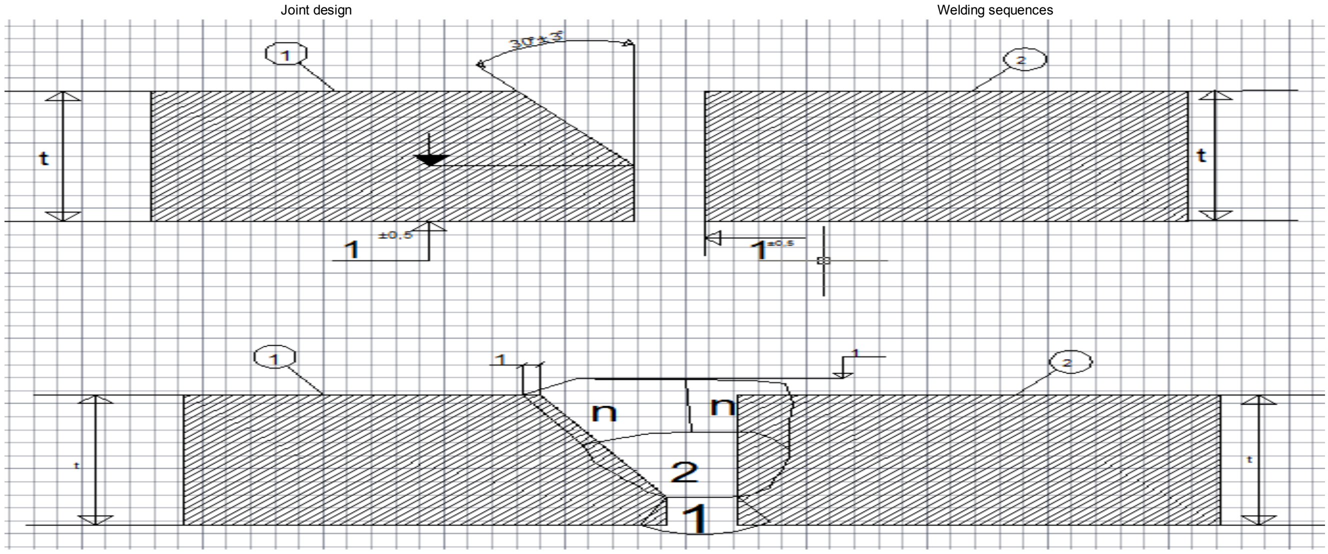
kauno technologijos universitetas (ktu 1922)	**Welding procedure specification** Welding procedure specification	**SPA Nr.** WPS No. 13.02-7 **SPPP Nr.** WPQR No. TPT 11/13 **Data** Date 2016-04-28

Gamintojas Manufacturer: A.Sriubas	**Objektas** Object: Specimen's welding
Užsakovas Customer	

	Elementų matmenys Elements measurement	**Metalas** Metal	**Grupė** Group		**Elementų matmenys** Elements measurement	**Metalas** Metal	**Grupė** Group
1	t 2,87…5,2	Structural steel steel S235JR	1.1	2	t 2,87…5,2	Structural steel S235JR	1.1

Jungties tipas Type of joint	Single butt	according LST EN ISO 17659	**Suvirinimo būdas** Welding process	136
Siūlės tipas Type of weld	BW	according LST EN ISO 17659	**Apsauginės dujos** Shielding gas	Carbonic Acid (LST EN 439: I1)
Suvirinimo padėtis Welding position	PH, PC	according LST EN ISO 6947	**Volframo elektrodas** Type of tungsten electrode	WT20; Ø – 2,4 mm;

Jungties paruošimas Joint design — **Suvirinimo eiliškumas ir siūlės forma** Welding sequences



Joint preparation: according - LST EN ISO 9692-1:2004

Pridėtinis metalas
The filler metal

Indeksas Index	**Pavadinimas** Name	**Gamintojas** Manufacturer	**Klasifikacija** Classification	**Standartas** Standard	**Iškaitinimas** Preheating	**Laikymas** Keep in thermos
W	CM5-IG	BOHLER	W CrMo5 Si	LST EN 12070	-	-

Suvirinimo parametrai
Parameters of welding

Ėjimas Run	**Procesas** Welding process	**Pridėtinis metalas** The filler metal		**Srovė** Current		**Suvirinimo greitis, cm/min** Welding speed	**Vielos pastūmos greitis, m/min** Wire feed speed	**Dujų debitas, l/min** Gas debit	
		Indeksas Index	**Ø, mm**	**A**	**Tipas/poliškumas** Type/poliarity			**Apsauginių** Shielding	**Padėklo** Back
1+2+n	141	W	2,4	100-130	DC/-	-	-	10	-

Aplinkos temperatūra Ambient temperature	≥ -20° C
Pašildymo temperatūra Preheating temperature	
Tarpėjiminė temperatūra Interpass temperature	
Temperatūros kontrolės priemonės Equipment of temperature measurement	
Pašildymo priemonės Preheating equipment	
Papildomos priemonės Additional equipment	
Terminis apdorojimas Post weld heat treatment	
Pastaba Note	Welding area must be protected from drafts and atmospheric precipitation. After welding, the welded areas must be cleaned to remove any residue, slag, spatter, and so on.

SPA sudarė WPS made	**SPA patikrino** WPS check	**Užsakovo atstovas** Customer
Algirdas Sriubas		

ktu kauno technologijos universitetas 1922	# Welding procedure specification Welding procedure specification	**SPA Nr.** WPS No. 13.02-7 **SPPP Nr.** WPQR No. TPT 11/13 **Data** Date 2016-04-28

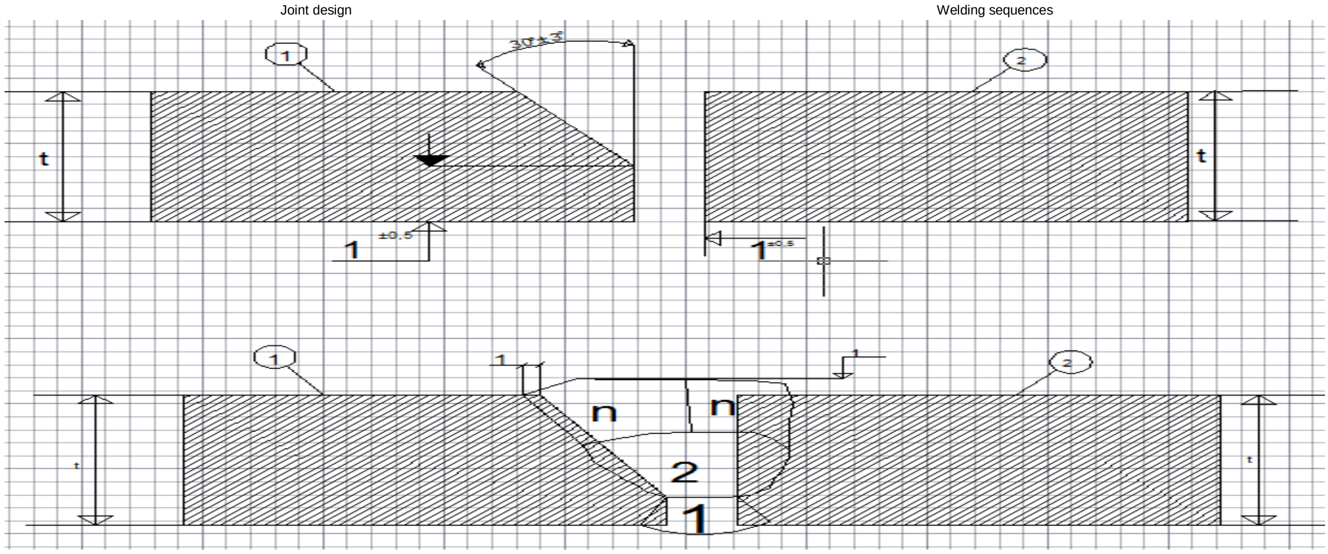
Gamintojas Manufacturer A.Sriubas	**Objektas** Object
Užsakovas Customer	Specimen's welding

	Elementų matmenys Elements measurement	**Metalas** Metal	**Grupė** Group		**Elementų matmenys** Elements measurement	**Metalas** Metal	**Grupė** Group
1	t 2,87…5,2	Structural steel steel S235JR	1.1	2	t 2,87…5,2	Structural steel S235JR	1.1

Jungties tipas Type of joint	Single butt	according LST EN ISO 17659	**Suvirinimo būdas** Welding process	141
Siūlės tipas Type of weld	BW	according LST EN ISO 17659	**Apsauginės dujos** Shielding gas	Argon (LST EN ISO 14175)
Suvirinimo padėtis Welding position	PH, PC	according LST EN ISO 6947	**Volframo elektrodas** Type of tungsten electrode	WT20; Ø – 2,4 mm;

Jungties paruošimas
Joint design

Suvirinimo eiliškumas ir siūlės forma
Welding sequences



Joint preparation: according - LST EN ISO 9692-1:2004

Pridėtinis metalas
The filler metal

Indeksas Index	**Pavadinimas** Name	**Gamintojas** Manufacturer	**Klasifikacija** Classification	**Standartas** Standard	**Iškaitinimas** Preheating	**Laikymas** Keep in thermos
W	EMK 6	BOHLER	W 42 5W3Si1	LST EN 26848:2000	-	-

Suvirinimo parametrai
Parameters of welding

Ėjimas Run	**Procesas** Welding process	**Pridėtinis metalas** The filler metal		**Srovė** Current		**Suvirinimo greitis, cm/min** Welding speed	**Vielos pastūmos greitis, m/min** Wire feed speed	**Dujų debitas, l/min** Gas debit	
		Indeksas Index	**∅, mm**	**A**	**Tipas/poliškumas** Type/poliarity			**Apsauginių** Shielding	**Padėklo** Back
1+2+n	141	W	2,4	100-130	DC/-	-	-	10	-

Aplinkos temperatūra Ambient temperature	≥ -20° C
Pašildymo temperatūra Preheating temperature	
Tarpėjiminė temperatūra Interpass temperature	
Temperatūros kontrolės priemonės Equipment of temperature measurement	
Pašildymo priemonės Preheating equipment	
Papildomos priemonės Additional equipment	
Terminis apdorojimas Post weld heat treatment	
Pastaba Note	Welding area must be protected from drafts and atmospheric precipitation. After welding, the welded areas must be cleaned to remove any residue, slag, spatter, and so on.

SPA sudarė WPS made **Algirdas Sriubas**	**SPA patikrino** WPS check	**Užsakovo atstovas** Customer

APPENDIX II

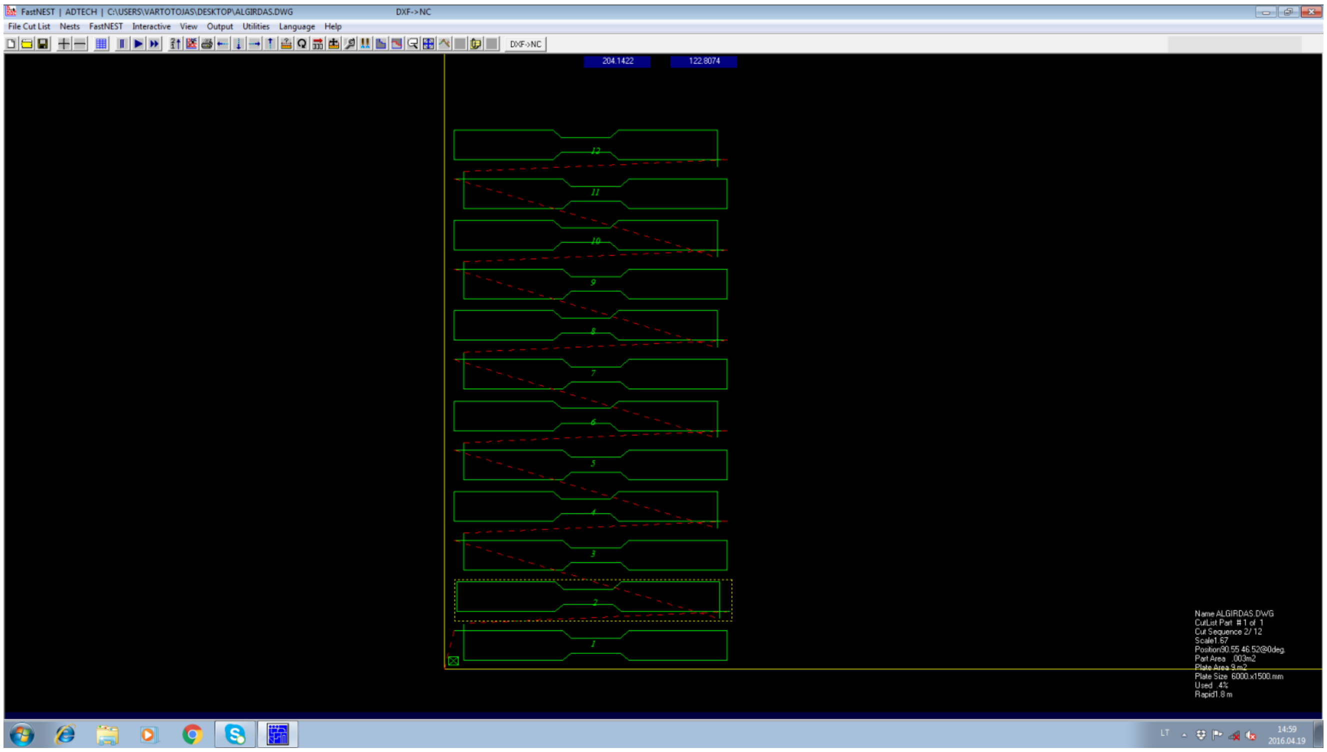


Figure 1. CNC plasma cutter tool path

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METESTA
UAB "METESTA"
PRAMONĖS PR. 4 LT-90112, PLUNGĖ

RADIOGRAFINIO BANDYMO PROTOKOLAS
Radiographic test report

Protokolo Nr. / Report No	Išdavimo data / Date	
209/136	2016 02 29	Page 1 of 1

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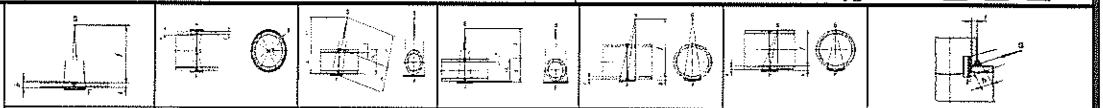
BANDYMAI ISO/IEC 17025 Nr. LA. 01.082

Paraiškos / Order		Bandymų atlikimo data / Date		Bandymą atliko / Test performance		
Nr. / No.	Pateikimo data / Date:	Nuo / Off	Iki / To	Vardas Pavardė / Name Surname	Sertifikato Nr./Certificate No.	Lygis / Level
-	2016 02 29	2016 02 29	2016 02 29	Arūnas Piečius	1A 007/13	2

Užsakovas ir adresas / Client & address	Rangovas / Contractor	Projektas / Project
Algirdas Sriubas	-	Quality inspection
Kontrolės objektas / Object of control	**Brėžinio Nr. / Drawing No.**	**Kontrolės atlikimo vieta / Control Place**
Welding sample plates	-	UAB „Metesta" Montuotojų g. 2, 89101 Mažeikiai, Lietuva

Kontrolės standartas/Quality Control standard:	Priėmimo kriterijai / Acceptance criteria:	
☒ LST EN ISO 17636-1:2013 Klasė/Class: ☒A ☐B	☒ LST EN ISO 10675-1:2013 Lygis/Level: ☒1; ☐2; ☐3 ☐ LST EN ISO 10675-2:2013 Lygis/Level: ☐1; ☐2; ☐3	☒ LST EN ISO 5817:2014 Lygis/Level: ☒B ☐C ☐D ☐ LST EN 10042:2006 Lygis/Level: ☐B ☐C ☐D



Radiografijos atlikimo technika/ Radiographic techniques (LSTEN ISO 17636-1:2013)	☒ Fig.No.1	☐ Fig.No.5	☐ Fig.No.11	☐ Fig.No.12	☐ Fig.No.13	☐ Fig.No14	☐ Figure No.4
Įtampa/Anodic voltage, Kv (Aktyvumas/Source activity (Ci))	150						
Anodinė srovė/ Anodic current,mA	3,0						
Fokus.atstumas/ Min.distance to film,mm	500						
Eksp. laikas / Exposition time, min	1,0						
Jautrio etelonas/Penetrometer	13FeEN						
Nuo šaltinio pusės /off Source side (Ss); Nuo juostos pusės /off Film side (Fs)	Ss	Fs	Fs	Fs	Fs	Fs	Ss

Prietaisas, Nr.,(Fokusinis taškas) / Equipment, No.,(Focal spot size)	☒ Eresco 42 MF 4, Nr.12 2246-49,(3,0 mm) ☐ LPX-200, Nr.101824940-A00003, (3,0 mm)	☐ Delta 880 Nr.4831 (Ir192),(3,0mm) ☐ Delta 880 Nr.5281 (Ir192), (3,0mm)	☐ ☐

Juostos klasė / Film system class	Švino ekrano storis / Leads screens thickness, mm			Densitometras / Densitometer	Juostų peržiūrėjimo įrenginys,/ Film viewer
	Priekinis / Front	Galinis / Back	Apsauginis / Protective		
☒C3; ☐C4; ☐C5	0,02	0,02	0,1	☒ DDS2 Nr. 3075 ☐	☐ Kowolux-4s, No. 83-06 ☒ LCNDT FV008 ,No.802956

Juostų apdirbimas / Films processing	Ryškalas / Developer	Fiksažas / Fixer	Temperature °C
☒ Automatinis / Automatic; Ryškinimo mašina ; ☐ Rankinis / Manual	FUJI HUNT	FUJI HUNT	+30

Gamybos stadija/ Production stage	Suvir.būdas/ Weld. method	Medžiaga/Base material	Aplinkos.temperatūra°C / Ambient temperature °C
☒ Ruošiniai/ Prefabrications ☐ Montažas/ Erection ☐ Prieš term.apdirb./Before PWHT ☐ Po term.apdirb./After PWHT	111,135,141	S235JR	+2

Eil.Nr Row No	X-RAY. Film No.	Siūlės Nr. Weld No.	Kontrolės pozicija zona, Control position,zona (cm)	Išmatavimai Dimensions (mm)	Suv. Nr. Welder No.	Optinis tankis Density	Jautris IQI wire	Defektų aprašymas Interpretation	Įvertinimas Evaluation Taip Yes	Įvertinimas Evaluation Ne No	Pastabos Notes
1	1835	Test Plate-AR	1	t-4	Romualdas Bučmys	2.7	W17	2011	X		**141**
2	1835	Test Plate-PA	1	t-4	Romualdas Bučmys	2.8	W17	4011, 2013		X	**135**
3	1835	Test Plate-EL	1	t-4	Romualdas Bučmys	2.7	W17	2013		X	**111**

Defektų klasifikavimas ir apibūdinimas pagal / Classification and explanation of imperfection to LST EN ISO 6520-1:2007
100-plyšiai / Cracks 300-kietieji intarpai / Solid inclusions 500-formos ir matmenų defektai / Imperfect shape and dimension
200-tuštumos / Cavities 400-nesulydimai ir nesuvirinimai / Lack of fusion and penetration 600-įvairūs defektai / Miscellaneous imperfection.

Pastabos / Notes: **R**- remontas / repair; **P**- papildoma siūlė / penalty; **FD**-Film defect

Priedai /Attachments:

Specialisto parašas/ Specialist signature	Protokolą patikrino/ Ascertainable		
	Juozapas Pakalniškis		

FO.4.4.7-3 2012-06-20

METESTA	**UŽSAKYMAS KONTROLEI/ Order**			**UAB "METESTA"** BANDYMŲ LABORATORIJA PRAMONĖS PR. 4 LT-90112, PLUNGĖ
	Užsakymo data / Order Date:	Užsakymo Nr. / Order No	Puslapis./Page	
			1 IŠ/OFF 1	

Metodo atlikimas / Method:

Vizualinis / Visual VT	Magnetinis/ Magnetic MT	Kapiliarinis/ Penetrant PT	Radiografinis/ Radiographic RT	Ultragarsinis/ Ultrasonic UT	Kitas metodas/ Other Method
☒ LST EN ISO 17637:2011	☐ LST EN ISO 17638:2010	☐ LST EN ISO 3452-1:2010	☒ LST EN ISO 17636-111:2013 Klasė ☒A ☐B	☐ LST EN ISO 17640:2011 Lygis ☐A ☐B ☐C	

Priėmimo kriterijai pagal / Acceptance criteria:

					Kitas standartas/other standard
☒ LST EN ISO 5817:2014 Lygis/level: ☒B ☐C ☐D	☐ LST EN ISO 23278:2015 Lygis/level: ☐2 ☐3 ☐X	☐ LST EN ISO 23277:2015 Lygis/level: ☐2 ☐3 ☐X	☐ LST EN ISO 10675-1:2013 Lygis/level: ☒1 ☐2	☐ LST EN ISO 11666:2011 Lygis/ level: ☐2 ☐3	

Kiti norminiai standartai / other noramative standard

☒ LST EN ISO 5817:2014 Lygis/level: ☒B ☐ C ☐ D — ☐ LST EN 13480-5:2012/A1:2014 Kategorija/Category ☐ I ☐ II ☐ III

☐ LST EN 14015:2004

☐ ASTM B31.3 table341.3.2 ☐Normal and Category M Fluid Service ☐Severe CyclicCondition ☐Category D Fluid Service ;

Kontroliuojamo objekto duomenys / Control information

Užsakovas (adresas)/ Client(address)	Rangovas(adresas)/ Contractor(address)	Kontrolės atlikimo vieta(adresas)/Control Place(address)
Algirdas Sriubas (+370 629 07264)	-	UAB „Metesta" Montuotojų g. 2, 89101 Mažeikiai

Projekto pavadinimas / Project

Quality inspection

Kontrolės objektas (linijos,detalės, mazgo, gaminio pav.) Object of control

Suvirinimo pavyzdžiai-plokštelės (welding sample- plates)

Atsakingas už paruošimą V. Pavardė, parašas / Executive over control preparation Name, Signature	Pageidaujama atlikimo data / Desirable performance test date
Algirdas Sriubas (+370 629 07264)	2016 02 29

Užsakymą priėmė V. Pavardė, parašas / Order receiver	Įpareigoju bandymą atlikti: V. Pavardė, parašas / Obligation to perform test
UAB„Metesta"	UAB„Metesta"

EilNr	Detalė / Linijos Nr./Brėžinio Nr./ Sekcijos Nr./ Detail / Line No./DWG No./Section No	Spool	DWG sheet	Suv. siūlės Nr. Weld No.	Diametras, Storis, ilgis/ Diam./thick.	Suvirintojas Welder	Medžiaga / Material	Suv. būdas Weld method	Suv. padėt Weld position	Briaunų paruošimas Basil set-up (I-Y-V-U-K-X)	PWHT YES/ NO	Atžyma apie įvykdymą, (protokolo Nr.;data, parašas) Performance, date, sign.
1	Plate test- AR			AR	t-4mm	Romualdas Bučmys	S235JR	141	PA	V	No	
2	Plate test- PA			PA	t-4mm	Romualdas Bučmys	S235JR	135	PA	V	No	
3	Plate test- EL			EL	t-4mm	Romualdas Bučmys	S235JR	111	PA	V	No	
4												
5												
6												
7												
8												
9												
10												
11												
12												

Atlikta 2016 02 29

209/136

Arūnas Piečius
NDT specialistas
RT-2/UT-2/MT-2/PT-2/VT-2