Olga Barrera, Tomasz Pfeifer, Aleksander Żak

Structure of dissimillar joints of steel and nickel alloy

Abstract: Results of research on the structural examination of the interface between AISI 8630 M steel and Inconel 625 butter layer have been presented. Special attention has been paid to results obtained by Scanning and Transmission Electron Microscopy in the scope of Mintweld Project.

Keywords: nickel alloy, dissimillar joints, Mintweld Project

Introduction

Instytut Spawalnictwa is an active participant in the implementation of the MINTWELD project, the purpose of which is to develop a number of welding process numerical models in various scales (atomic, nano, micro etc.) aimed to enable a complex understanding of phenomena taking place during the development and formation of grain boundaries. Another objective of the MINTWELD project is to determine which material–technological conditions ensure the proper structure of a welded joint and excellent functional properties.

One of the issues analysed with reference to numerical modelling is cracking during the operation of dissimilar welded joints of elements made of unalloyed steels applied in the construction of subsea pipelines. Pipes made of steel grade X65 are joined with branch pipes or valves made of steel grade AISI 8630M (forgings). In the case of butt joints, at the production stage the first phase consists in buffering butting faces of the edges of welded elements made of steel grade AISI 8630M (using a nickel alloy). Next, welded elements undergo a heat treatment (tempering HAZ) and a mechanical treatment, the purpose of both procedures is to obtain a proper shape of the weld groove. The successive stage consists in making a welded joint of these elements using the same filler metal as the one used in buffering (Fig.1).

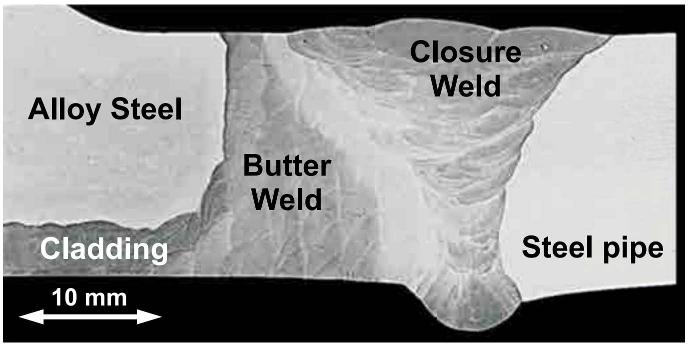


Fig. 1. Macrostructure of welded joint connecting gas branch pipe made of steel grade AISI 8630 with pipe made of steel grade X65, wall thickness 20 mm [1]

Tests carried out by Britain's TWI (The Welding Institute) in Cambridge revealed that such joints function properly in a seawater environment. However, in some cases structural damage was detected, probably caused by hydrogen cracking [1-3]. The purpose of the tests conducted within the framework of the MINWELD project was to develop a numerical model for the phenomenon of hydrogen cracking on the interface: buffering layer – butting surface of an element made

Olga Barrera PhD Eng., Department of Engineering Science, University of Oxford
dr inż. Tomasz Pfeifer (PhD Eng.), Instytut Spawalnictwa, Gliwice
mgr inż. Aleksander Żak (MSc Eng.), Frenzak Sp. z o.o.

of steel AISI 8630M. In order to develop a reliable and usable cracking process model, first it was necessary to carry out a thorough structural test of a buffered joint as such a test would make it possible to determine the structure of individual areas and explain the cracking mechanism.

Instytut Spawalnictwa in Gliwice developed a technology for buffering elements made of steel grade AISI 8630M by means of the MIG method and an electrode wire Inconel 625 as well as prepared a model element for tests. Afterwards, in conjunction with Oxford University and TWI, detailed metallographic tests of the model joint were conducted. The test objective was to explain the mechanism responsible for joint cracking and to develop a set of data enabling the creation of a reliable numerical model of crack propagation.

Tests and results

The technological overlay welding tests involved the use of 40 mm thick forgings made of steel AISI 8630M provided by Britain's TWI. Due to the fact that in the process of making dissimilar welded joints, buffering includes applying a nickel alloy layer up to 70 mm thick (entailing the necessity of subsequent machining – preparing the geometry of the groove), prior to welding the element underwent milling in order to obtain a shape presented in Figure 2. Afterwards, the element was heated up to 250°C and underwent overlay welding by means of the MIG method and an electrode wire LNM NiCro 60/20 produced by the Lincoln Electric company (PN-EN ISO 18274: S Ni 6625). The chemical composition of the wire corresponded to the Inconel 625 nickel alloy. Figure 2 presents a scheme of the welding sequence used (over 60 runs were applied), whereas Table 1 presents the chemical composition of the base metal and that of the electrode wire.

Having in mind a real production process, directly after the overlay welding process, the element with overlays underwent heat treatment, i.e. heated to 650°C, held at the temperature for 2 hours and, finally, cooled

Table 1. Chemical composition of base metal and electrode wire used in buffering process technological tests, %m/m

	C	Mn	Si	P	S	Cr	Ni	Mo	Nb	Fe
AISI 8630M	0.33	0.90	0.25	0.01	0.01	0.60	0.5	0.25	-	rest
NiCro60/20	0.02	0.06	0.07	-	-	22	64	9	3.5	1.7

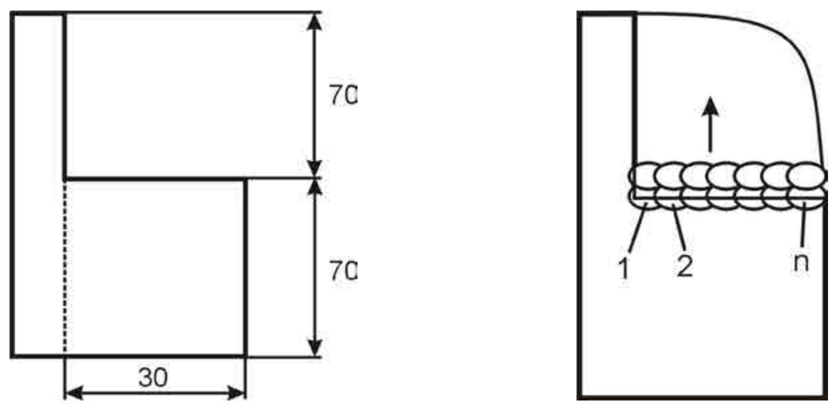


Fig. 2. Preparation of element for overlay welding (left) and layer application sequence during buffering overlay welding by means of MIG method and wire NiCro 60/20 (right)

Fig. 3 Test element during (left) and after (right) overlay welding

slowly. The heat treatment was carried out with heating mats. Figure 3 presents the element during and after the overlay welding, whereas Figure 4 presents the macrostructure of the weld.

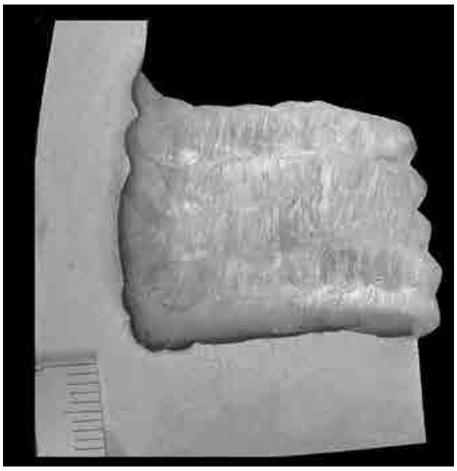


Fig. 4. Macrostructure of overlay weld made with MIG method and electrode wire NiCro 60/20 on steel AISI 8630M, etching with Adler's reagent

Afterwards, microscopic metallographic tests with a light microscope (Leica ME4M), electron scanning microscope (JEOL 6300) and a transmission electron microscope (Philips CM20 and JEOL 2010) were carried out. The scanning microscope, provided with an EDS attachment, was used to carry out the X-ray microanalysis of the chemical composition of the layer near the fusion line. Figure 5 presents the microstructure of the material in the HAZ area from the steel AISI 8630 side, obtained by means of the light microscope, Figure 6 presents the photograph of this area obtained by means of the scanning microscope using backscattered electrons. Figure 7 presents the microstructure of the overlay weld (test pieces sampled from the central part of the overlay welded layer), Figure 8 presents the microstructure of the interface areas from the overlay welded layer side, obtained by means of the scanning electron microscope, and Figure 9 presents the results of the X-ray microanalysis in the interface area (fusion line). The microanalysis was conducted on both sides of the line.

The metallographic tests and observations of the microstructure of the material in the HAZ of AISI 8630M steel, carried out with the light microscope, revealed that the heat affected zone is approximately 0.6 mm in width and is characterised by a bainitic–martensitic structure. In the direct vicinity of the fusion line it is possible to observe a significant grain growth and the deformation of the crystalline structure (Fig.5), which is additionally presented in Figure 6.

The metallographic tests of the test pieces sampled from the central area of the overlay-welded layer revealed the presence of a dendritic structure, characteristic of a filler metal with the composition of nickel alloy 625. The tests revealed a non-homogenous chemical composition and the presence of significant segregations. Chemical elements

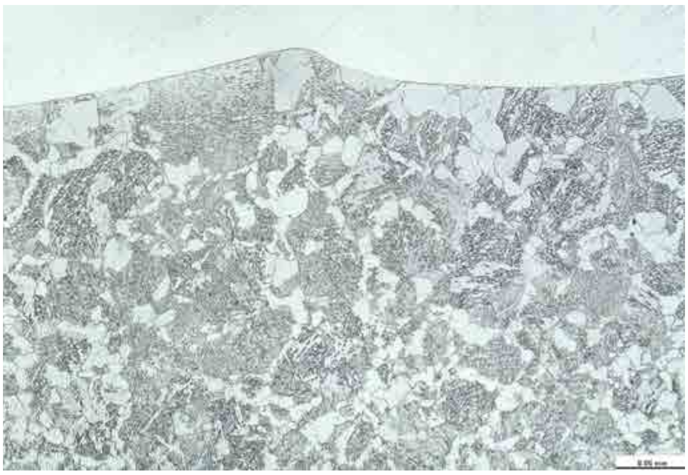


Fig. 5. Microstructure of material in HAZ of steel AISI 8630M, mag. 200x, etchant Nital

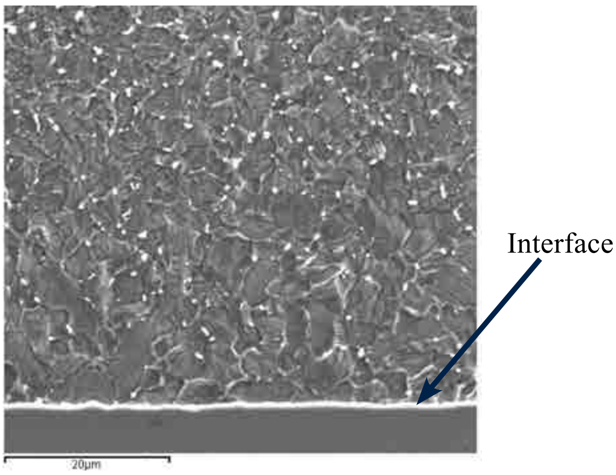
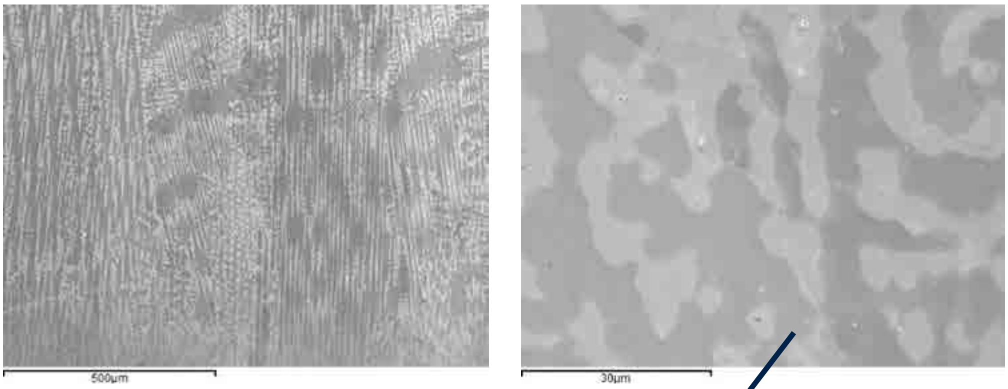


Fig. 6. Microstructure in interface area, zone depleted in cementite visible directly over interface [4]

such as Ni, Cr and Fe were present mainly in the dendrite, whereas Mo and Nb existed mainly in interdendritic spaces [1-2]. The tests revealed the presence of fine precipitates in the base, which, by means of the transmission microscope, were identified as MC type primary carbides. The tests also revealed the presence of phase μ banded precipitates in the interdendritic spaces [1].



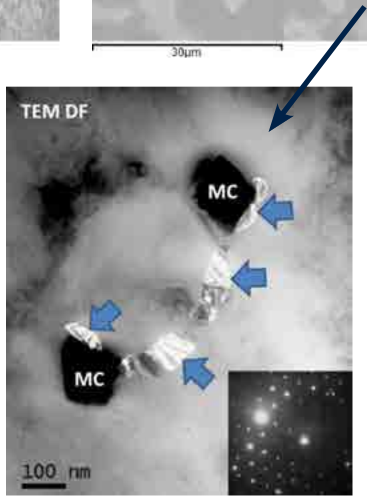


Fig. 7. Microstructure of layer overlay-welded with filler metal NiCro 60/20, images obtained by means of scanning microscope (above) and precipitates of MC type primary carbides (below), image obtained by means of transmission microscope [4]

The tests of the fusion line area from the overlay-welded layer side revealed also the presence of a dendritic structure. However, near the interface it was possible to observe the so-called "white zone" approximately 5 μm in width (Fig. 8) which proved difficult to identify by means of the scanning microscope. It was not possible to obtain a clear image of this area by means of backscattered electrons either. For this reason it was necessary to carry out additionally the microanalysis of the chemical composition across the fusion line. The microanalysis revealed a significant diffusion of chemical elements between both areas characterised by different chemical compositions. The diffusion was responsible for the fact that the chemical composition of the "white zone" was the mixture of the composition of steel AISI 8630 and of the weld deposit having the same composition as Inconel 625 alloy.

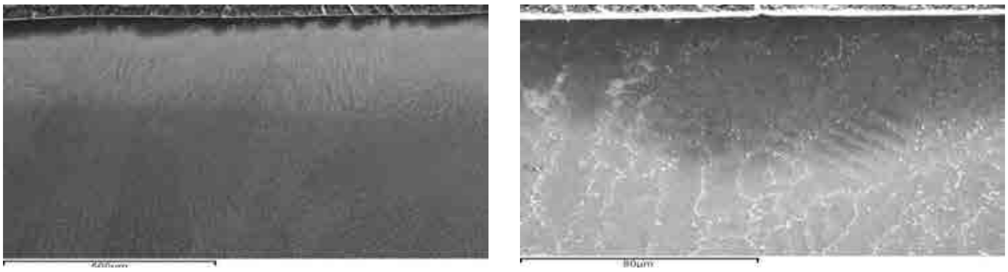


Fig. 8. Microstructure in fusion line area from the side of layer overlay-welded with electrode wire NiCro 60/20 [4]

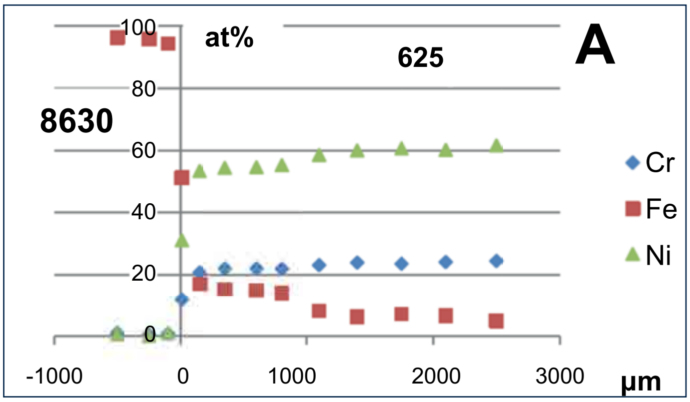


Fig. 9. Results of EDS X-ray analysis carried out across interface

In order to identify the "white zone" in detail it was necessary to carry out tests using the electron microscope. Publications [1, 4] thoroughly present the preparation of test pieces and the manner of testing. Figure 10 presents an image from the transmission microscope obtained in the dark field and in the white field. Figure 11 presents the precipitate characteristic of this zone and the microanalysis of the chemical composition of this phase.

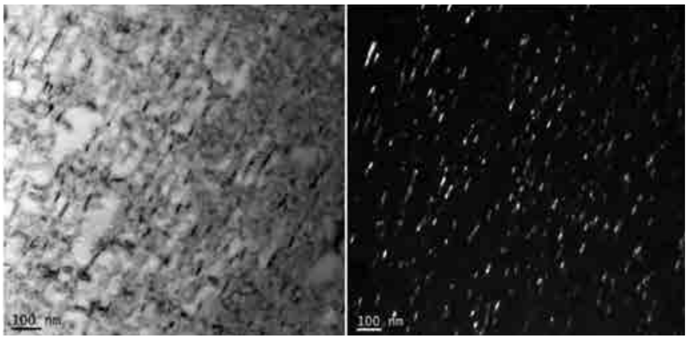


Fig. 10. Image of “white zone” area near fusion line obtained in bright field (left) and in dark field (right) by means of transmission microscope, visible precipitates of MC type carbides [4]

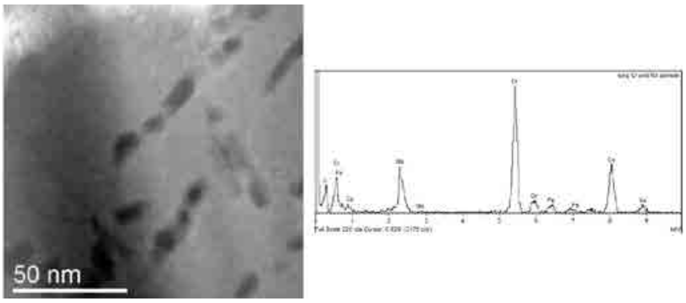


Fig. 11. Image of precipitates in “white zone” near fusion line obtained in white field by means of transmission microscope and results of X-ray microanalysis of visible phase

The test results revealed that the “white zone” contains characteristic precipitates in the form of dark bands (observation in the white field). Observations at a greater magnification revealed that the precipitates are spherical (Fig. 11). The EDX spot analysis revealed that the precipitates are probably M6C and M23C6 type chromium and molybdenum carbides a few nanometres in length and a few tenths of a nanometre in width [4].

Concluding remarks

The technological tests carried out within the framework of the MINTWELD project made it possible to develop a technology for buffering steel AISI 8630M elements using the MIG method and an electrode wire NiCro 60/20 (the chemical composition of the wire corresponds to Inconel 625 alloy). The metallographic tests enabled the determination of the structure of the interface between steel AISI 8630M and the buffering layer made of nickel alloy type Inconel 625. The tests revealed that the structure of the areas on both sides of the fusion line is very complex. It was also possible to observe the phenomenon of a reactive diffusion consisting in the diffusion of iron and carbon from the steel to the nickel alloy layer and the formation of M6C and M23C6 type carbides. These carbide precipitates are the most probable reason for hydrogen cracking of joints in subsea pipelines. Hydrogen penetrates into the material from seawater by way of surface adsorption [5]. As a result of diffusion, hydrogen penetrates deep into the material along grain boundaries, glide planes or crystallographic directions [5-7]. According to information contained in reference publications the accumulation of recombined hydrogen molecules in gaps and vesicles as well as near defects of metal structure and non-metallic inclusions under high pressure causes the formation of blowholes filled with molecular hydrogen and leads to the generation of metal cracks. In order to confirm a complex mechanism of buffered joint cracking it was necessary to additionally carry out static tensile test of the test piece sampled from the interface with an initiated notch causing cracking in a specific direction. The entire test was carried out in an environment rich in hydrogen. A subsequent article will present the methodology and the results of testing the surface of a developing crack.

The test results obtained made it possible to collect information necessary for the development of a hydrogen cracking model of the material system referred to above.

References

1. Dodge, M. et al. (2012). “Environment – induced cracking in weld joint in subsea oil and gas systems – Part I”. Proceedings of 31. ASME Conference: *Ocean, Offshore and Arctic Engineering* OMAE 2012, Rio de Janeiro.
2. Olden, V. et al. (2003). “The effect of PWHT on the material properties and micro structure in Inconel 625 and Inconel 725 buttered joints”. Proceedings of 22. ASME Conference: *Ocean, Offshore and Arctic Engineering* OMAE 2003, Cancun.
3. Gittos, M. et al. (2009). “Hydrogen embrittelment of 8630M/625 subsea dissimilar joints: factors that influence the performance”. Proceedings of 28. ASME Conference: *Ocean, Offshore and Arctic Engineering* OMAE 2012, Honolulu
4. *Modelling of Interface Evolution in Advanced Welding*. Fragmentary Report M18 on execution of the MINTWELD project, Leicester 2011
5. Kubica, M. (1996). Hydrogen Induced Cracking (HIC) of simulated HAZ’s in steels designed for gas piping. *Biuletyn Instytutu Spawalnictwa* 40 (6) pp. 23-30.
6. Dziubiński, P. Adamiec, P. (2000). Pękanie wodorowe stali rurowych w warunkach korozji naprężeniowej. *Przegląd Spawalnictwa* (5).
7. Tasak, E. Ziewiec, A. (2001). Pękanie połączeń spawanych eksploatowanych w atmosferze wodoru. *Przegląd Spawalnictwa*, (7).