Professional paper
Received: August 4, 2014
Accepted: November 11, 2014

The effect of welding flux and welding wire on the microstructure and characteristics of the welded joint

Vpliv varilnega praška in varilne žice na mikrostrukturo ter lastnosti zvarnega spoja

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Abstract

The tendency in the production process is to make products of good quality with minimal cost. The same applies for the products - yokes that are welded with submerged arc welding. Because we were dealing with yokes that were not of good quality, we analysed the process of the existing production method. We checked the dimensions of the products and measured their hardness. There was waste due to irregular shape of the welding piece after calibration. We searched for causes of this fault in connection with the weld hardness. We made four different specimens for our research, which differed in the chemical composition of the welding flux, type of the welding wire and preheating of the base material. At the end of welding we used specimens to carry out measurements of concentricity of the products after the process of calibration, made metallographic examination, measured tensile strength and hardness of the weld. The hardness was measured in the weld, base material and heat affected zone. The results of our research showed that hardness of the weld was lowest in specimen 3, which was welded with basic welding flux and preheated welding piece. Measurements of the concentricity of the product showed that it is the best in specimen 3 and the worst in specimen 1, which was welded by the existing filler materials.

Key words: submerged arc welding, concentricity, hardness

Izvleček

V proizvodnji je težnja izdelati kakovosten izdelek hitro in z minimalnimi stroški. To velja tudi za izdelke okrove, ki smo jih varili po postopku varjenja pod praškom. Zaradi preveč nekakovostnih okrovov smo analizirali potek dosedanje izdelave. Izdelke smo pregledali dimenzijsko in izmerili trdoto. Izmet se je pojavil zaradi nepravilne oblike varjenca po kalibraciji. Vzroke za napako smo iskali v povezavi s trdoto zvara. Za preiskavo smo izdelali štiri različne preizkušance, ki so se razlikovali v kemični sestavi varilnega praška, vrsti varilne žice in predgrevanju osnovnega materiala. Po končanem varjenju smo pri preizkušancih opravili meritev koncentričnosti izdelka po procesu kalibracije, naredili smo metalografsko analizo, izmerili natezno trdnost in trdoto zvara. Trdoto smo merili v varu, osnovnem materialu in toplotno vplivani coni. Rezultati preiskave so pokazali, da je trdota vara najmanjša pri preizkušancu 3, varjenem z bazičnim varilnim praškom in predgrevanim varjencem. Meritve koncentričnosti izdelka pa so pokazale, da je ta najboljša pri preizkušancu 3, najslabša pa pri preizkušancu 1, varjenem s sedanjimi dodajnimi materiali.

Ključne besede: varjenje pod praškom, koncentričnost, trdota

Introduction

The production process constantly strives for the best possible quality of products. This, however, depends on various factors, such as machines, man, working methods and material[1]. In searching for faults we use different techniques such as Ishikawa diagram or Deming circle, which help us to find possible causes of problems that can be systematically eliminated. Our problem was increased waste in the process of submerged arc welding or SAW.

SAW is a type of electric arc welding[2], where in the place of welding, welding wire, base material and welding flux melt. During the welding process the arc is invisible, because it is covered with welding flux that is introduced to welding area from a flux hopper. During the welding process part of the welding flux does not melt while the other part does. This melted flux protects the arc and the melted weld metal from the atmospheric influences, attracts impurities and oxides, stabilizes the arc and metallurgically work the melt of the weld.

This process of welding is suitable for unalloyed steels and low-alloyed steels. Based on the base material we choose the right combination of the welding flux and the welding wire. Elements and their concentration which affect the weld quality are silicon, manganese, carbon, phosphorus and sulphur.

Fluxes for SAW are a mixture of various components in the powder form[3–7] that differ among each other by their grain size, chemical composition and way of production. The most widely used formula to calculate the basicity of the flux is the Bonisszewski formula. The basicity of the welding flux[8] can also be determined with equation 1.

$$B = \frac{CaO + MgO + BaO + CaF_2 + Na_2O + K_2O + \frac{1}{2} \times (MnO + FeO)}{SiO_2 + \frac{1}{2} \times (Al_2O_3 + Ti_2O + ZrO_2)} \quad (1)$$

In our research we welded the yoke by the SAW procedure. After the welding process the yokes were calibrated. At that point there was eccentricity between the inner and the outer diameter. This occurrence of difference in the thickness of a yoke wall is important, as it affects magnetic characteristics during the operation. Thus we set a goal to determine what influences the difference in wall thickness of a yoke after calibration in the process of submerged arc welding.

Experimental work

Due to the fact that there was eccentricity present on the workpieces, we analyzed bad products. We presumed that the cause of differences in wall thickness of the yoke after the calibration was caused by filler materials which are currently in use. We made four types of specimens. These were yokes from the series production. Figure 1 a) shows the final product which had a cylindrical form. The wall thickness of base material for the production of yoke was 5.5 mm and the width was 86 mm. After bending them, semi products were welded by the SAW procedure.

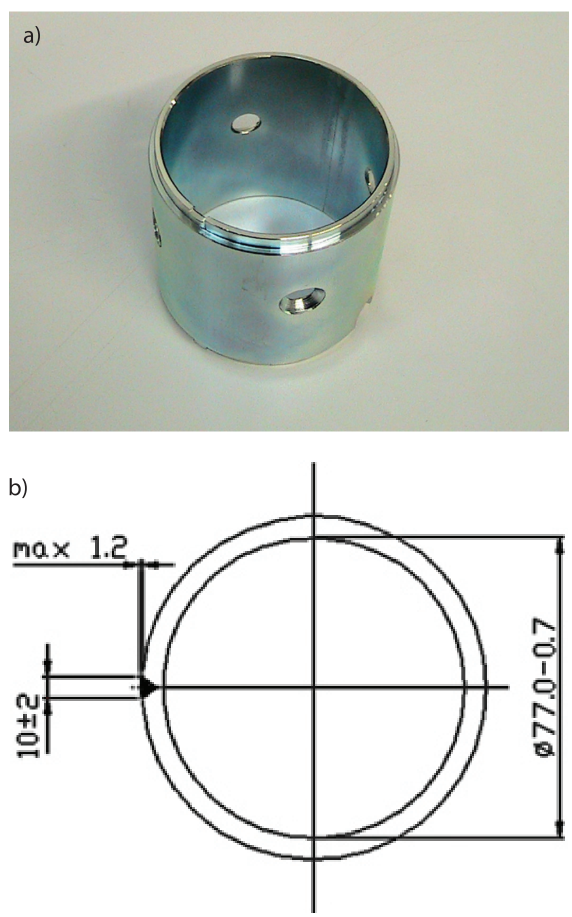

Figure 1: *a) Finished yoke, b) drawing of the welding spot .*

Welding was performed by the welding machine manufactured by OVEN. The welding wire and welding flux were introduced from the upper part of the welding machine. For the purpose of this research, the rectifier ESAB LAF 635 DC with maximum voltage of 44 V at direct current of 630 A was used.

During the welding process we made sure that the depth of penetration did not exceed 2/3 of the thickness of the base material. The weld width was between 8 mm and 12 mm, height of the weld face was not allowed to be higher than 1.2 mm (Figure 1 b). After the welding process the products cooled slowly on the stationary air.

Weldability is an important factor in welding. It was determined with the help of carbon equivalent (equation 2). In our case carbon equivalent for base material was 0.17. This type of steel is known to have good weldability without the need of preheating.

$$C^{eqIIW} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad (2)$$

Results and discussion

The yoke did not have the required regular form. We expect differences in wall thickness of the welded yoke (as much as 0.5 mm and more) and irregular concentricity after calibration because of differences in the weld hardness and height of the weld face, since harder welds have lower plasticity than the base material. Base material for the production of yokes was steel sheet in strips 86 mm in width and 5.5 mm in thickness. Chemical composition of base material is in table 1.

Table 1: *Chemical composition of base material*

Type of workpiece	Chemical composition in mass fractions, (w/%)				
	C	Mn	S	P	Al
Steel	0.10	0.45	0.035	0.035	0.025

We prepared four specimens for the test and they differed in type of welding wire, welding flux and preheating temperature (table 2). For specimen 1 we used the welding wire with 0.1 % of carbon, 0.15 % of silicium and 1 % of manganese and aluminate rutile welding flux which is used for automatic welding of regular construction steels. Flux basicity by Boniszewski was 0.5, which means that the flux had more acid than basic components.

The welding wire for specimens 2 and 3 contained 0.09 % of carbon, 0.06 % of silicium and 0.5 % of manganese. The specimens differed in their state, since the workpiece of specimen 2 was not preheated while the workpiece of specimen 3 was. They were both welded with the basic welding flux of basicity 1.1 by the Boniszewski rating.

Table 2: *Chemical composition of welding wire, type of welding flux and state of workpiece*

Specimen type	Chemical composition of welding wire (w/%)			Type of flux	State of workpiece
	C	Mn	Si		
Specimen 1	0.10	1	0.15	Flux 1	Not preheated
Specimen 2	0.09	0.5	0.06	Flux 2	Not preheated
Specimen 3	0.09	0.5	0.06	Flux 2	Preheated
Specimen 4	0.09	0.5	0.1	Flux 3	Not preheated

Welding wire and type of welding flux of specimen 4 are presented in table 2. The welding wire used for welding specimen 4 contained 0.09 % of carbon, 0.1 % of silicium and 0.5 % of manganese, while the welding flux was basic. Its basicity was 1.6 by the Boniszewski rating. Table 3 shows chemical composition of welding fluxes and table 4 presents chemical composition of all weld metal according to their manufacturer's specifications.

For testing there were the same starting welding parameters used for all three tested combinations of filler materials (welding voltage 26.25 V; welding current 284 A). In welding workpieces 2 and 3 the penetration was too deep at same welding parameters, which led us to raise the welding voltage to 28 V and reduce the welding current to 260 A. At this welding voltage and welding current we reached the depth of penetration that was in tolerance by the technological drawing, i.e. up to 2/3 of the base material thickness. At the end of the welding process and the calibration we measured the concentricity of the yokes (Figure 2). The Figure 2 shows the measurements of devia-

Table 3: *Chemical composition of welding flux*

Type of welding flux	Chemical composition (w/%)										
	SiO_2 + TiO_2	Al_2O_3 + MnO	CaO + MgO	SiO_2	MnO	MgO	CaF_2	Na_2O	Al_2O_3	CaO	TiO_2
Flux 1	30	55	/	/	/	/	5	/	/	/	/
Flux 2	/	/	/	19	11	17	12	2	32	2	2
Flux 3	20	35	25	/	/	/	0.3	/	/	/	/

Table 4: *Chemical composition of all weld metal according to the manufacturer's specifications[9–11]*

Typical all weld metal properties	Chemical composition (w/%)		
	C	Mn	Si
Weld 1	0. 06	1.35	0.6
Weld 2	0.05	1	0.2
Weld 3	0.07	1	0.2

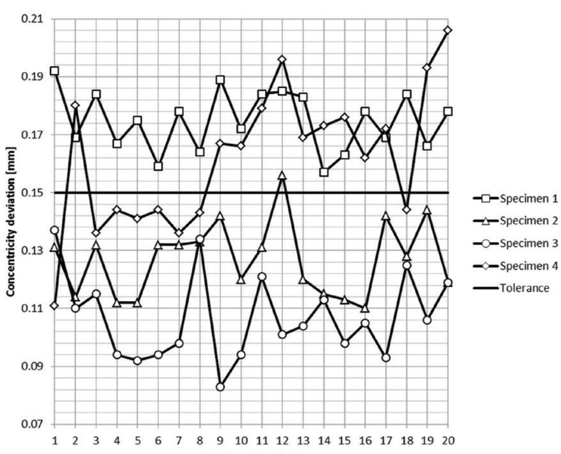

Figure 2: *Deviations in measurements of concentricity on products with different specimens.*

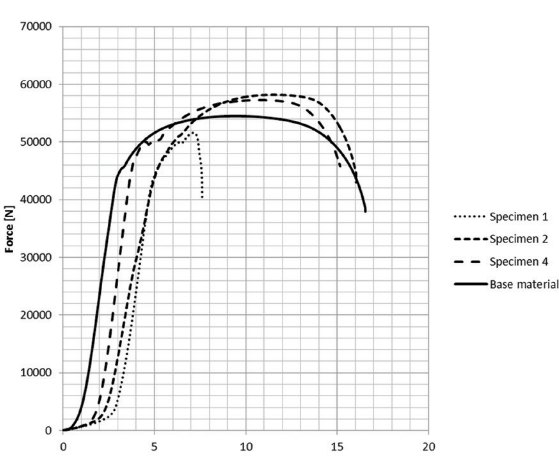

Figure 3: *Diagram force – change in length of specimens 1, 2, 4 and base material.*

tions of concentricity in using different welding flux and welding wire. The lowest deviation in concentricity occurred in using welding flux and welding wire for the welding specimen number 2, which is additionally caused by preheating.

We also measured tensile strength of base material and the welded joint. Figure 3 shows the results of measurements. With the tensile test we determined that the characteristics of the welded joint are completely comparable with the characteristics of the workpiece base material.

To determine the hardness of the welding joint we made metallographic samples from the workpieces (Figure 4). To prepare the samples we used a saw for cutting metals and in the middle of the welding joint we cut samples across the whole weld including the heat affected zone and base material, 30 mm in length and 5 mm in width.

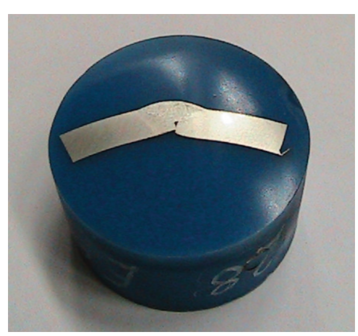

Figure 4: *Polished and etched sample ready to be measured for hardness.*

We carried out the measurements of hardness on the computer operated measuring device Struers Duramin–A300 by Vickers HV5. The measurements of hardness were done diagonally from the weld face, across heat affected zone and to the base material. The points of measurements were set up the same in all cases, where the 1st point of measurement was on the weld face, points of measurements 7 and 8 were on the base mate-

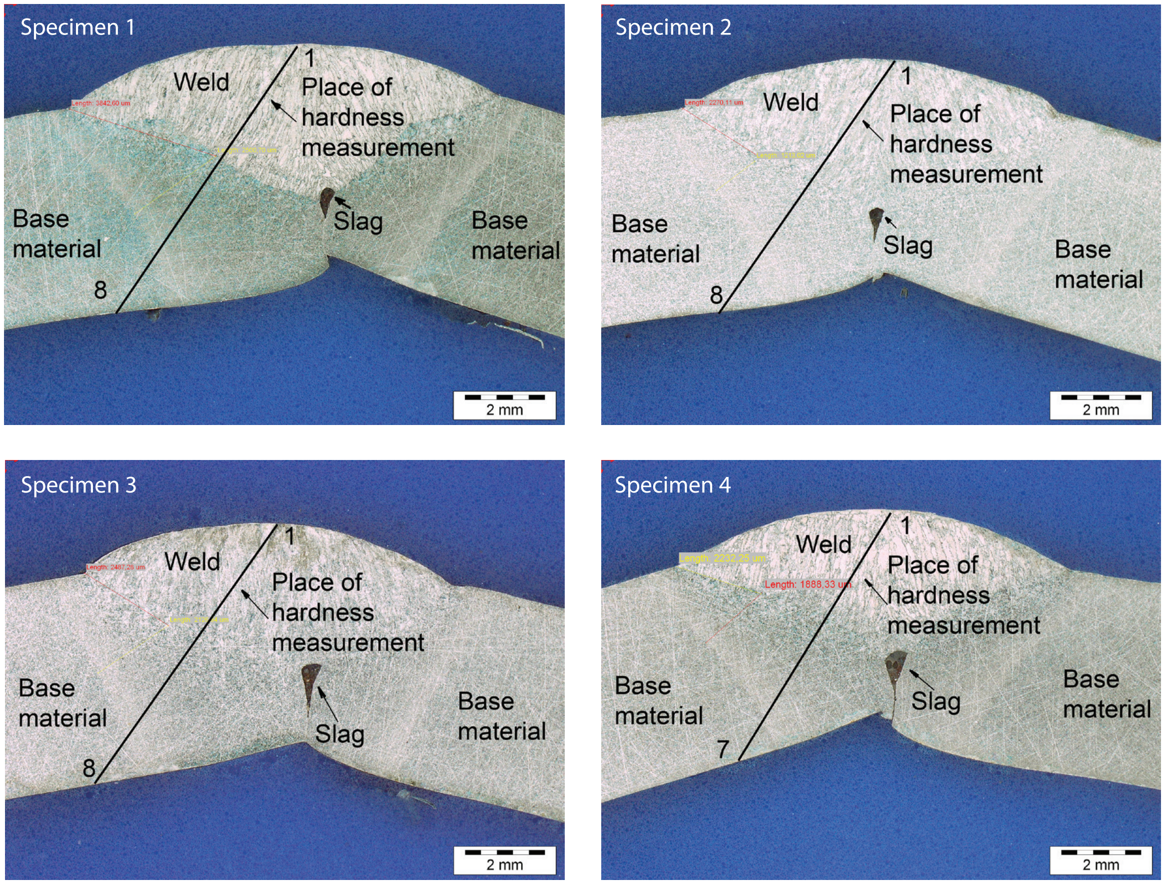

Figure 5: *Course of hardness measurements.*

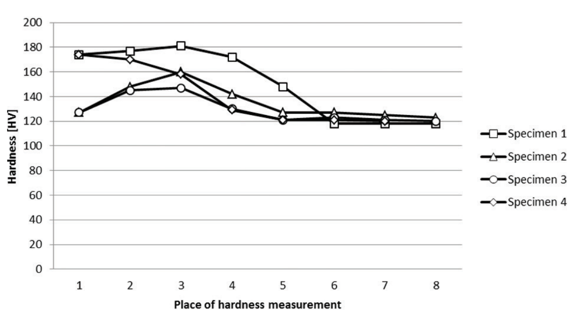

Figure 6: *Course of hardness on the welded specimens.*

rial, which can be seen in Figure 5. All results of these measurements are graphically shown in Figure 6. Under the root of the weld, there is a large dark inclusion of the welding slag. The lowest hardness was measured in specimen 3.
Figure 7 shows the microstructure of the welds, which consists of ferrite and bainite. In welds of specimens 2 and 3 there is more ferrite while in weld of specimen 1 and 4 the amount of bainite is higher.

Conclusions

Weld quality depends on various factors, one of them being the welding method. We analysed bad products due to the occurrence of eccentricity on the welded pieces. We found that irregular concentricity after calibration has to do with differences in hardness among different welds welded with different filler materials and heights of weld face. Differences in hardness are due to different chemical composition and microstructure of the welds. That is why we made specimens on which we measured the weld hardness and product dimensions.
Currently, the flux used in the production process is a rutile flux (marked flux 1) for SAW. The usage of this flux is advisable since it is not as sensitive to atmospheric moisture as the basic welding flux is.
In this research we studied the effect of the welding flux and welding wire on the mechanical characteristics of the weld as well as the dimensional characteristics of the product.

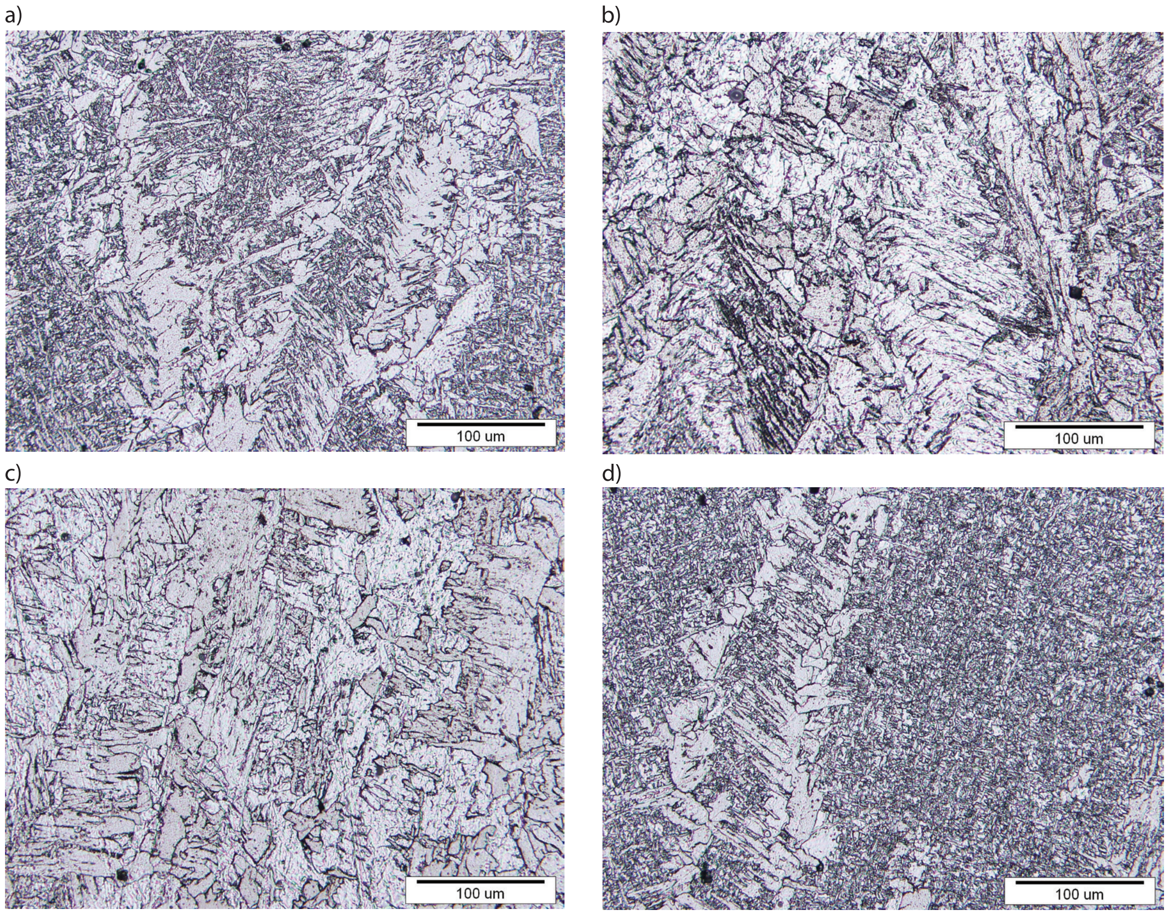

Figure 7: *Microstructure of the welds in specimens: a) 1, b) 2, c) 3, d) 4.*

Based on the measurements it is evident that the usage of combination of welding flux 2 and welding wire with 0.09 % of carbon, 0.06 % of silicium and 0.5 % of manganese is the most suitable for the production process. The weld hardness is additionally reduced in case the workpiece is preheated, which is evident in observing hardness of specimen 3. This specimen has the best concentricity.

The results of these measurements show that the dimensional deviations are much improved and with them also stability of the production process.

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