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## CAUSES OF THE MOST COMMON DEFECTS ON BOILER MEMBRANE WELDS

### UZROCI POJAVE NAJČEŠĆIH GREŠAKA NA KOTLOVSKIM MEMBRANSKIM ZAVARIMA

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#### Abstract

The paper describes causes of the most common defects on boiler membrane welds according to EN ISO 12952-5. The research is carried out on water tube boiler manufactured by the company Đuro Đaković Termoenergetska postrojenja d.o.o. This paper elaborates the most common defects like cavities and undercuts that appear on membrane welds.

#### 1. Introduction

The aim of this paper is to describe the causes of the most common defects that occur in boiler membrane welds. The most common defects dealt with in this paper are:

1. Cavities
2. Undercuts
3. Unwelded parts
4. Irregular geometric shape of the weld
5. Incorrect position of the welded connection plate

The valid standard that describes welding requirements for membrane welds on boiler wall panels is EN ISO 12952-5 [1] and EN ISO 12952-6 [2].

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**Ključne reči:** membranski zavari, greške u membranskim zavarima, EPP zavarivanje, zajedni, poroznosti

#### Rezime

U radu su opisani uzroci najčešćih nedostataka na zavarenim spojevima membranskih zidova prema EN ISO 12952-5. Istraživanja se temelje na proizvodnji kotlova u tvrtki ĐĐ Termoenergetska postrojenja d.o.o. U ovom radu opisani su uzroci grešaka kao što su zajedni, poroznosti te drugi tipovi grešaka, a koje su ujedno najčešće greške na membranskim zavarima.

#### 2. Research procedure

Welding foreman working in the production process is responsible for supervising the entire welding process on membrane welding. The welding process is also supervised by a quality engineer appointed by the quality assurance department and by a welding engineer authorised by the technical department. If noticing unacceptable deviations in the welding process, welding operations manager is obliged to stop the welding process and to notify the authorised welding engineer about occurrences.

Welding personnel (welders and operators) shall be certified and shall apply all technological measures as determined in the Welding Procedure Specification (WPS) and in the in-house instructions referring to welding and repairs of membrane welds applied at a company level. [3]

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## 2.1 Welding process

The company Đuro Đaković Termoenergetska postrojenja d.o.o. determines the membrane welding process as follows: when joining two tubes and a connection fin, welding is done first parallel on one side from the beginning to the end of the weld length, upon which the weld spatter is cleaned. The panel (two-tube, four-tube, eight-tube) is then turned over and the membrane welds are welded on the other side. This is followed again by the cleaning of spatter. The welding is supervised by the welding foreman. Welding is performed according to WPS, as determined by the company's welding techniques service. In addition to WPS, the welding process has to be in compliance with the parameters determined within the welding trial. During the welding process, the welder is obliged to monitor the process and, if noticing some deviations, he has to mark them with a pen or chalk, so that such deviations can be corrected later on manually by TIG welding.

The welder is obliged to handle welding flux and welding wire responsibly. Wire and flux have to be stored according to the manufacturer's specification. Before welding, welding flux should be dried according to the in-house instructions or the manufacturer's specification printed on the package. The welder keeps a log on drying the welding flux near the drying oven, in which he records the drying temperature, which has to be in line with the manufacturer's specification. [4, 5, 6]

If some unacceptable errors occur, such as tube burning or contamination with a copper tip, the welder is obliged to mark such errors with a red pen and inform the welding foreman about them. When such defects occur, the authorised controller from the control and quality department is obliged to make a deviation report, i.e. non-conformance report (NCR), and the welding technologist is

obliged to define appropriate repair method on behalf of the welding techniques service.

Welders perform repairs manually by TIG welding according to the prescribed welding procedure specification (WPS) approved by the welding department. The welder is obliged to repair all defects on the membrane panel prior to the inspection of the controller.

Membrane welds are controlled by the controller authorised by the control and quality service. After welding, a 100% visual inspection and dimensional control of the panel is performed.

## 3. The most common defects in boiler membrane welds

Defects may occur during automated welding of boiler membrane welds, among which the most common are:

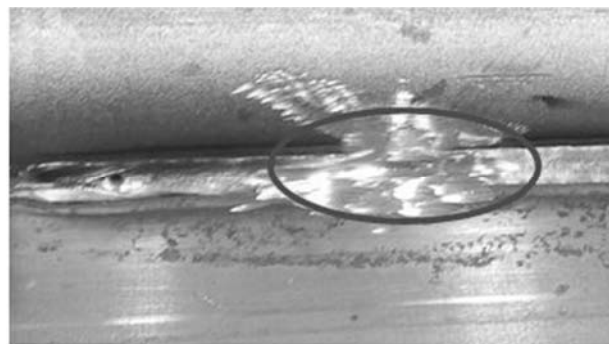
- a. Surface cavity
- b. Undercuts
- c. Unwelded parts
- d. Irregular geometric shape of the weld
- e. Incorrect position of the welded connection plate

Automated welding uses rates from 800 - 1000 mm/min, which refers to high-speed welding during which the welder has to complete a considerable length of membrane welds in one shift.

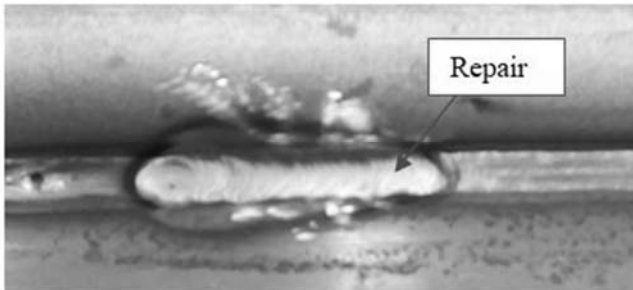
a. Surface cavities as defects are elaborated in the group 200 of the standard EN ISO 6520-1. Smaller pores (less than 3 mm in diameter) can be repaired without grinding. Larger pores or those formed as nests have to be removed by grinding and welded again according to WPS (Figures 1 - 3). The maximum allowable surface cavity dimension that does not require any repair is  $\varnothing 2$  mm, if such cavity does not occur at stopping or restarting of the welding.



**Figure 1. Cavity**  
**Slika 1. Šupljina**



**Figure 2. Grinding of the defect**  
**Slika 2. Brušenje greške**



**Figure 3.** Repair of the defect by TIG welding

**Slika 3.** Popravka greške TIG zavarivanjem

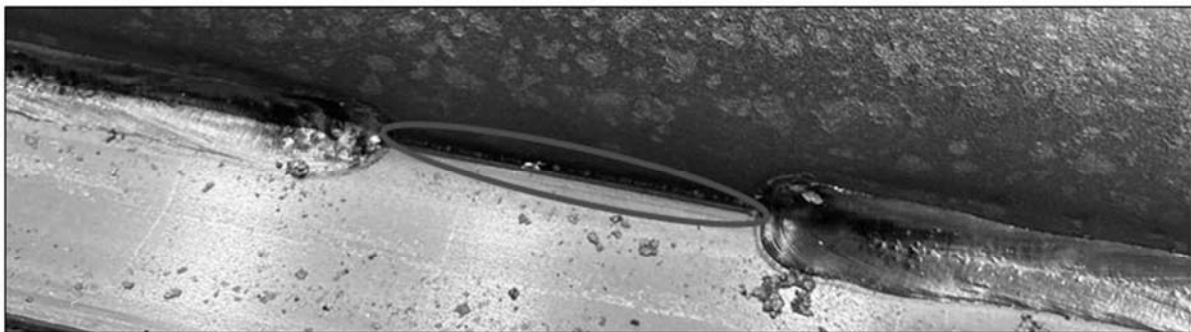


**Figure 4.** Undercut

**Slika 4.** Zajed

b. Undercuts (Figure 4) - according to EN ISO 6520-1 [7], undercuts are classified as defects of the group 5011 and 5012. The maximum allowable undercut depth with a smooth transition is  $\leq 0,5$  mm. Undercuts with greater depths have to be repaired by grinding and/or welding according to WPS.

c. Unwelded parts - the occurrence of unwelded parts or discontinuities (Figure 5) happens due to welding interruption, i.e. when the welding machine stops. This causes a sort of skips on the membrane weld.



**Figure 5.** Unwelded parts

**Slika 5.** Nezavareni delovi

d. *Irregular geometric shape of the weld* - means that the appearance of the weld is inappropriate. The weld of improper geometry cannot pass visual inspection because of that defect.

e. *Incorrect position of the welded connection plate* - refers to the position of the connection plate that is not in line with requirements set by the standard EN ISO 12952-5.

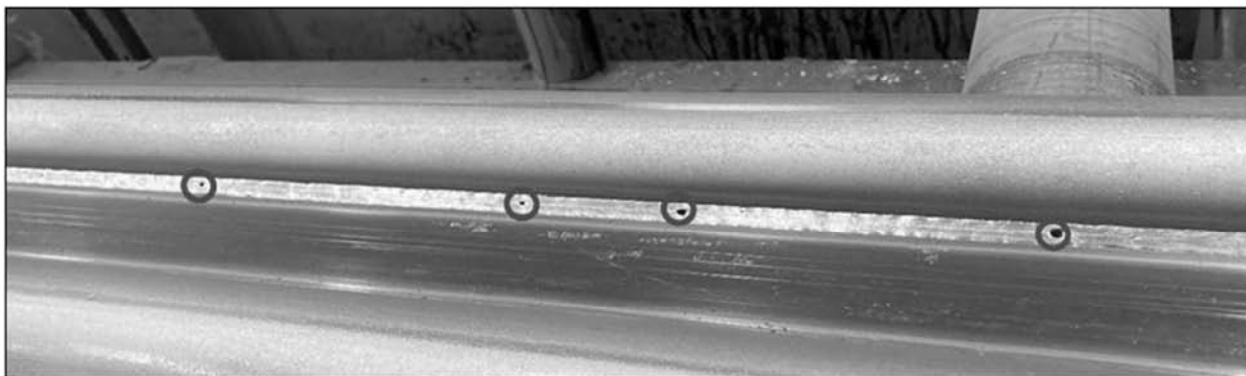
#### 4. Causes of defects on boiler membrane welds

Membrane welding is a highly efficient process during which certain requirements must be fulfilled from the beginning to the end of the process in order to make welding successful. The base and filler material, tubes and fin in the panel have to be of good quality, and welding material has to be prepared well. Before welding, the tubes are shot-blasted by machine, while the wire coming from the welding wire reel is calibrated and cleaned with a chemical agent to remove all impurities, such as various greases and coatings. The welding flux is

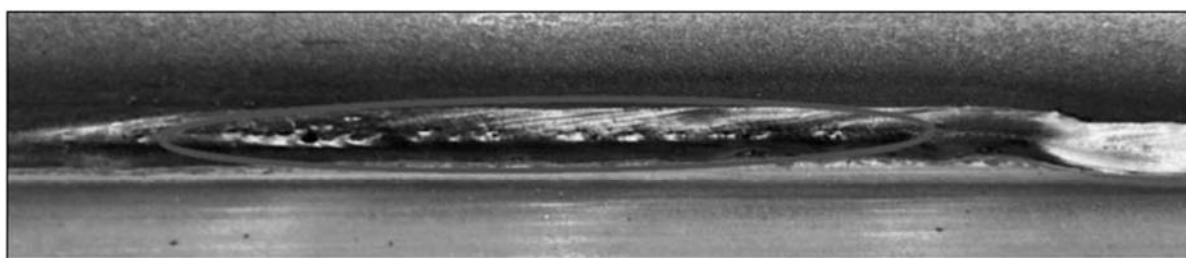
kept in a plastic bag, so it has to be dried to a temperature defined in the manufacturer's specification. The welding flux is used for a specific number of times, after which it is disposed of as no longer useful. The cleanliness of the surface to be welded is also one of the important factors to be dealt with prior to welding. Welding of dirty, greasy and poorly prepared material leads to the occurrence of welding defects, thus resulting in poor quality of welds.

##### 4.1. Surface cavity

Surface cavities are classified into the group 200 according to EN ISO 12952-5. Cavities in welded joints occur as a consequence of residual gas that remains in the material because of impurities, dirt and grease on the surface of welded joints, moist base or filler material, poor welding performance, or non-compliance with the welding procedure specification (WPS). Surface cavities can appear individually, as shown in Figure 6, or in form of a nest, as shown in the Figure 7.



**Figure 6. Individual cavities**  
**Slika 6. Pojedinačne šupljine**



**Figure 7. Nest of cavities**  
**Slika 7. Gnezdo šupljina**

#### 4.2. Unwelded parts

Unwelded parts (discontinuities) refer to defects that occur during welding of a large amount of membrane welds. The most common causes of discontinuities in welds are:

- Lack of welding flux in a welding machine, due to which the welding process stops. The welding flux is stored in plastic bags, dried in a drying oven prior to welding, and then transferred into the welding machine flux container.

- Lack of welding wire - welding wire is coiled up in reels of two sizes, i.e. small reels (15 - 25 kg) and large reels (350 kg). Wire reels have to be replaced when running out of wire, yet it can happen that the wire runs out during welding, which causes discontinuity of welding and occurrence of unwelded parts.

- Changing the copper contact tip (nozzle) - the contact tip (nozzles) are usually replaced before the start of each shift, when it is noticed that they have been used up to the extent that they can no longer be efficient in welding, as the wire may stick to the copper tip of the contact tip or the tip may get in contact with the workpiece (Figure 8).

- Mechanical stopping of the welding machine occurs primarily because of the overload of the membrane welding line or because of poor welding machine maintenance.



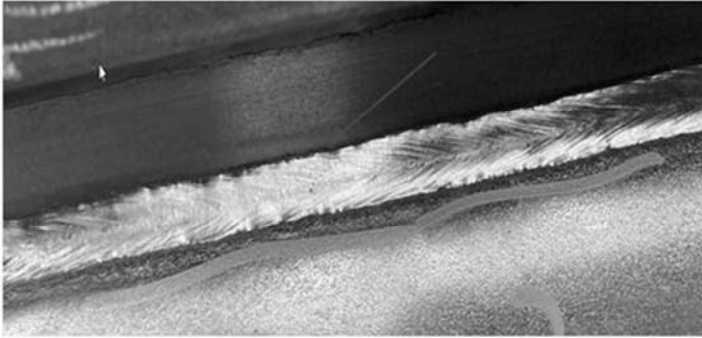
**Figure 8. Damaged contact tip (nozzle)**  
**Slika 8. Oštećen kontaktni vrh (mlaznica)**



### 4.3. Undercuts

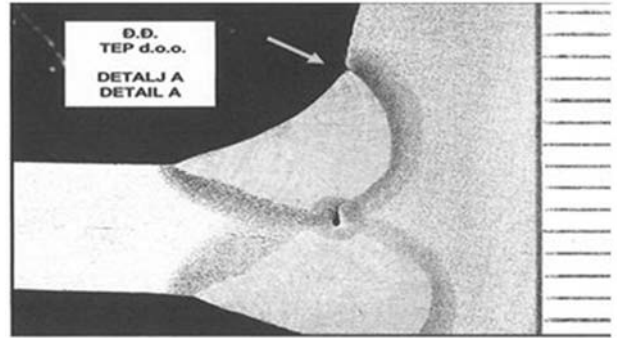
Defects like undercuts classified as 5011 and 5012 are elaborated in EN 12952-5, Table C.1. The maximum allowed depth of the undercut has to be less than or equal to 0,5 mm, regardless of the undercut length, provided that the undercut has a

smooth transition. The Figure 9 shows a marked small undercut on a weld. Such defects are the most difficult ones to be determined as acceptable or unacceptable by visual inspection only, since such inspection is unreliable in terms of determining the undercut depth and its transition.



**Figure 9. Small undercuts**

**Slika 9. Mali zajedi**



**Figure 10. Macrostructure of the undercut**

**Slika 10. Makrostruktura zajeda**

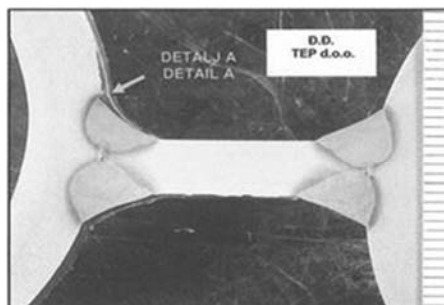
Performing the destruction test, i.e. testing the macrostructure is the only reliable way of determining the dimensions of the undercut and the type of its transition.

Dimensional control of the sample presented in the Figure 10 revealed the undercut depth of 0,21 mm. According to the standard and the macro cross section of the defect, as shown in the Figure 10, this undercut can be considered as acceptable.



**Figure 11. Larger undercut**

**Slika 11. Veći zajed**



**Figure 12. Macrostructure of the undercut**

**Slika 12. Makrostruktura zajeda**

As presented by the sample in Figure 12, the undercut marked as the detail A shows sharp transition, because of which it is not acceptable according to EN ISO 12952-5. The undercut depth

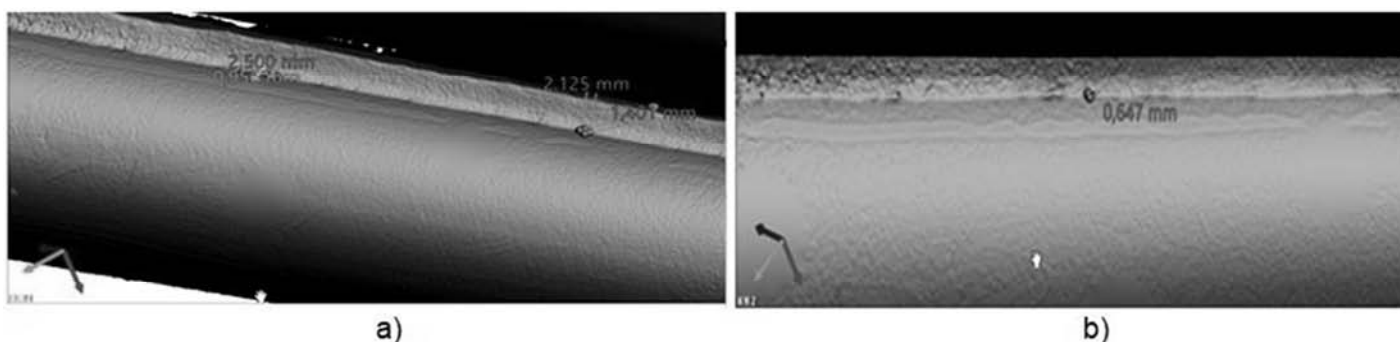
measures 0,45 mm on the marked undercut presented by the Figure 11, which is close to the upper value limit of acceptance set at 0,5 mm.



Since this undercut has a sharp transition, as shown in Figure 11, it is recommended for repair.

Testing of the macrostructure on the product is not possible, yet the visual inspection is not suitable for proper assessment of such type of weld defect in terms of determining whether its quality is acceptable or unacceptable. There is an attempt to apply the template with predetermined sizes of defects, which are visually compared with occurring undercuts on membrane welds. Sizes of the undercuts can be also determined by scanning the

surface with Creaform Ametek and VXelements™ software. However, such scanning method is also questionable because it depends on the determination of points on the weld surface and on their mutual angle, which affects the determination of the undercut depth. The Figures 13a and 13b present the determined undercut dimensions, which are as follows: undercut length 2,5 mm, undercut width 0,956 mm, and the generated undercut depth 0,647 mm.



**Figure 13.** Measuring of the undercut depth by scanning: a) undercut length 2,5 mm, width 0,956 mm, b) depth 0,647 mm

**Slika 13.** Merenje dubine zajeda skeniranjem: a) dužina zajeda 2,5 mm, širina 0,956 mm, b) dubina 0,647 mm

In general, both methods, macrostructure testing and surface scanning, are not appropriate for assessment of the membrane weld undercut sizes in real production conditions.

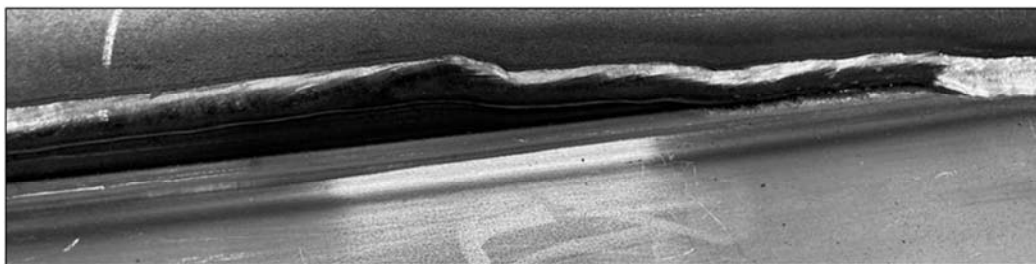
The main causes of undercuts are the following:

- Impurity of the base material (tubes), oxidized surface of the tube along the weld.
- Welding parameters, such as excessive welding current or welding voltage, inappropriate welding speed.
- Inappropriate angle of the torch.

Incorrect position of the connection plate with respect to tube position, which causes a shift along the electric arc, thus causing an increase in voltage, i.e. greater length and width of the arc and eventually the formation of an undercut.

#### 4.4. Irregular geometric shape of the weld

Irregular geometric shape of the weld refers to visually unacceptable weld geometry that does not conform to EN ISO 12952-5. Possible causes of such defect are machine jamming (mechanical problems with the welding machine), problems with the wire feeder because of which the melt is not distributed evenly, thus forming deviations in the weld geometry, incorrect position of the welding torch, incorrect handling with the welding torch and improper monitoring of the membrane welding process by a welder. The Figure 14 presents an irregular geometric shape of the weld at which the membrane weld went up the tube as a consequence of welding deviation.



**Figure 14.** Irregular geometric shape of the weld

**Slika 14.** Nepravilan geometrijski oblik šava

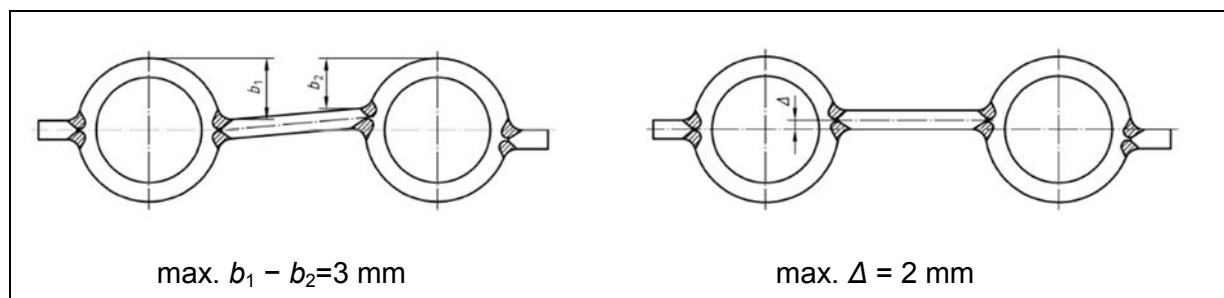


#### 4.5. Incorrect position of the welded connection plate

Incorrect position of the welded connection plate refers to the situation when the linear or angular displacement of the plate happens to be greater than the allowed, so the plate needs to be carefully cut and removed. Cutting of the connection plate is performed with a grinder with a cutting disc. During

cutting, the cutting disc should be directed toward the plate, so that it cannot damage the tubes. The prepared plate is inserted into the membrane wall and welded according to the welding instructions (WPS). After welding, the joint is tested by applying the surface method [8].

Allowed linear and angular connection plate displacement is shown in the Figure 15.

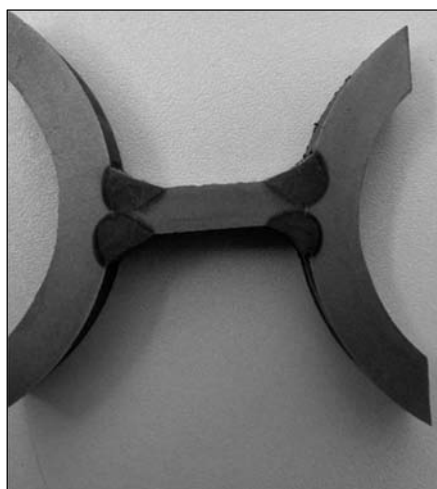


**Figure 15.** Connection plate displacement

**Slika 15.** Pomeranje vezne ploče

Incorrect position of the welded connection plate occurs during adjustment of the plate and the tubes. If the plate is not properly adjusted, it can

shift during welding thus causing unacceptable defects. The Figure 16 shows an incorrect position of the welded connection plate.



**Figure 16.** Incorrect position of the welded connection plate

**Slika 16.** Nepravilan položaj zavarene vezne ploče

## 5. Conclusion

Membrane welding is a highly efficient process that requires compliance with determined welding procedure in order for the welding to result in quality welds. Welding procedure and requirements are determined in the standards EN ISO 12952-5 [1] and EN ISO 12952-6 [2]. Compliance with the welding procedure and requirements defined by the standards facilitates efficient welding and results in a high-quality product. This refers also to completion and supervision of membrane welding

in accordance with the standard, which is not an easy task to be performed. The welder has to monitor the process constantly in order to assure the highest quality of welding.

Defects such as cavities are very difficult to be completely fixed because of the considerable length of membrane welds. Clean welding is one of the basic prerequisites for a quality weld. Undercuts are also frequently appearing and are also difficult to be dealt with, primarily because of impossibility of visual inspection. Furthermore, two presented



methods of controlling the undercut depth proved that it is very difficult for the controller to assess the size of the undercut, due to which they sometimes mark such undercuts as unacceptable defects, even when they could be acceptable without repair, as confirmed by the performed research tests. It is impossible to examine the macrostructure on the final product, while scanning procedure for each undercut or cavity is time-consuming. Therefore, training of controllers by the welding quality assurance service is necessary to make them skilled in efficient detection and assessment of defects that occur on membrane welds.

## 5. Zaključak

Membransko zavarivanje je visoko efikasan proces koji zahteva poštovanje utvrđene procedure zavarivanja kako bi zavarivanje rezultiralo kvalitetnim zavarenim spojem. Postupak i zahtevi zavarivanja određeni su standardima EN ISO 12952-5 [1] i EN ISO 12952-6 [2]. Usklađenost sa procedurom zavarivanja i zahtevima definisanim standardima omogućava efikasno zavarivanje i rezultira visokokvalitetnim proizvodom. Ovo se odnosi i na završetak i nadzor membranskog

zavarivanja u skladu sa standardom, što nije lak zadatak. Zavarivač mora stalno da prati proces kako bi obezbedio najviši kvalitet zavarivanja.

Greške kao što su šupljine je veoma teško u potpunosti popraviti zbog velike dužine membranskih zavara. Čisto zavarivanje je jedan od osnovnih preduslova za kvalitetan zavar. Često se javljaju i zajednice koje je takođe teško sanirati, pre svega zbog nemogućnosti vizuelnog pregleda. Dalje, dve predstavljene metode kontrole dubine zajednice dokazale su da je kontroloru veoma teško proceniti veličinu zajednice, zbog čega ponekad takve zajednice označavaju kao neprihvatljive nedostatke, čak i kada bi mogli biti prihvatljivi bez popravke, što je i potvrđeno izvršenim istraživačkim ispitivanjima. Nemoguće je ispitati makrostrukturu na finalnom proizvodu, dok je procedura skeniranja za svaki zajednicu ili šupljinu dugotrajna. Zbog toga je neophodna obuka kontrolora od strane službe za obezbeđenje kvaliteta zavarivanja kako bi bili osposobljeni za efikasno otkrivanje i procenu nedostataka koji se javljaju na membranskim zavarenim spojevima

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