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ANALYSIS OF LACK OF FUSION IN WELDS AT WATER HEATERS

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The paper treats a weld discontinuity called lack of fusion, which is frequently a cause of leakage of a water heater. The heater was produced by MAG welding using two wires (twin arc welding). The paper states some reasons for the occurrence of lack of fusion, i.e. the arc blow effect, an inappropriate gun position, uncontrolled movement of the weld pool, too low energy input, an improper joint preparation. The defect is illustrated in a macrograph of a weld produced at the water heater with twin wires in a shielding gas. Welding with twin wires is schematically represented with a circumferential welded joint between the end and shell of the water heater.

Key words: *lack of fusion, leakage of the water heater, welding with two wires, arc blow*

Analiza nepotpunog staljivanja u zavarenim spojevima na grijačima vode. U ovom članku razmatra se greška u zavaru, nazvana naljepljivanje, a koja je najčešće uzrok curenja grijača vode. Grijač je proizveden postupkom MAG s upotrebom dviju žica (zavarivanje sa dvostrukim električnim lukom). Navedeno je nekoliko uzroka za pojavu nepotpunog staljivanja. Pogreška je ilustrirana na makrografskoj epruveti zavara grijača zavarenog s dvije žice u zaštitnom plinu. Zavarivanje s dvije žice shematsko je prikazano zavarivanjem kružnog zavara između poklopca i oplate grijača.

Ključne riječi: *naljepljivanje - nepotpuno staljivanje, curenje grijača vode, zavarivanje s dvije žice, skretanje električnog luka*

INTRODUCTION

Quality assurance for products to be sold in the open market is an important issue of any production. Quality assessment of products, in-production quality monitoring, recording, and storage of various manufacturing parameters are prerequisites of an efficient market sale and competitiveness [1 - 5]. In this connection some products should fulfil requirements of various standards and regulations, others those of various guidelines, and still others should only be market-competitive. Thus the products dedicated to wide consumption and a low-quality of which could produce damage or injuries to consumers are subjected to the strictest control. Here belong also all types of pressure vessels, for which special control of production and testing is required.

Water heaters usually operate at a temperature lower than 100 °C and, consequently, according to European regulations, do not belong to pressure vessels. In certain cases, however, the temperature in water heaters may increase up to 130 °C; therefore, a manufacturer of water heaters should take into account the relevant regulations and carry out a 100 % control of the products concerned.

With welded products, like water heaters, it is recommended to record and store welding parameters. They may be useful if any complaints come up [1 - 5].

The application of twin-wire MAG welding instead of one-wire welding to making a water heater increased the deposition rate, energy efficiency and productivity of the process.

THE PROBLEM

The problem to be discussed in the paper is an analysis of lack of fusion (or incomplete fusion) [6 - 8] in welds, which is the most frequent cause of leakage of water heaters. Figure 1. shows a schematic of the water heater. The heater was produced by MAG welding using only one or two wires (twin arc welding) of 1,2 mm in diameter. It consists of a shell (a), two ends (b, c), connecters for water (d), and two adapters (e, f). The shell is made of a 1,8 mm thick sheet. To produce a shell, first the sheet was folded into a tube and then welded (1). Both ends are made of a 2,25 mm sheet. They were welded to the shell with one circumferential weld each (2, 3).

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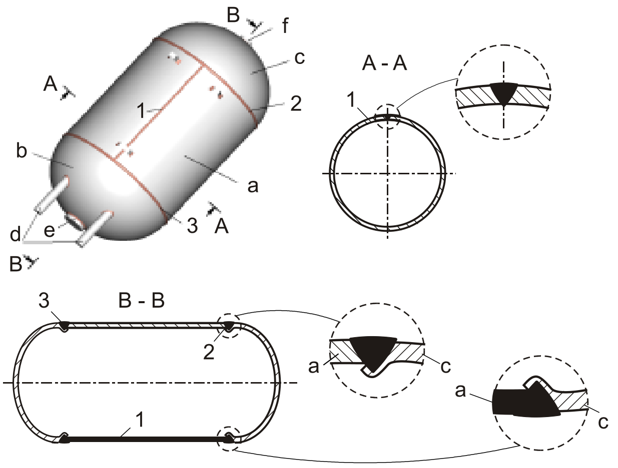

Figure 1. **Representation of water heater: a - heater shell; b, c - heater end; d - connecter for the water; e, f - adapter, 1 - longitudinal weld at shell; 2, 3 - circumferential welds between shell and ends**

Slika 1. **Shematski prikaz grijača vode: a - oplata gijača; b, c - poklopac grijača; e, f - priključnica; 1 - uzdužni zavar na oplati; 2, 3 - kružni zavari između poklopca i oplate**

Defects such as lack of fusion will most often occur at the intersections between the longitudinal and circumferential welds and at the contact between the start and end of the circumferential weld (Figures 3. and 8.). Figure 2.a schematically shows the longitudinal square-groove butt

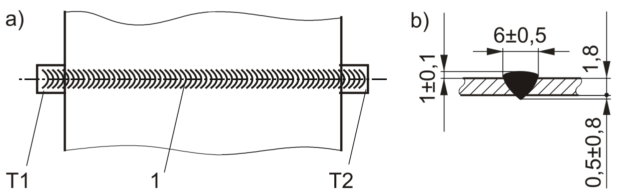

Figure 2. **Longitudinal weld (1) at heater shell: a) top view, b) cross section of square-groove butt weld, T1 - run-on and T2 - run-off plates**

Slika 2. **Uzdušni zavar (1) na oplati grijača: a) pogled odozgora, b) poprečni prerez sučeonog I - zavara, T1, T2 - pločice za početak i završetak zavarivanja**

weld at the shell including two small plates (T1, T2), i.e., the run-on plate and the run-off plate, at the beginning and end of the weld respectively. Figure 2.b shows a cross section of the longitudinal weld, including its size and tolerance range. The two plates at the beginning and end of the weld serve to begin and end the weld nicely. Thus the blow effect of the arc is prevented. The longitudinal butt weld having been finished, the two plates will simply be broken off.

Figure 3.a shows a joint assembly between the end and the shell where 1 is the end, 2 the shell, and 3 is the longitudinal weld at the shell. It is this longitudinal weld that represents a disturbance when the circumferential weld is being made. At the moment the circumferential weld is crossing the longitudinal weld at the shell, a disturbance will occur, which results in incomplete root fusion. This phenomenon can be explained by several physical principles such as welding-arc deflection, stronger removal of heat due to a higher mass, impurities, oxides present at the spot, and insufficient energy input at the welding area.

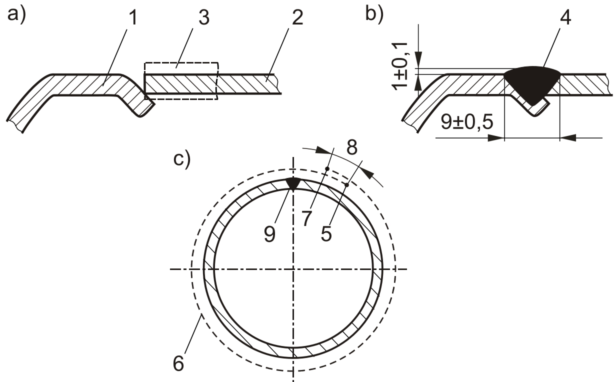

Figure 3. **Schematic representation of making circumferential weld: a) joint assembly between end and shell, b) cross section of circumferential weld between end and shell, c) schematic representation of circumferential welding, 1 - end, 2 - shell, 3 - longitudinal weld at shell, 4 - circumferential weld, 5 - beginning of welding circumferential weld, 6 - circumferential welding, 7 - end of welding circumferential weld, 8 - size of overlapping of circumferential weld, 9 - location of longitudinal weld at shell**

Slika 3. **Shematski prikaz izrade kružnog zavara: a) zavarni spoj između poklopca i oplate, b) poprečni presjek kružnog zavara između poklopca i oplate, c) shematski prikaz slijeda kružnog zavarivanja, 1 - poklopac, 2 - oplata, 3 - uzdužni zavar na oplati, 4 - kružni zavar, 5 - početak zavarivanja kružnog zavara, 6 - kružno zavarivanje, 7 - završetak zavarivanja kružnog zavara, 8 - veličina prekrivanja kružnog zavara, 9 - položaj uzdužnog zavara na oplati**

Figure 3.b shows a cross section of the circumferential weld (4), including its size, shape and tolerance range. Figure 3.c schematically shows making of the circumferential weld. Number 5 indicates the beginning of welding, curve 6 shows the progress of welding to point 7, and 8 indicates the length of overlapping of the end and beginning of the circumferential weld. Number 9 indicates the position of the longitudinal weld that should not be located in the overlapping zone of the circumferential weld (between position 7 and 8). The position of the welding burner during welding is constant and fixed. It is the water heater that is turning. This means that welding is performed in the flat position.

WHAT IS LACK OF FUSION IN THE WELDED JOINT

Lack of fusion is a weld discontinuity in which fusion has not occurred between weld metal and parent metal or between adjoining weld beads so that we may have lack of side fusion, lack of inter-bead fusion or lack of fusion at the weld root. Incomplete fusion is produced during welding, most often unnoticed by a welder or an operator. After welding, it is most difficult, if not impossible, to detect it by the visual inspection or other non-destructive testing methods (Figure 8.). It is most often detected in bend testing of the welded joint when fracture occurs at the location of lack of fusion in spite of a relatively low load applied. Fracture will usually run along the weld interface or individual beads, and thus indicate that there really is lack of fusion [7 - 14].

The main cause of the occurrence of lack of fusion is insufficient energy input at the weld area. Consequently, the parent metal in the weld groove or the previously made beads are not heated up to the melting temperature that is required for the parent metal to mix with the filler material and make a uniform weld. The lack of fusion is not due to the filler material used but exclusively to improper weld preparation, an unsuitable welding technology, including welding parameters, and weak performance of the qualified procedure. In practice, it has turned out that welders themselves are most often producers of the incomplete fusion. A well- qualified welder will melt the parent metal with an arc, mix it with the filler material, and thus make a weld. Operators should use a similar procedure in automatic and robotic welding. An unskilled or, often, careless welder is bound, for various reasons indicated below, to produce the incomplete fusion in the weld.

The lack of fusion is a planar discontinuity having various sizes and shapes. If often happens that only one dimension, i.e. the one in the direction of weld progression, is particularly remarkable.

Why does lack of fusion occur?

The definition of lack of fusion and the most frequent cause of its occurrence have already been mentioned. But there are some additional causes of the occurrence of lack of fusion between the weld metal and fusion faces and the bead respectively [7 - 9, 11].

The first cause is arc blow. It is defined as a lengthening or deflection of a welding arc due to various causes. The most frequent causes of arc blow are an electromagnetic force and a mechanical force due to wind or gas. Figure 4. shows the principle of action of the electromagnetic force deflecting the arc. In all four cases, there is an asymmetrically distributed magnetic field around the arc or two arcs that combines with the electric field to produce the electromagnetic force affecting the arc.

Figure 4A schematically shows welding close to the wall. In the wall the magnetic field is stronger than in the air around the arc and, therefore, the arc is attracted to the wall. The same situation is shown in Figure 4B. The electromagnetic field is stronger in the centre of the workpiece than at its edge and, consequently, the arc blow occurs. Figure 4C shows the arc defect in classical welding. The electromagnetic field around the arc is asymmetrical. For instance at point 7 the electromagnetic field is stronger than at the other points around the arc. Welding with two wires is shown in Figure 4D. The magnetic field is stronger around the two arcs than in the middle of them. Consequently, both arcs will be attracted to each other.

The second, very frequent cause of the occurrence of incomplete fusion is an improper gun position.

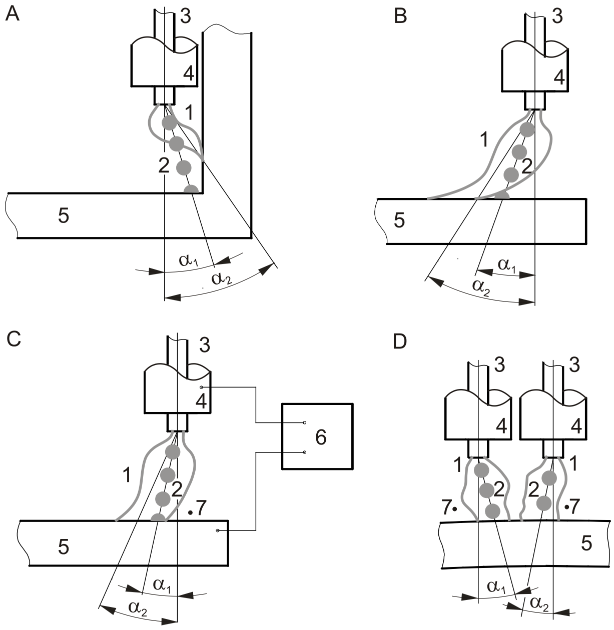

Figure 4. **Arc deflection due to the action of electromagnetic force; 1- arc, 2- drops, 3- wire, 4- contact tube, 5- workpiece, 6- power source, 7- point with stronger electromagnetic field, α_1 - angle of the direction of the drops, α_2 - angle of the welding arc**

Slika 4. **Skretanje električnog luka zbog utjecaja elektromagnetne sile; 1 - električni luk, 2 - kapljice, 3 - žica, 4 - kontaktna sapnica, 5 - radni komad, 6 - izvor struje, 7 - točka sa jačim elektromagnetnim poljem; α_1 - kut smjera kapljica; α_2 - kut električnog luka**

In Figure 5. two different types of imperfection, which very often appear during shielding gas welding of the

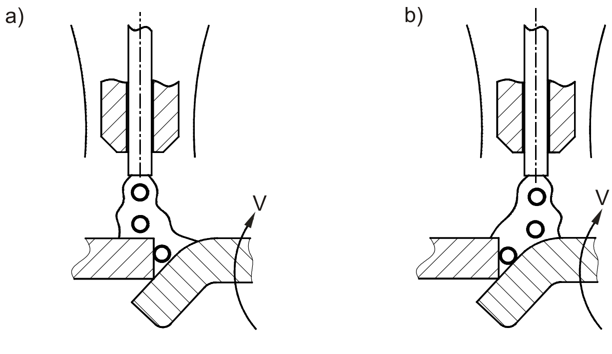

Figure 5. **Two cases of an improper gun position by MAG welding with two wires by making of the circumferential weld between end and shell of the water heater**

Slika 5. **Dva primjera nepravilog položaja glave-gorionika za zavarivanje MAG postupkom sa dvije žice, prilikom izrade kružnog zavara između poklopca i oplate grijača vode** water heater, are shown. In both cases the position of the gun is not correct and the arc does not burn in the welding groove. Consequently, the molten droplets detaching from the wire remain cold and unmelted. The weld root will not melt. The molten drops fall into the groove but they do not mix with the parent metal. Consequently, lack of fusion occurs.

The third cause is uncontrolled "flight" of the weld pool (Figure 6.). In arc welding processes using a filler material, which are characterized by a large weld pool, it often happens that the weld pool "flees" in the direction of weld progression or any other direction. If the weld pool runs ahead of the arc it prevents heating of the groove, which is shown in Figure 6.a.

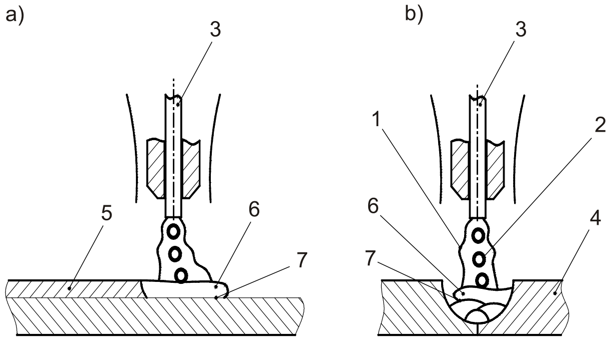

Figure 6. **Weld pool "fleeing" ahead of the arc a) and on the side of the arc b) to produce lack of fusion on the side (a-left) and inter-bead (b-right) fusion; 1 - arc, 2 - molten drops, 3 - wire, 4 - workpiece, 5 - solid weld, 6 - weld pool, 7 - lack of fusion**

Slika 6. **"Bježanje" kupke pred električni luk a) i na strani električnog luka b), što je uzrok nepotpunog staljivanja na rubu zavara (bočno naljepljivanje) (a - lijevo) i naljepljivanje među slojevima (b - desno); 1 - električni luk, 2 - rastopljene kapljice: 3 - žica; 4 - radni komad; 5 - stvrdnuti zavar, 6 - kupka taline; 7 - naljepljivanje, nepotpuno staljivanje**

Consequently, incomplete fusion will occur between the parent metal and the weld pool. Another difficulty encountered is that the weld pool flows to the right and to the left of the unmelted weld groove (Figure 6.b).

The fourth cause is welding with too low energy input to the workpiece. Welding parameters in arc welding have different effects on the final weld shape and size. The welding current affects mostly joint penetration and, to a lesser degree, weld width. The welding voltage affects mostly weld width. The welding speed, however, affects weld depth and weld width.

The fifth cause is improper joint preparation. This is not the primary cause of the occurrence of the lack of fusion but it creates conditions fostering its occurrence. Most frequent mistakes made in the joint preparation are too small a bevel angle, an improper penetration dept-to-width ratio, misalignment of the joint members, and insufficiently cleaned surface.

ANALYSIS OF LACK OF FUSION IN THE WELDED JOINT BETWEEN THE END AND THE SHELL

Figures 3. and 7. is schematically show making of a circumferential weld between the shell and the end of the water heater. Welding is carried out with two wires (Figure 7.) linked by a control unit thus making a single welding system. Each wire has its own power source (6, 7), its own

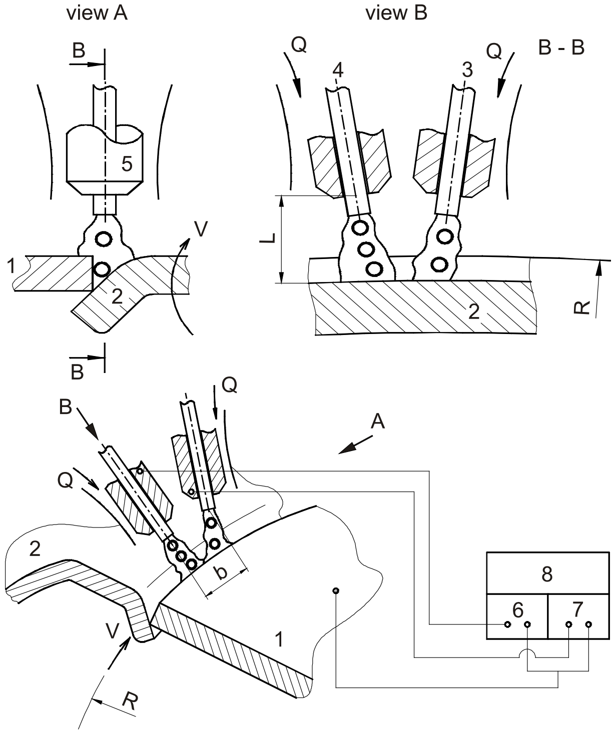

Figure 7. **Schematic shown of making the circumferential weld with two wires in the shielding gas mixture (82 % Ar, 18 % CO_2): *b* - distance between wires, *L* - wire extension, *v* - welding speed, *Q* - gas flow; 1 - shell, 2 - end, 3 - the first wire, 4 - the second wire, 5 - contact tube, 6, 7 power sources, 8 - control unit**

Slika 7. **Shematski prikaz izrade kružnog zavara sa dvije žice u mješavini zaštitnih plinova (82 % Ar, 18 % CO_2): *b* - udaljenost između žica, *L* - slobodni kraj žice, *v* - brzina zavarivanja, *Q* - protok plina; 1 - oplata, 2 - poklopac, 3 - prva žica, 4 - druga žica, 5 - kontaknta sapnica, 6, 7 - električni izvor, 8 - komandna jedinica**

feeding and straightening mechanism, and its own contact tube. But the two wires have joint regulation (8) so that the current pulses in the two wires may be coordinated. This means that a high pulse current in one wire is accompanied by a low background current in the other wire, and vice versa. Thus the material transfer is harmonized. With each current pulse a droplet is transferred from the wire to the weld pool, melting-off of the droplets being alternating. In this way the electromagnetic influence between the two wires is prevented.

Figure 8. shows a macrosection of the welded joint between the end (2) and shell (1) of the water heater. The

weld shape is very nice and without imperfections. This is a cross section at the very intersection of the longitudinal weld of the shell and the circumferential weld between the shell and the end of the water heater (Figure 3.). The external appearance of the weld is nice and shows no undercuts or any other imperfections.

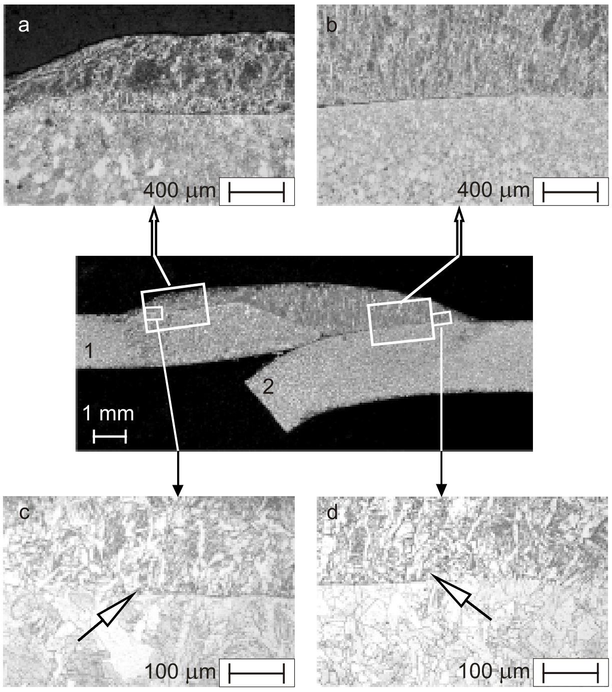

Figure 8. **Macrosection of welded joint between the end (2) and shell (1) of the water heater; a), b) part of the welded joint with lack of fusion (50 ×); c), d) part of the welded joint with beginning of the lack of fusion (200 ×); I_1 = 244 A, I_2 = 224 A, U = 31V, b =11,5 mm, L = 20,5 mm, v =2,1 m/min**

Slika 8. **Makrografska epruveta zvarnog spoja između poklopca (2) i oplate (1) grijača vode; a), b) dio zvarnog spoja s nepotpunim staljivanjem (50×), c), d) dio zavarnog spoja s početkom nepotpunog staljivanja (200×); I_1 =244 A, I_2 = 224 A, U = 31 V, b = 11,5 mm, L = 20,5 mm, v = 2,1 m/min**

The weld was produced with two wire electrodes in the shielding gas mixture (82 % CO_2 + 18 % Ar). The wires were positioned one after another in the welding direction (Figure 7.). The distance between the two wires was equal to 11,5 mm and the wire extension length to 20,5 mm. Welding speed was 2,1 m/min. During welding the wires had different feed speeds. The current at the first wire amounted to 244 A and at the second to 224 A. The arc voltage was 30,5 V, which was too high.

An accurate analysis of the macro specimen, however, showed that there was lack of fusion in the weld since the dilution between the parent metal and the filler material was not sufficient due to insufficient heating of the parent metal. At several locations in the weld lack of fusion defects can be noticed. Figure “a” shows a lack of fusion defect on the left side of the macro specimen magnified 50 times. With the same magnification a lack of fusion defect is shown in Figure “b”. This one is even more distinct than that in Figure “a”. The end of the water heater was made of a thicker plate than the shell; therefore, the removal of heat was stronger and the energy available for heating and fusion of the parent metal was lacking. With Figures “c” and “d” a magnification of 200 times was used. The arrows in the two figures show the beginning of the lack-of-fusion defects. In Figure “c” the weld on the left to the arrow is sound. There are coalesced grains between the parent metal and the filler material. To the right of the arrow there is the boundary between the grains of the parent metal and those of the filler material. Almost the same is true of Figure “d”. To the left of the arrow there is a lack-of -fusion defect and to the right of it the weld is sound.

There seem to be two causes of lack of fusion, the first being an improper positions of the burner and the second an arc voltage too high, i.e., an arc too long. To our mind the long arcs in welding with the two wires are the reason for the occurrence of lack of fusion. This statement can be substantiated by the high arc voltage and a very wide weld face. This indicates that the arc energy of the two arcs is distributed over a large area, the energy density is small, and the energy supplied is not sufficient to melt the parent metal.

To improve the weld quality the arc length and, consequently, the arc voltage should be reduced and welding parameters should be recorded and stored [2].

CONCLUSION

In the paper the most frequent causes of lack of fusion in welding of water heaters are shown. Based on the investigations carried out and the results obtained, several conclusions can be drawn:

- lack of fusion is one of the most frequent defects in the welds in the production of water heaters,
- the main cause of the occurrence of lack of fusion is insufficient energy input at the weld area i.e. into the parent metal,
- the most frequent cause for the insufficient energy input at the weld area is an arc too long; i.e. an arc voltage too high, which causes too low energy density at the welding area,
- incomplete fusion is most difficult, if not impossible, to detect by the visual inspection or other non-destructive testing methods,
- for each welded joint at the water heater a welding procedure specification (WPS) has to be elaborated and welders and operators have to hold an approval test certificate,
- it is recommended to record and store welding parameters.

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