RESEARCH PAPERS
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

2010 Number 28

ELECTRON BEAM WELDING OF DUPLEX STEELS WITH USING HEAT TREATMENT

Ladislav SCHWARZ, Tatiana VRTOCHOVÁ, Koloman ULRICH

Abstract

This contribution presents characteristics, metallurgy and weldability of duplex steels with using concentrated energy source. The first part of the article describes metallurgy of duplex steels and the influence of nitrogen on their solidification. The second part focuses on weldability of duplex steels with using electron beam aimed on acceptable structure and corrosion resistance performed by multiple runs of defocused beam over the penetration weld.

Key words

duplex stainless steel, electron beam welding, heat treatment

Introduction

Duplex stainless steels are very attractive constructional materials for service in aggressive environments. Their physical properties are between those of the austenitic and ferritic stainless steels, but tend to be closer to those of the ferritics and to carbon steel. Such steels offer several advantages over the common austenitic stainless steels. The duplex grades are highly resistant to chloride stress, corrosion cracking, have excellent pitting and crevice corrosion resistance and are about twice as strong as the common austenitic steels.

The first-generation duplex stainless steels provided good performance characteristics, but had limitations in the as-welded condition. These limitations confined the use of the first-generation duplex stainless steels, usually in the unwelded condition, to a few specific applications. The heat-affected zone of welds had low toughness because of excessive ferrite and significantly lower corrosion resistance than that of the base metal. Nitrogen alloying of

---

Ladislav Schwarz, MSc. Eng., Tatiana Vrtochová, MSc. Eng., Koloman Ulrich, Professor, PhD. - Institution of Production Technologies, Department of Welding, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava, J. Bottu 25, 917 24 Trnava, Slovak Republic,
e-mail: ladislav.schwarz@stuba.sk, tatiana.vrtochova@stuba.sk, koloman.ulrich@stuba.sk

duplex stainless steels enhances HAZ toughness and corrosion resistance, which approaches that of the base metal in the as-welded condition. Nitrogen also reduces the rate at which detrimental intermetallic phases are formed.

Normally, duplex steels are weldable using welding procedures generally used for high alloyed steels. The experience with such comparatively new welding method like electron beam welding is still limited. However, there have been a few successful applications and there is every reason to expect that procedures will be developed more fully.

Chemical composition and metallurgy of duplex stainless steel

Duplex stainless alloys have 18 % to 28 % chromium, 2.5 % to 7.5 % nickel and low carbon contents. Some of the alloys will also have additions of nitrogen, molybdenum and copper. Chemical composition of some duplex, superduplex and hyperduplex steels are given in Table 1 [8].

The second-generation duplex stainless steels are defined by their nitrogen alloying. It is generally accepted that the favourable properties of the duplex stainless steels can be achieved for phase balances in the range of 30 to 70 % ferrite and austenite. Fig. 11 shows the typical microstructure of duplex stainless steel.

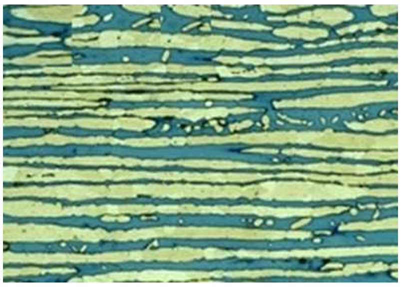

***Fig. 1** Typical microstructure of duplex stainless steel*

The interactions of the major alloying elements, particularly chromium, molybdenum, nitrogen, and nickel, are quite complex. To achieve a stable duplex structure that responds well to processing and fabrication, care must be taken to obtain the correct level of each of these elements.

Mechanical properties of duplex stainless steels are excellent in the temperature range from - 50 °C to 300 °C. When steel is subjected to elevated temperatures, numerous different solid state reactions can take place. These lead to the formation of different precipitates resulting in detrimental changes in the properties of the material, especially in its toughness. When duplex steels are exposed to temperatures over 300 °C they are susceptible to 475 °C embrittlement. During heat treatments in temperature range 500 °C – 900 °C, duplex stainless steels are prone to microstructure changes and precipitation of intermetallic phases.

CHEMICAL COMPOSITION OF SOME DUPLEX STEELS SANDVIC SAF Table 1

Steel grades	**EN**	**ASTM**	***Chemical composition (%)***					**PRE**
			C max.	***Cr***	***Ni***	***Mo***	***N***	
SAF 2205 (duplex)	X2CrNiMoN22-5-3	S32205	*0,02*	*22*	*5,7*	*3,1*	*0,17*	35
SAF 2507 (super duplex)	X2CrNiMoN25-7-4	S32750	*0,03*	*25*	*7*	*4*	*0,3*	42
SAF 2707 HD (hyper duplex)	X2CrNiMoN27-6-5	S32707	*0,03*	*27*	*6,5*	*5*	*0,4*	49

***PRE** – Pitting Resistance Equivalent*

The iron-chromium-nickel ternary phase diagram is a roadmap of the metallurgical behaviour of the duplex stainless steels.

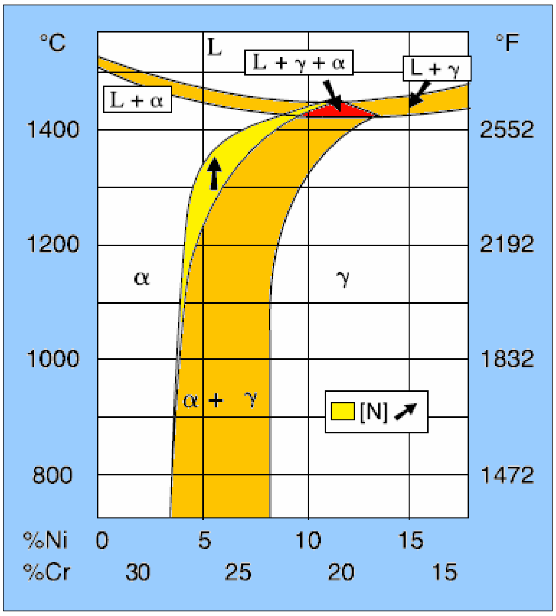

Fig. 2 *Section through the Fe-Cr-Ni Ternary Phase Diagram at 68 % Iron*

A section through the ternary at 68 % iron (Fig. 2) illustrates that these alloys solidify as ferrite. As temperature decreases (*to 1000 °C*), austenite develops. For cast duplex, a structure of austenite islands in a ferrite matrix can be observed. For wrought alloys, the microstructure has morphology of laths of austenite in a ferrite matrix. Thermodynamically, because the austenite is forming from the ferrite, it is impossible for the alloy go past the equilibrium level of austenite. However, as cooling proceeds to lower temperatures, carbides, nitrides, sigma and other intermetallic phases are all possible microstructural constituents [1, 2].

The effect of increasing nitrogen is also shown in Fig. *2*. Another beneficial effect of nitrogen is that it raises the temperature at which the austenite begins to form from the ferrite. Therefore, even at relatively rapid cooling rates, the equilibrium level of austenite can almost be reached. In the second-generation duplex stainless steels, this effect reduces the problem of excess ferrite in the HAZ [5].

Electron beam welding of duplex stainless steels

Electron beam welding uses energy from a high velocity focussed beam of electrons made to collide with the base material. When electrons in a focused beam hit a metal surface, the high energy density instantly vaporizes the material, generating a so-called key hole (Fig. 3).

A characteristic of this phenomenon is that it allows the unique capability for deep, narrow welds with very small heat affected zones (HAZ) and minimized thermal distortions of welded assemblies.

Depth-to-width ratios of up to 40:1 have been achieved in production for many years. With high beam energy, a hole can be melted through the material and penetrating welds can be formed at speeds of the order of 20 m/min.

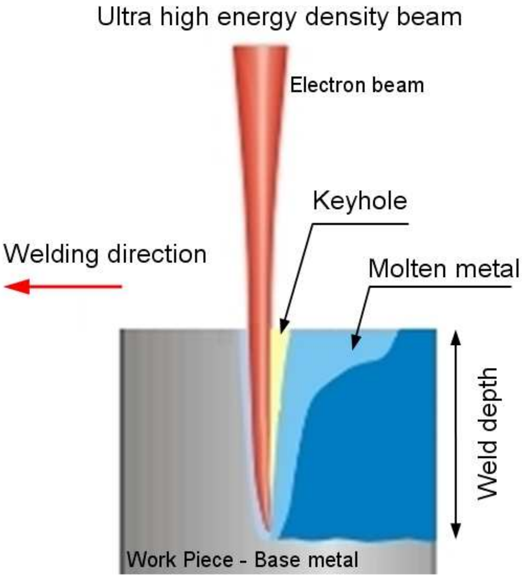

Fig. 3 *Schematic illustration of the Electron beam welding process*

Welds are made in vacuum, which eliminates contamination of the weld pool by gases. The vacuum not only prevents weld contamination but produces a stable beam.

The concentrated nature of the heat source makes the process very suitable for stainless steels. The available power can be readily controlled and the same welding machine can be applied to single pass welding of stainless steel in thicknesses from 0.5 mm to 40 mm [4, 5].

Characteristic of a problem

Electron beam welding process is used without the addition of filler metal and is not very suitable for the welding of duplex stainless steels as the welds will be very high in ferrite. Such a weld must be quench-annealed in order to get the correct structure.

Electron beam welding is especially suited to produce joints of heavy section materials in one or two passes. Unfortunately, it tends to produce rapid cooling rates and therefore highly ferrite in the melt zone, particularly in thin sections. Nevertheless, the toughness remains high which can be attributed to the very low oxygen content in the weld. Still the qualification of the procedure must be alert to the possibility of excessive ferrite in the HAZ and even in the weld when the high speed welding capabilities of these methods are considered.

The cooling rate has a considerable impact on the austenite-ferrite ratio developing at ambient temperature. This means that slow cooling causes a higher austenite content than rapid cooling, during which approx 60 to 90 % ferrite is to be expected (Fig. 4). In this way it is possible to influence the ferrite-austenite ratio, depending on the weld process and weld geometry.

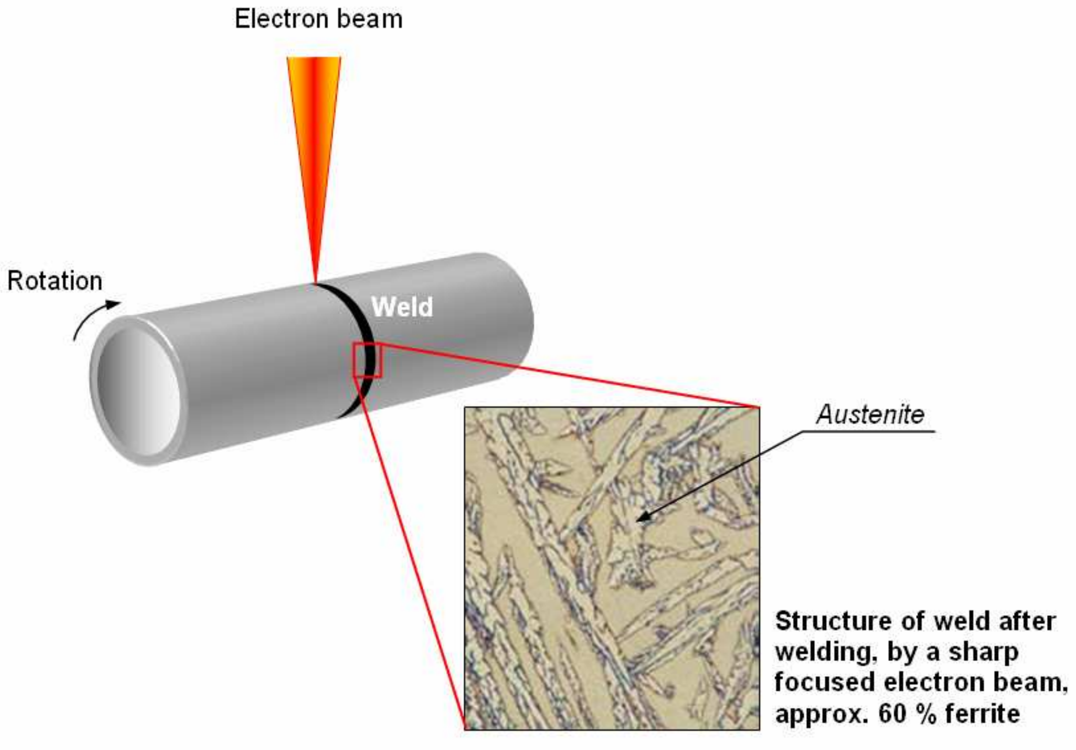

***Fig. 4** Welding of duplex steel by a sharp focussed electron beam*

In order to guarantee a balanced ferrite/austenite ratio of the weld, heat treatment after welding, and solution annealing is recommended, what however represents an undesired operation increasing the welding costs. Solution annealing temperature should be approx. 1,080 °C and holding times of around 2 – 3 min / mm wall thickness, followed by a rapid water quench. In order to avoid the development of a sigma phase, the cooling time from 950 °C down to 700 °C should not be more than 2 minutes.

Low heat input may result in undesirable proportion of ferrite in weld and in the heat affected zone and in corresponding loss of toughness and corrosion resistance. Maximum average ferrite content should be within 40 to 50%.

We try to solve the mentioned drawbacks of beam welding duplex steels application of post-heat after welding by a defocused beam with several passes along the weld zone (Fig. *5*).

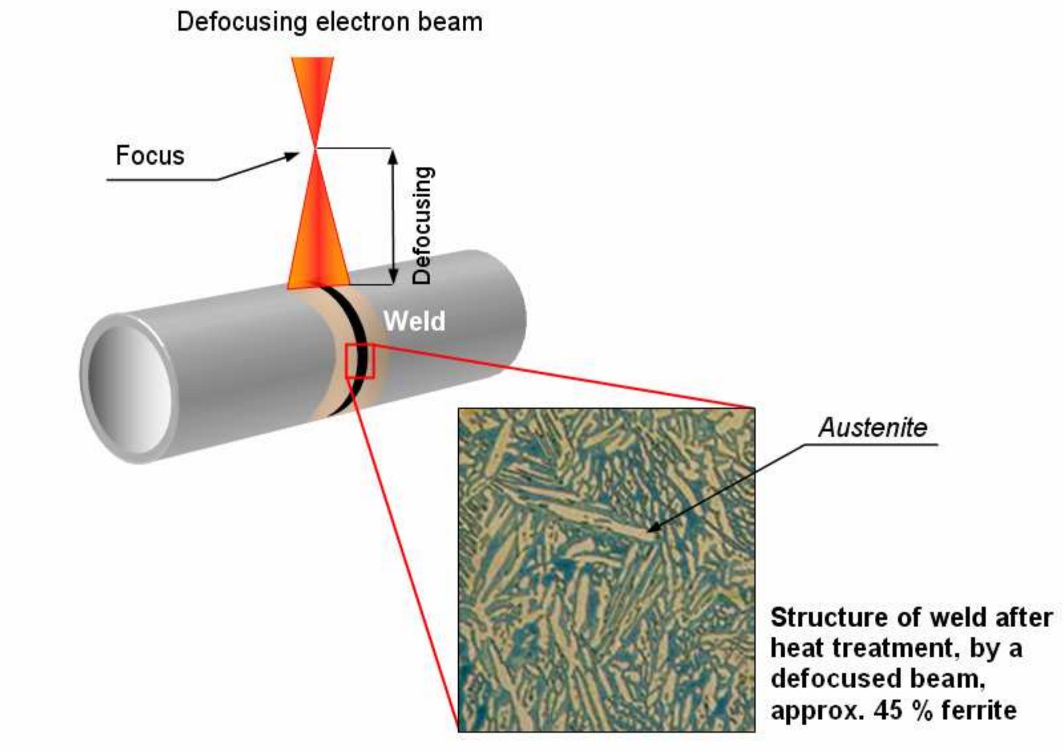

Fig. 5 *Heat treatment by a defocused electron beam*

The post heat is realized by a combination of defocusing (*defocusing current*) and oscillation of electron beam with a certain swap – generation of alternating course set on generator with subsequent cooling down in vacuum.

Parameters of post heat:

- acceleration voltage,
- electron beam current,
- defocusing current,
- oscillation of electron beam by generation of sine course with 90° phase shift,
- number of passes after welding [3].

Own contribution

Our own contribution to this article is a theoretical overview of solution to the problem of weldability of duplex stainless steels. This article describes technology of heat treatment after welding for the purpose of acquisition of desired properties. The paper defines the parameters of heat treatment after welding by electron device.

Conclusion

Exceedingly low heat input may result in fusion zones and HAZ which are excessively ferritic with a corresponding loss of toughness and corrosion resistance. Exceedingly high heat input increases the danger of forming intermetallic phases. It is generally agreed that the characteristic benefits of duplex stainless steels are achieved when there is at least 35% ferrite with the balance austenite. The heat input introduced by the controlled post heat, applied after welding, enabled to affect the proportional volume of ferrite in weld metal. These results suggest that such a procedure leads to positive results.

References:

[1] LIPPOLD, J, C., KOTECKI, D,J. *Welding Metallurgy and Weldability of Stainless Steels*. New Jersey: WILEY-INTERSCIENCE, 2005. 357 p. ISBN 0-471-47379-0

[2] HRIVŇÁK, I. Dual-Phase Stainless Steels – material of pipelines for aggressive media. In *Corrosion of Underground Structures 2003. Proceedings of the 13th International Conference Corrosion of underground structures 2003*, 27 and 28 may 2003. Košice: Technická univerzita v Košiciach, 2003. pp. 54-59. ISBN 80-7099-251-4

[3] KOLENIČ, F., IŽDINSKÁ, Z., FODREK, P. Influence of EB Welding Parameters on Properties of Welded Joints in Duplex steel type SAF 2205. In *60th Annual Assembly and International Conference: Proceedings of the IIW International Conference Welding and Materials. Technical, Economic and Ecological Aspects*. 01-08 July 2007 Dubrovnik & Cavtat. Croatia, Zagreb: Croatian welding society, 2007. pp. 1-13. ISBN 978-953-7518-00-4

[4] Dr. G. SCHUBERT. Electron Beam Welding – Process, Applications and Equipment. In *Proceedings of the IIW International Conference on Advances in Welding and Allied Technologies*, Singapore: Published by Singapore Welding Society, 2009, ISBN 978-981-08-3259-9, pp. 283 – 288.

[5] Available on internet: <http://www.euro-inox.org.>

[6] Available on internet: <http://www.imoa.info.>

[7] Available on internet: <http://www.stainless-steel-world.net.>

[8] Available on internet: <http://www.smt.sandvik.com.>

Reviewers:

Roman Koleňák, Assoc. Professor, PhD. – Institution of Production Technologies, Department of Welding, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava

Peter Polák, Assoc. Professor, PhD. – Prvá zváračská, a. s. (*First welding company, Inc.)*, Bratislava