



**ARCHIVES**  
 of  
**FOUNDRY ENGINEERING**

ISSN (2299-2944)  
 Volume 18  
 Issue 2/2018

15 – 20

DOI: 10.24425/122495

3/2



Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

# Surfacing 24Cr-5Ni-2.5Mo Duplex Steel Castings by TIG

**J. Kasinska<sup>a,\*</sup>, A. Skrzypczyk<sup>a</sup>, B. Kalandyk<sup>b</sup>**

<sup>a</sup> Kielce University Technology, Faculty of Mechatronics and Mechanical Engineering, Department of Metal Science and Manufacturing Processes, Al. Tysiąclecia P.P.7, 25-314 Kielce, Poland

<sup>b</sup> Department of Cast Alloys and Composites Engineering, Faculty of Foundry Engineering, AGH University of Science and Technology, 30-059 Krakow, 23 Reymonta Str., Poland

\* Corresponding author. E-mail address: kasinska@tu.kielce.pl

Received 05.12.2017; accepted in revised form 19.02.2018

## Abstract

This article discusses the influence of Tungsten Inert Gas (TIG) surfacing of duplex cast steel on its hardness and structure. The samples of 24Cr-5Ni-2.5Mo ferritic-austenitic cast steel were subjected to single-overlay processes with the use of solid wire having the chemical composition similar to that of the duplex cast steel. As a result of the surfacing, the welds were obtained that had no welding imperfections with a smooth transition to the base material. In the test without the heat treatment, directly below the fusion line, we observe a ferrite band with a width of approximately 200  $\mu\text{m}$  without visible austenite areas. Some of the samples were then solution treated (1060°C). Both variants, without and after solution heat treatment, were subjected to testing. Significant changes in the microstructure of the joint were observed after the heat treatment process (heat affected zone and weld microstructure changes). In both areas, an increase in the austenite volume fraction after solution heat treatment was observed. Changes in the microhardness of the ferrite in the HAZ area directly below the fusion line were also observed.

**Keywords:** Duplex cast steel, Surfacing, TIG method, Solution heat treatment, Microstructure

## 1. Introduction

Duplex type cast steels and steels are widely used for the manufacture of machinery parts and equipment for the chemical, mining and power industries. Turbine blades, rotors and piping components [1, 2] are produced thereon. The production of duplex type cast steel faces the highest expectations as for the technological process and requires high purity input materials [3]. It is also important to ensure low carbon content in the casting and the use of appropriate modifiers, which significantly increases the cost of production. The increase in carbon content may affect the nature of the crystallization process, which in turn may favor the emergence of carbide-rich segregation areas and sigma phase in the casting [2]. The sigma phase dramatically increases the

susceptibility of castings to cracking during cooling after crystallization, due to very high internal stresses ( $\sim 2$  GPa) [4].

Brittle precipitations (Fig. 1) form mainly in the ferritic phase in the following temperature ranges:

- a) 600–1300°C: precipitation of carbides  $\text{M}_{23}\text{C}_6$ ,  $\text{M}_7\text{C}_3$ , nitrides CrN,  $\text{Cr}_2\text{N}$  and Cr- and/or Mo-rich phases such as  $\sigma$ ,  $\chi$ , R,
- b) 300–550°C: formation of  $\pi$ ,  $\epsilon$  (Cu-rich),  $\alpha'$  and G phases [5].

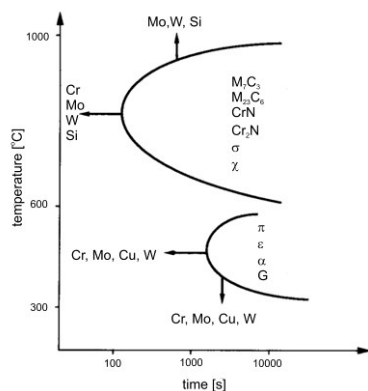


Fig. 1. Isothermal cooling curve for the ternary Fe-Cr-Ni system showing the effect of alloying addition on the precipitation of the secondary phases [5, 6]

Table 1

Chemical composition of the duplex type cast steel

Materials	C	Mn	Si	P	S	Cr	Ni	Mo	other
	wt. %								
F-A	0.06	1.00	0.41	0.013	0.009	24.00	5.20	2.52	2.83% Cu 0.25% Nb

At lower linear energy values, surfacing causes a significant increase in cooling rate, which results in a high ferrite structure in the heat affected zone (HAZ), thus worsening the plastic properties of the overlay in the HAZ.

## 2. Materials

Two-phase ferritic-austenitic steels 24Cr-5Ni-2.5Mo were melted in a laboratory induction oven with a capacity of 30 kg. The charge to the furnace was composed of Armco iron containing 0.02% C, scrap 18Cr-9Ni steel, metallic Cr, Ni and Mn. For deoxidation Al and ferroalloys FeSi, FeCaSi were used. Two "Y" type ingots were made, which after cutting off the excessive weld metal, were subjected to a heat treatment consisting of solution heat treatment at 1060°C and cooling in water. Metallography was performed using the Hirox microscope and the JSM 7100F scanning electron microscope. Etching was carried out with a solution of FeCl<sub>3</sub>, CuCl<sub>2</sub>, HCl, HNO<sub>3</sub> in C<sub>2</sub>H<sub>5</sub>OH. Hardness tests were performed using a Nexus 3000 hardness meter.

## 3. Methods

One-run overlays were made by TIG (141) on 25 mm thick samples from the ingots. The welding was carried out using a Ø 2.4 mm solid wire OK Tigrod 2209 (W22 9 3 NL according to PN-EN ISO 14343-A) in argon as a shielding gas (I1). The typical chemical composition of the weld metal is shown in Table 2. This alloy is characterized by a ferrite number of 35-40 according to WRC-92. The increased content of Ni in the binder by 2% relative to the cast steel being used was supposed to provide the best ferrite-austenite

The 650÷950°C temperature range has the most undesirable effects on the mechanical and corrosion properties. The presence of brittle phase in ferrite or at the ferrite/austenite boundary is related to the segregation of alloy elements and higher diffusion rate in the ferritic phase, which is particularly important in the case of cast parts [7].

The development of brittle phases also determines the repair procedures for castings made of duplex cast steel. Welding methods, such as surfacing for the defects removal, are most commonly used. It is important that the welding process is carried out in such a way that the material is not kept for too long at 600-1000°C [8-10]. Arc weld surfacing is recommended for duplex cast steel repairs, performed mostly under Ar+CO<sub>2</sub> shielding and at low linear welding energies of 0.5 to 2.5 kJ/cm [10-12]. The narrow range of linear surfacing energy requires careful selection of surfacing process parameters and maintaining them at constant levels. Slow cooling after surfacing in the upper linear energy range can lead to a significant decrease in plastic properties (impact strength) and corrosion resistance.

balance. The overlays were made in flat position (PA) using the parameters given in Table 3. The outward appearance of the overlay was assessed and its characteristic dimensions (width, height and depth of fusion) were determined.

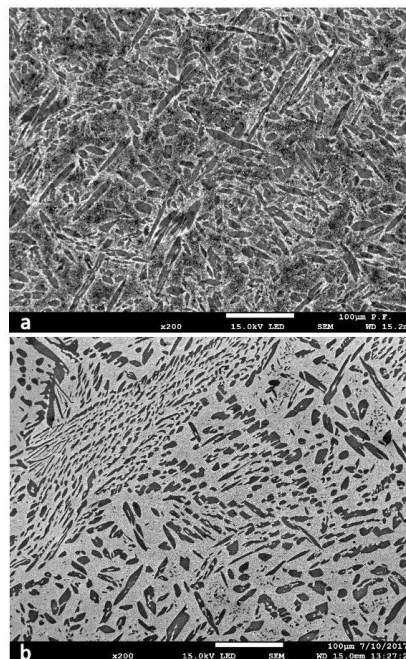


Fig. 2. Microstructure of duplex type cast steel a) molten state, b) after solution heat treatment, light microscope; etching: Carpenter's reagent

Table 2

Chemical composition of OK. Tigrod 2209 wire (acc. to catalogue data)

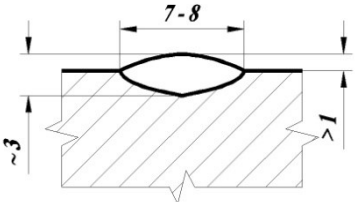
Deposit	Chemical composition, (wt. %)						
	C	Si	Mn	Cr	Ni	Mo	N
OK. Tigrod 2209	≤0.25	0.50	1.50	22.50	8.50	3.20	0.15

## 4. Study results and analysis

### 4.1. Macrostructure

The effects of the surfacing using the parameters given in Table 3 are shown on the overlay macrostructure in the cross section (Fig. 3). The overlay has an evenly convex face with a gentle transition to the weld base material without undercuts or overlaps. The shape and size of the heat affected zone (HAZ) is influenced by the adopted surfacing linear energy and heat transfer conditions in the surfacing area.

Table 3.  
Surfacing process parameters for duplex type cast steel

TIG surfacing	Process parameters					
	Deposit diameter [mm]	I [A]	U [V]	V [cm/min]	Shielding gas flow [l/min]	Heat Input [kJ/mm]
	2.4	110	11.6	10.3	10 - 11	1.2

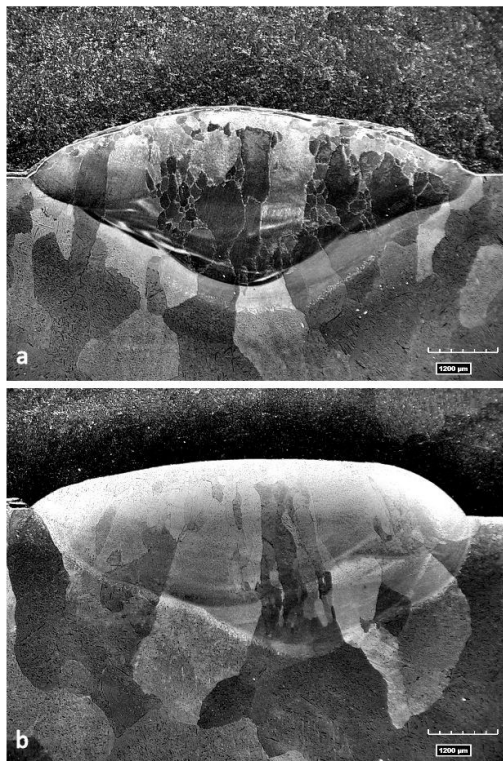


Fig. 3. Macrostructure of the overlay a) without solution heat treatment, b) after solution heat treatment; SEM

### 4.2. Hardness measurements

Changes that may occur during heating and cooling while surfacing and welding of duplex cast steel have a significant effect on the microstructure and therefore on the hardness of the test material in the weld area. The ferrite (with higher than austenite hardness) and austenite fractions depend, inter alia, on the joint cooling speed, which should be high enough to prevent precipitation processes and transition of ferrite  $\delta$  into the  $\sigma$  phase, other brittle phases (Fig. 1) or  $\gamma_2$  (poorer in Cr) [8]. Distribution of measurement points and results of cross-sectional measurements are shown in Figures 4 and 5. Due to the low penetration depth of about 2 mm, no measurements could be made according to the standard recommendations. Both the non-solution heat treated samples and those subjected to solution heat treatment exhibited an increase in hardness within the HAZ and a decrease in the center of the padding weld (Fig. 5). Surfacing resulted in lower measured values of hardness with the character of their distribution maintained.

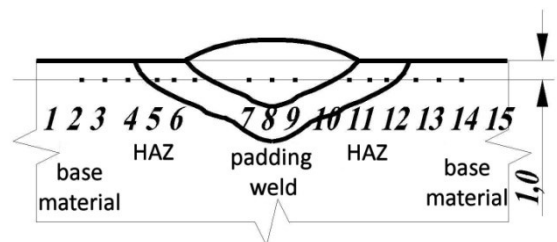


Fig. 4. Distribution of hardness measurement points in the cross section



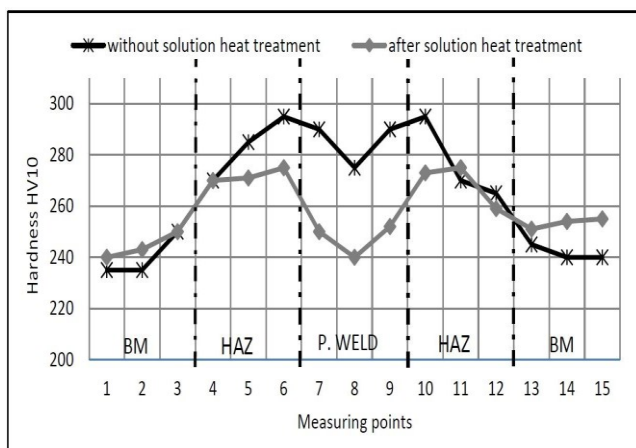


Fig. 5. Distribution of hardness HV in the cross section

### 4.3. Microstructure and microhardness

High temperature and high temperature gradient occurring during welding and surfacing of duplex type cast steel has a decisive influence on the kinetics of precipitation processes (formation of intermetallic phases, carbides, nitrides) and phase transformations (ferrite into austenite  $\gamma$  and secondary austenite  $\gamma_2$ ). The volume fraction and morphology of the resulting phases have a decisive influence on the mechanical properties of the HAZ and weld.

The microstructure of the overlay, like the base material, exhibits the presence of ferrite and austenite (Figure 2, 6). Solution heat treatment resulted in a change in the morphology of ferrite and austenite in the weld. Variable phase distribution in the base material usually adversely affects the HAZ. Figure 7b shows the change in this area after the heat treatment, where the appearance of the secondary austenite  $\gamma_2$  areas is observed and the particle boundaries are more clearly visible. The SEM-EDS observation of the weld microstructure did not show the presence of brittle phases at the interface between ferrite and austenite. However, at high magnifications in both phases there were small precipitates, analysis of which, due to limited SEM capabilities, requires additional tests, e.g., SEM-TEM.

As a consequence of changes in the microstructure, changes in hardness were observed. In the joint without the treatment, the hardness of the overlay was about 40 HV<sub>10</sub> higher than that of the base material (Fig. 5). After the solution heat treatment, the hardness was comparable to the hardness of the base material. In the HAZ area in both cases, a tendency of hardness increasing in the direction from the base material to the HAZ-overlay boundary was observed, which may suggest the occurrence of precipitation processes and/or changes in the phase participation in this area. The microhardness measurements of individual phases in the HAZ are shown in Fig. 8. The average hardness value in austenite HAZ was  $\mu\text{HV}_{0.02}$  and that of ferrite was 345  $\mu\text{HV}_{0.02}$  (Fig. 8).

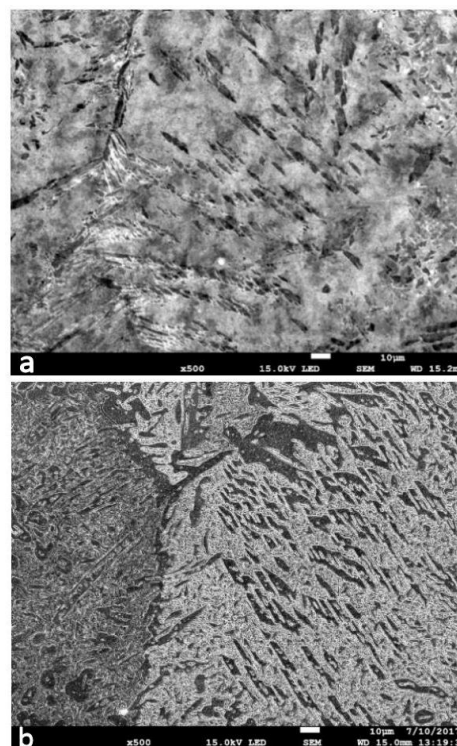


Fig. 6. Padding weld microstructure: a) without solution heat treatment, b) after solution heat treatment; SEM

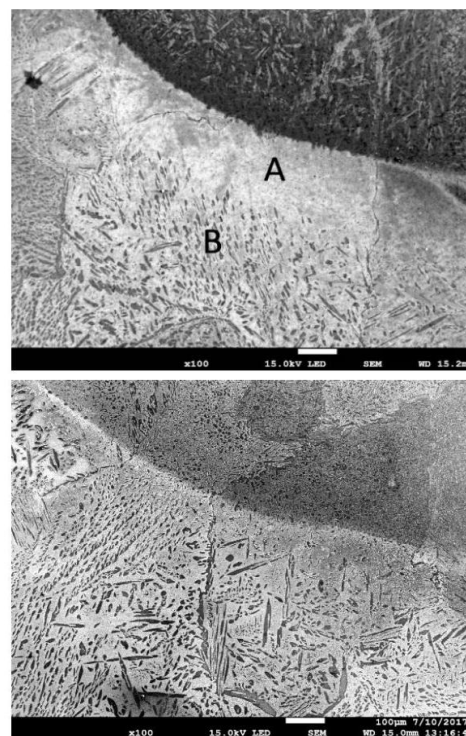


Fig. 7. Fusion line a) joint without solution heat treatment, b) joint after solution heat treatment; SEM

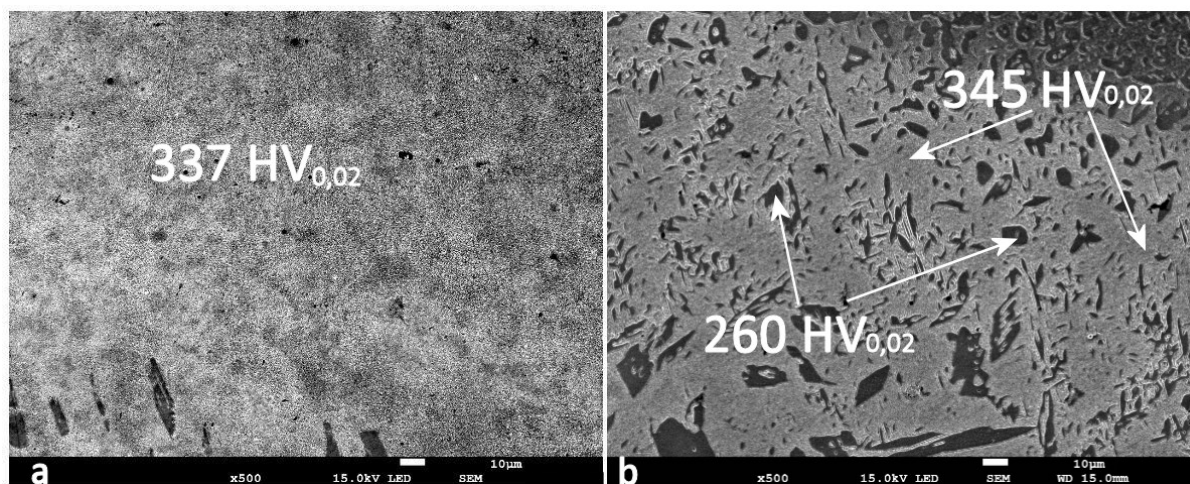


Fig. 8. HAZ microstructure below the fusion line a) no solution heat treatment (region A in Fig. 7), b) after solution heat treatment

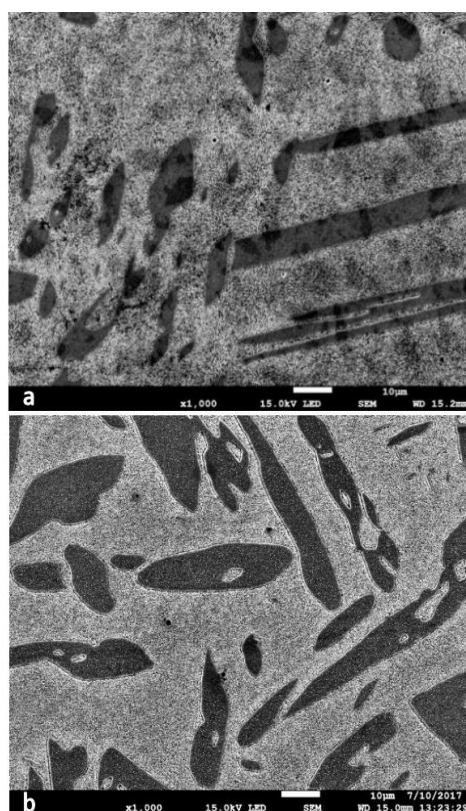


Fig. 9. HAZ microstructure a) no solution heat treatment (region B in Fig. 7), b) after solution heat treatment

## 5. Conclusions

The well-selected overlaying process parameters provided the welds without welding imperfections. Significant changes in the microstructure of the joint were observed after the solution heat treatment (HAZ and weld microstructure changes). In both areas,

an increase in the austenite volume fraction after solution heat treatment was observed. These changes are particularly visible in the HAZ area directly below the fusion line.

For the joint not subjected to solution heat treatment, a pure ferritic area was observed in the HAZ area. After the treatment, ferrite was partially transformed into secondary austenite. This change is accompanied by an increase in the microhardness of ferrite up to about 337  $\mu\text{HV}_{0.02}$ . For the base material, the ferritic phase has a microhardness in the range of 284 - 296  $\mu\text{HV}_{0.02}$ . The higher hardness value of the ferritic area in the HAZ is also observed for the cast steel after the solution heat treatment.

## References

- [1] Charles, J. (1995). Composition and properties of duplex stainless steels. *Welding in the World/Le Soudage dans le Mond.* 36, 43-54.
- [2] Stradomski, Z., Stachura, S., Dyja, D. & Zyska, A. (2005). Technological problems in elaboration of massive casting from duplex cast steel in aspect of productive process, *Archiwum Odlewnictwa.* 5(17), 287-292.
- [3] Bartocha, D. (2014). Two-Phase Cast Steel Production with Regenerative Method. *Archives of Foundry Engineering.* 14(spec.3), 3-8.
- [4] Hofmann, E. & Santos, R. (2004). Steuering der Erstarrungsmorphologie austenitisch - ferritischer Superduplex-Stahle. *Giesserei.* 1, 18-28.
- [5] Avesta Polarit Welding – Katalog (2002).
- [6] Messner, C., Silberschmidt, V.V. & Werner, E.A. (2003). Thermally induced surface roughness in austenitic-ferritic duplex stainless steels. *Acta Materialia.* 51(6), 1525-1537.
- [7] Kalandyk, B. (2011). Characteristics of microstructure and properties of castings made from ferritic-austenitic steel. *Archives of Foundry Engineering.* Katowice-Gliwice (in Polish).
- [8] Nowacki, J. (2009). *Duplex steel and its weldability.* Warszawa: WNT. (in Polish).



- [9] Karlsson, L. (2012). Welding of duplex stainless steels - a review of current recommendation. *Biuletyn Instytutu Spawalnictwa*. 5, 48-60.
- [10] Żuk, M. (2015). Repair duplex steel castings GX2CrNiMoCu25-6-3-3 MAG cored wire. *Przegląd spawalnictwa*. 5, 9-14.
- [11] Meka, K. (2000). Influence of nitrogen upon the shape and quality of padding welds applied by the GMA method. *Przegląd Spawalnictwa*. 12, 7-11.
- [12] Meka, K. (2003). Mechanical properties of duplex steel connections. *Przegląd Spawalnictwa*. 11, 7-10. (in Polish).