UDK 669.14:621.791.05
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 44(6)407(2010)

METALLOGRAPHIC CHARACTERIZATION OF THE JOINING PART FOR EN 10216-1 AND EN 10083-3 MADE WITH DIFFERENT CONSUMABLES

METALOGRAFSKA KARAKTERIZACIJA VEZNEGA ČLENA IZ EN 10216-1 IN EN 10083-3, IZDELANEGA Z RAZLIČNIMI DODAJNIMI MATERIALI

Neva Štrekelj[1], Marko Lampič[1], Ladislav Kosec[1], Boštjan Markoli[1]

Faculty of Natural Sciences and Engineering, University of Ljubljana, Aškerčeva 12, Slovenia
strekeljn@gmail.com

Prejem rokopisa – received: 2010-03-22; sprejem za objavo – accepted for publication: 2010-08-23

The microstructures of the base materials (EN 10216-1 and EN 10083-3) and three consumables (EVB 50, EVB CrMo and INOX R 29/9) were investigated in the as-welded and heat-treated states. The base material where the fracture occurred was EN 10216-1, which is why the characterization was focused only on that side of the weld. The microstructure of the base material EN 10216-1 consisted mainly of ferrite. The weld with EVB 50 showed a ferritic and bainitic microstructure. The weld with the consumable EVB CrMo showed a microstructure that consisted of ferrite and some bainite. The microstructure of the weld with the consumable INOX R 29/9 showed an austenic and ferritic microstructure and the fusion line is more pronounced than in the previous two cases. Heat treatment (1 h, 600 °C) affected only the columnar dendrite-like morphology in the case with the consumable EVB CrMo. The weldment is free of typical welding defects, such as inclusions, porosity, microcracks, etc. Out of the three consumables, the EVB CrMo was slightly better in terms of its ultimate tensile strength.

Keywords: microstructure, arc-welding, steel, consumables

Preiskovana je bila izhodna in toplotno obdelana mikrostruktura dveh osnovnih materialov (EN 10216-1 in EN 10083-3) in treh dodajnih (EVB 50, EVB CrMo in INOX R 29/9). Prelomi so nastopili na strani z osnovnim materialom EN 10216-1, zato je bila karakterizacija osredinjena samo na to stran zvara. Mikrostruktura osnovnega materiala EN 10216-1 je bila sestavljena večinoma iz ferita. Mikrostruktura vara z dodajnim materialom EVB 50 je bila feritno bainitna, mikrostruktura področja vara z EVB CrMo je bila prav tako iz ferita in bainita, var z dodajnim materialom INOX R 29/9 pa je izkazoval avstenitno feritno mikrostrukturo. Črta spajanja je bila očitno tanjša kot v drugih dveh primerih dodajnih materialov. Toplotna obdelava (1 h, 600 °C) je vplivala le na stebrasto dendritno morfologijo v primeru z dodajnim materialom EVB CrMo. Pri vseh treh zvarih ni bilo najti tipičnih defektov, kot so vključki, poroznost, mikrorazpoke itd. Med vsemi tremi dodajnimi materiali je v smislu natezne trdnosti dodajni material EVB CrMo nekoliko boljši.

Ključne besede: mikrostruktura, ročnoobločno varjenje, jeklo, dodajni materiali

1 INTRODUCTION

Welding is a very useful procedure for joining different materials of different shapes that cannot be manufactured by casting. It is also used for different repairs of worn and poorly manufactured pieces. However, it is very important as to how the welding technique and the consumables are chosen. The consumable should be similar to the base material. When welding, the focus must be on the heat input, which significantly affects the development and the properties of the weld, i.e., the microstructure, the appearance of cracks and inclusions. In some cases a protective gas has to be employed as well as a pre-welding heat treatment.[1,6,8]

In this paper the constitution and the development of the microstructure of the base material and the weld material were investigated (in the as-welded and heat-treated states) in the links for drilling rigs using metallographic methods, i.e., optical microscopy and scanning electron microscopy with energy-dispersive X-ray spectroscopy. Hardness measurements were made with a Vickers testing machine and tensile tests were conducted for all three consumables.

2 THEORETICAL BACKGROUND

For quality welds in arc welding an awareness of the metallographic properties of the base and filler materials is very important. The basic properties of welds are very dependent on the chemical composition of the base and filler materials and on the regime of the welding. It is very important to identify the microstructural ingredients of the weld and their morphology in connection with the properties of non-equilibrium solidification, which is usually present during the welding procedures.[1]

When welding heavy alloyed steel, such as chromium and nickel alloyed steel, it is essential for the metallographic analysis to use a Schäffler diagram.[2] With this one can make an estimate of the presence and the fraction of austenite, ferrite, bainite and martensite, depending on the chemical composition.

The most appropriate procedure for welding the links for the drilling rigs was patented in 1998,[3] while the filler materials were patented in 1996.[4] In the literature the data on the welding parameters is scarce for these types of welds, which also goes for the microstructural behavior while welding.[1]

Table 1: Chemical composition of steel EN 10216-1 and EN 10083-3 (mass fraction, *w*/%)[1]
Tabela 1: Kemična sestava jekla EN 10216-1 in EN 10083-3 (mas. deleži, *w*/%)[1]

Material/ Element	C	Si	Mn	P	S	Cr	Mo
EN 10216-1	0.115	0.270	1.119	/	/	/	/
EN 10083-3	0.40 – 0.45	up to 0.40	0.6 – 0.9	up to 0.025	up to 0.035	0.9 – 1.2	0.15 – 0.3

Table 2: Chemical composition of consumables (mass fractions, *w*/%)[5]
Tabela 2: Kemična sestava dodajnih materialov (mas. deleži, *w*/%)[5]

Consumable/Element	C	Si	Mn	Cr	Mo	Ni
EVB 50	0.07	0.60	1.00	/	/	/
EVB CrMo	0.06	0.60	0.95	1.10	0.50	/
INOX 29/9	0.11	up to 0.90	0.90	29.00	/	9.00

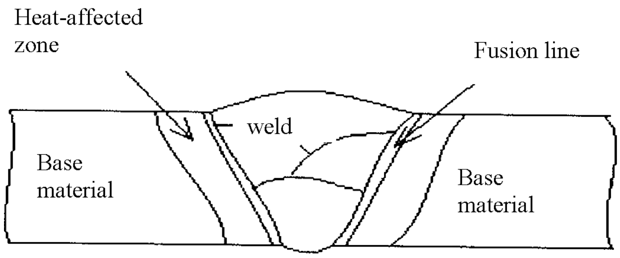

Figure 1: The section through the weldment[1]
Slika 1: Videz zvara po varjenju[1]

The section through the weldment is presented in **Figure 1**.

3 EXPERIMENTAL

3.1 Materials

The weld was made from two parts: a support made of EN 10216-1 steel and the flange attached to it made of EN 10083-3 steel. The chemical compositions of these two alloys are given in **Table 1**. For the welding we used three different consumables: EVB 50, EVB CrMo and INOX R 29/9 (**Table 2**). The welding root had a typical 'V' shape.

The workpiece was made of two parts. The welding was in the form of arc-welding with three different consumables, in the shape of welding electrodes with a diameter of 3.25 mm. The welding involved using a direct electric current (+) with 110 A and 22 V. The welding with preheating was performed only when welding with the consumable EVB CrMo.

3.2 Microstructural characterization

The microstructural characterization of the base and filler materials (as-welded and heat-treated state) was performed using light optical microscopy (LOM – ZEISS Axio Imager. A1m) and scanning electron microscopy (SEM – JEOL JSM 5610). The emphasis was on the characterization of the specimens on the side where the fracture occurred. The metallographic specimens were etched using a solution of 2 % nital. Prior to the etching all three specimens were polished. The microstructural characterization of the tensile-test specimens was also made using the SEM on the fracture surfaces in the welds and on the spots of the welds close to the fracture.

3.3 Hardness measurements

The hardness measurements for each consumable were made on a Shimadzu Micro Hardness Tester with a load of 25 g and an indentation time of 15 s. The measurements were made on both basic materials, both heat-affected zones and the filling material on all three specimens. The measurements were performed on specimens in the as-welded condition and specimens in the heat-treated state.

3.4 Tensile Test

The tensile tests were made on an INSTRON 1255. For these tests the standard specimens were used. No tensile tests were performed on the heat-treated specimens.

3.5 Heat treatment

After the metallographic analysis the specimens were heat treated in a chamber electrical resistance furnace. The specimens were heated to 600 °C for one hour and then cooled in the air. After the heat treatment the metallographic examinations and the measurements of the hardness were made on these specimens as well.

4 RESULTS AND DISCUSSION

4.1 Microstructural characterization

In the case of the consumable EVB 50 in the region of the weld the microstructure consisted of ferrite and bainite and in heat-affected zone (HAZ) there was also a ferritic and bainitic microstructure. So, the weldment consists mainly of ferrite and bainite (**Figure 2a**). The microstructure of the base material EN 10216-1 mainly consisted of ferrite. The heat treatment did not significantly affect the microstructure in any part of the weld-

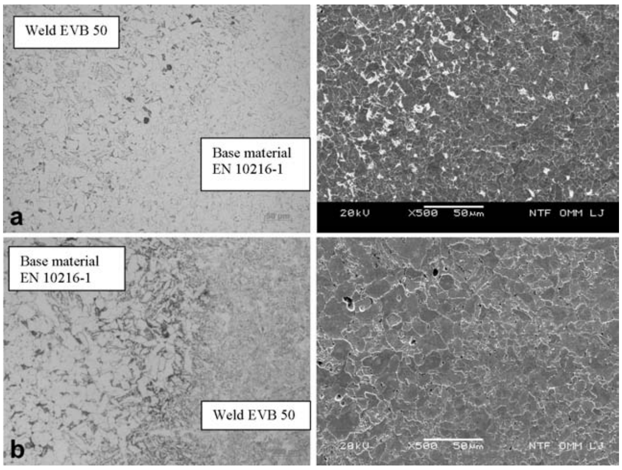

Figure 2: Microstructure of consumable EVB 50 on the side of the base material EN 10216-1 as-welded state (a) LM (left figure) and SEM (right figure) and in heat-treated state (b) LM (left figure) and SEM (right figure)

Slika 2: Mikrostruktura dodajnega materiala EVB 50 na strani osnovnega materiala EN 10216-1 v osnovnem stanju (a) SM (leva slika) in SEM (desna slika) in v toplotno obdelanem stanju (b) SM (leva slika) in SEM (desna slika)

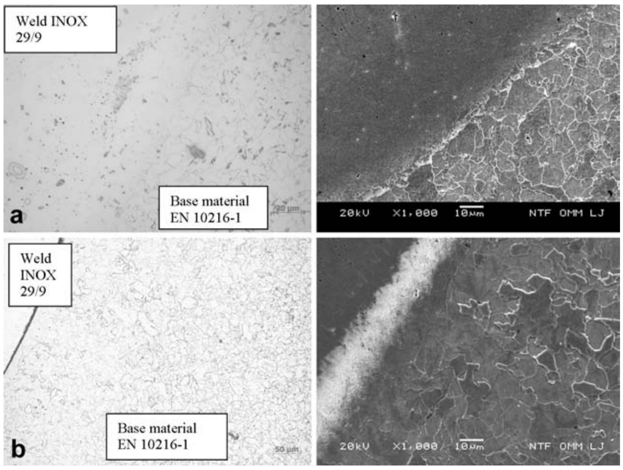

Figure 4: Microstructure of consumable INOX R 29/9 on the side of the base material EN 10216-1 in as-welded state (a) LM (left figure) and SEM (right figure) and in heat-treated state (b) LM (left figure) and SEM (right figure)

Slika 4: Mikrostruktura dodajnega materiala INOX R 29/9 na strani osnovnega materiala EN 10216-1 v osnovnem stanju (a) SM (leva slika) in SEM (desna slika) in v toplotno obdelanem stanju (b) SM (leva slika) in SEM (desna slika)

ment or the HAZ (**Figure 2b**). **Figure 3a** shows the region of the weld with the consumable EVB CrMo, which consists of ferrite and bainite. The HAZ shows a ferritic microstructure with a small amount of bainite. The heat treatment affected the columnar dendrite-like morphology[7] (**Figure 3b**). The weld with the consumable INOX R 29/9 in the as-welded state is shown in **Figure 4a** and in the heat-treated state in **Figure 4b**. According to the Schäffler diagram,[2] in the microstructure there should be austenite and ferrite. **Figure 4a** shows the HAZ, which consists of ferrite, and the weld, which consists of ferrite and pearlite. The microstructure shows a dendritic morphology and the fusion line is much thinner than in the previous two cases because of the different compositions of the consumable and the base materials. The diffusion of chromium and nickel from the consumable INOX R 29/9 is limited to the area of the fusion line, which was confirmed by the EDS spot analyses and points to microsegregation. After the heat treatment no changes were observed. In **Figure 4b** the line between the weld and the base material EN 10216-1 probably shows the diffusion of the carbon to the interface. The weldment is free of typical welding defects, such as inclusions, porosity, microcracks etc., in all three cases.

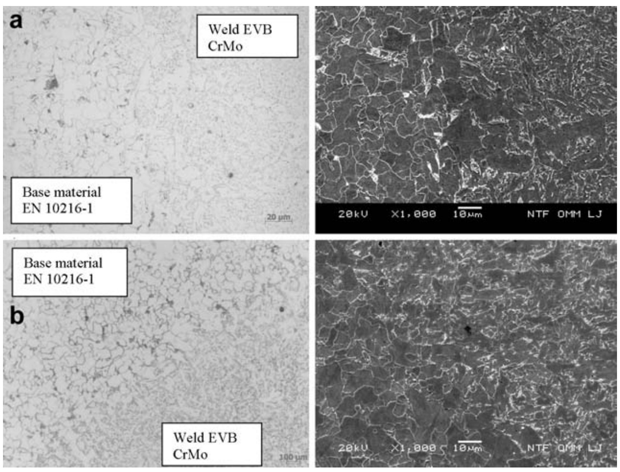

Figure 3: Microstructure of consumable EVB CrMo on the side of the base material EN 10216-1 in as-welded state (a) LM (left figure) and SEM (right figure) and in heat-treated state (b) LM (left figure) and SEM (right figure)

Slika 3: Mikrostruktura dodajnega materiala EVB CrMo (desno) na strani osnovnega materiala EN 10216-1 (levo) v osnovnem stanju – SM in SEM (a) in v toplotno obdelanem stanju – SM in SEM (b)

4.2 Hardness

Consumable EVB 50

The hardness measurements are in **Figure 5** in conjunction with the mean hardness, calculated in **Table 4a**. The hardness measurements (**Figure 5**) showed that the average hardness of the base material EN 10083-3 in the as-welded state was ≈270 HV and for the EN 10216-1 it was ≈180 HV. In the heat-treated state the average hardness of the base material EN 10083-3 was ≈ 260 HV and for the base material EN 10216-1 it was ≈240 HV. The base material EN 10216-1 and consumable EVB 50 had similar compositions; therefore, they had similar hardness values. The maximum hardness was in the heat-affected zone (HAZ) on the side of the base material EN 10083-3 (≈420 HV). It slowly increased near the HAZ (on the side of EN 10083-3), then sharply increased near the fusion line, where it reached a maximum of ≈420 HV. Through the fusion line the hardness decreased and reached an average hardness of ≈200 HV in the weld. In the HAZ on the side of the EN

10216-1 the hardness slightly decreased, where it was around 150–200 HV.

In the heat-treated state the overall hardness was lower on the side of the base material EN 10083-3. Nevertheless, the hardness of the weld itself was higher with ≈280 HV. On the side of the base material EN 10216-1 the overall hardness was higher in heat-treated state than in the as-welded state. The hardness of the weld was also the highest hardness measured in the heat-treated state of the weldment with the consumable EVB 50.

Table 3: Ultimate tensile strengths
Tabela 3: Natezne trdnosti ob porušitvi

Side of the base material	Consumable	Ultimate strength σ/MPa
EN 10216-1	EVB 50	520
EN 10216-1	EVB CrMo	590
EN 10216-1	INOX R 29/9	550

Table 4: Mean hardness measurements of the weldments: a) EVB 50; b) EVB CrMo anc c) INOX R 29/9
Tabela 4: Povprečne vrednosti trdot zvarjencev: a) EVB 50; b) EVB CrMo in c) INOX R 29/9

a)

EVB 50	EN 10083-3	HAZ	Weld	HAZ	EN 10216-1
As-welded	270	340	200	180	180
Heat-treated	260	270	280	210	240

b)

EVB CrMo	EN 10083-3	HAZ	Weld	HAZ	EN 10216-1
As-welded	280	360	260	260	200
Heat-treated	260	270	280	270	250

c)

INOX R 29/9	EN 10083-3	HAZ	Weld	HAZ	EN 10216-1
As-welded	260	330	270	200	160
Heat-treated	270	320	360	230	260

Consumable EVB CrMo

The hardness measurements (**Figure 6 and Table 4b**) in the as-welded state showed that the highest hardness was in the HAZ on the side of the base material EN 10083-3 (≈460 HV). The hardness of the base material EN 10216-1 in as-welded state was ≈200 HV, in heat-treated state it was ≈250 HV, and in the base material EN 10083-3 it was ≈280 HV in as-welded state, and in the heat treated state it was ≈260 HV. On the transition from weld to the base material EN 10083-3 the hardness sharply increased to 400 HV and then it decreased through the HAZ to ≈260 HV in the weld.

In the heat-treated state the hardness was generally decreased on the side of the base material EN 10083-3. In the heat-treated state the highest average hardness was in the weld (≈280 HV). On the other side of the weld (base material EN 10216-1) the hardness decreased. In

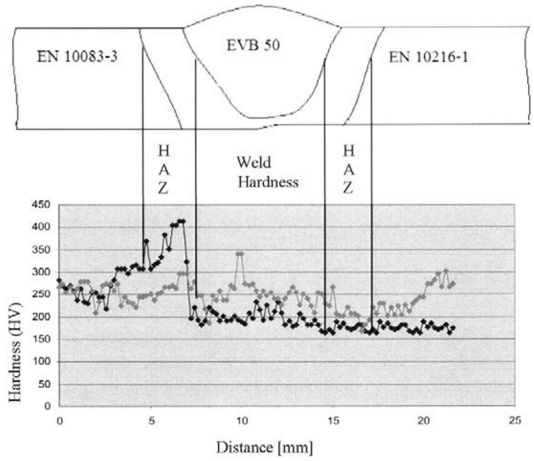

Figure 5: Hardness of the weldment with the consumable EVB 50 (blue line – as-welded state; red line – heat-treated state)
Slika 5: Trdote zvarjenca z dodajnim materialom EVB 50 (modra črta – v osnovnem stanju; rdeča črta – v toplotno obdelanem stanju)

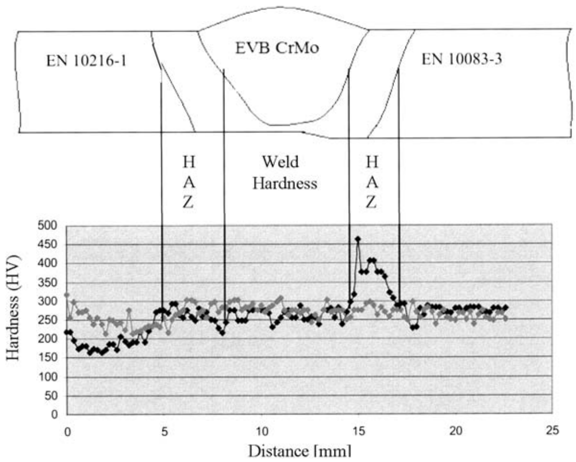

Figure 6: Hardness of the weldment with the consumable EVB CrMo (blue line – as-welded state; red line – heat-treated state)
Slika 6: Trdote zvarjenca z dodajnim materialom EVB CrMo (modra črta – v osnovnem stanju; rdeča črta – v toplotno obdelanem stanju)

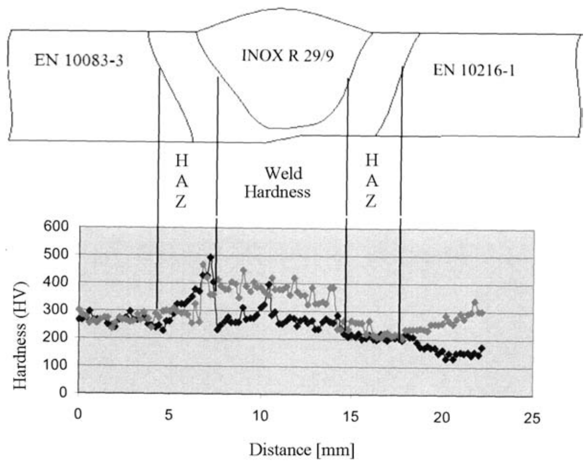

Figure 7: Hardness of the weldment with the consumable INOX R 29/9 (blue line – as-welded state; red line – heat-treated state)
Slika 7: Trdote zvarjenca z dodajnim materilom INOX R 29/9 (modra črta – v osnovnem stanju; rdeča črta – v toplotno obdelanem stanju)

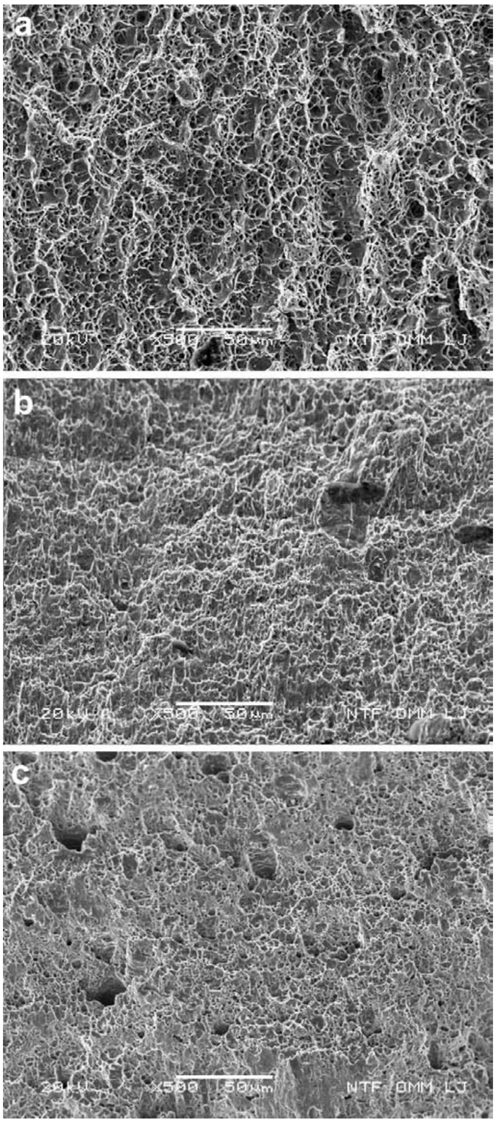

Figure 8: Fracture surfaces, examined using SEM; a) consumable EVB 50, b) consumable EVB CrMo and c) consumable INOX R 29/9

Slika 8: Površine prelomov, preiskovane s SEM; a) dodajni material EVB 50, b) dodajni material EVB CrMo in c) dodajni material INOX R 29/9

this case the hardness in the heat-treated state followed the same trend as in the previous case and was higher on the side of the base material EN 10216-1 than in as-welded state.

Consumable INOX R 29/9

In this case the major difference was when the specimen was heat treated (**Figure 7 and Table 4c**). The hardness in the HAZ slightly increased (on the side of the base material EN 10216-1) and in the weld it strongly increased. This is due to the chromium (29 %) in the consumable and the diffusion of the carbon into the filler material. On the other side of the weld the hardness again decreased slowly. The average hardness of the base material EN 10216-1 was ≈260 HV, and for the base material EN 10083-3 it was ≈270 HV.

In the as-welded state the hardness of the base material EN 10083-3 was ≈260 HV and of the base material EN 10216-1 it was ≈160 HV. In the weld the hardness was ≈270 HV, but the maximum average hardness was in the HAZ (≈330 HV) on the side of the base material EN 10083-3. Again, the average hardness in the heat-treated state was higher than in the as-welded state. In all three cases the hardness in the heat-treated state obviously increased due to the precipitation hardening (on the side of the base material EN 10216-1).

4.3 Tensile Test

All the weldments were tested on an INSTRON 1255. The specimens were loaded until the fracture occurred. After that the fracture surfaces were examined using an SEM in order to establish the nature of the fracture mechanics. In **Figure 8** the fracture surfaces for all three consumables are presented and in Table 3 the ultimate tensile strengths are shown.

In all three cases the fracture occurred on the side with the base material EN 10216-1. Therefore, the characterization was focused on the sides of the fracture. It is clear that in all three cases the fractures are ductile, which is evident from **Figure 8**.

5 CONCLUSIONS

From the results of the tensile tests it is clear that the problems occur on the side with the base material EN 10216-1, which is why the attention was focused on that side of the weld. From the results of the microscopic investigations of the welds with three base materials it can be seen that the microstructure of the base material EN 10216-1 consisted mainly of ferrite with some pearlite (15%). The heat treatment did not significantly affect the microstructure of the weldment with the consumables EVB 50 and INOX R 29/9. However, the heat treatment did change the columnar microstructure of the weldment with the consumable EVB CrMo. The EDS analysis of the weldment with INOX R 29/9 showed an increased concentration of chromium and nickel close to the fusion line. This clearly showed the presence of microsegregation. The hardness measurements showed that the average hardness of the base material EN 10083-3 in the as-welded state was ≈275 HV and for the EN 10216-1 it was ≈180 HV. The maximum hardness in the weldment with the consumable EVB 50 was in the HAZ on the side of the base material EN 10083-3 (≈420 HV). The hardness measurements of the weld with the consumable EVB CrMo in the as-welded state showed that the highest hardness was in the HAZ on the side of the base material EN 10083-3 (≈460 HV). The hardness of the base material EN 10216-1 was ≈200 HV. On the transition from the weld to the base maerial EN 10083-3 the hardness sharply increased to 400 HV and then it decreased through the HAZ to ≈260 HV in the weld. In the heat-treated state the highest average hardness was in the weld with ≈280 HV. In the case with the consumable INOX R 29/9 the major difference was when the specimen was heat treated. The hardness in the weld strongly increased. This was due to the chromium (29 %) in the consumable and the diffusion of the carbon into the filler material. In all three cases precipitation hardening was present because the hardness increased in the heat-treated state (in comparison with the as-welded state). The consumable EVB CrMo shows a slight advantage over the consumable EVB 50 and INOX R 29/9, in terms of the ultimate tensile strength. When welding EN 10216-1 and EN 10083-3 it is slightly better to weld with the consumable EVB CrMo.

6 REFERENCES

[1] M. Lampič, Metallography of the joining part for the EN 10216-1 and EN 10083-3 made with different consumables, Diploma work (in Slovene), Ljubljana 2009

[2] R. Vrban, Metallography of the welded joint of an alloyed steel, Diploma work (in Slovene), Ljubljana 2004

[3] H. Schabereiter: Grundregeln für die Auswahl von Schweisszusatzen für Mischverbindungen, Schweis und prüftechnik 10/98, Kapfenberg

[4] W. Wuich, Nicht immer mit gleichen Schweisszusatz verwerden – Probleme beim Schweissen von Gelenkwellen, 1996

[5] Elektrode Jesenice: Consumables for welding, SIJ – Slovenian industry of steel

[6] V. Grdun, B. Godec, Unfavourable micro-constituents in the welded joints of construction steel, Mater. Tehnol., 36 (**2002**) 5, 247–254

[7] R. Celin, J. Tušek, D. Kmetič, J. Vojvodič Tuma, An investigation of welding of tool-steel, Mater. Tehnol., 35 (**2001**) 6, 405–408

[8] S. Kastelic, P. Mrvar, J. Medved, M. Slovaček: Simulation of the welding and heat treatment process for S355 steel, Livarski vestnik, 56 (**2009**) 1, 25–38