University Review, Vol. 15, Issue 4, p. 37-42, 2021.

INVESTIGATION OF MICROSTRUCTURE AND STRENGTH PROPERTIES OF INTERFACE BETWEEN INCONEL 625 WELD LAYER AND 16Mo3 STEEL

Patrik Klučiar*[1] – Michal Krbaťa[1] – Igor Barényi[1] – Ján Palkech[2]

[1]Department of Mechanilcal Engineering Technologies and Materials, Faculty of Special Technology, Trenchiniensis Univeritas of Trencin, Ku kyselke 469, 911 06 Trencin
[2] Konštrukta Defence, a.s., Lieskovec 575/25, Dubnica nad Vahom.

ARTICLE INFO

***Article history*:**
Received: 26.11. 2021
Received in revised form: 7.12. 2021
Accepted: 13.12. 2021

Keywords:
Weld
Tensile test
Microstructure

Abstract:

The article deals with the investigation of weld Inconel 625 layer low alloyed heat resistant 16Mo3 steel. The investigation was focused on the analysis of the behavior of the layer during the load by tensile strength test including strength properties evaluation of the layer – substrate system. The microstructure of the system was investigated too with a focus on the interface between layer and the substrate.

1 Introduction

Components of heating devices, used for the extraction of waste energy, which works in the most aggressive environments, are usually made by high alloyed high temperature resistant steel or low or medium alloyed with used a high temperature resistant layers and welds. Nowadays, weld layers of nickel based alloys are used to achieve high temperature resistance. Nickel alloy Inconel 625 is frequently used in this process, due to its very good high corrosive durability, even at high temperature, good creep resistance, and good weldability too [1,2].

During the technological welding process, a specific layer of primary material (steel) melts and then is mixed with covering metal in the welding bath. Between primary material and weld coating so-called transitional are ais created (Fig. 1).
The transitional area is the area where are primary and welding materials are mixed. The chemical composition, microstructure and properties of primary material in this zone are changing smoothly by distance from the weld material [3,4]. The width of the transition zone is a function of the chemical composition of the primary metal and the weld, the method of welding, the heat input, as well as the feed rate of the cover wire [5,6].

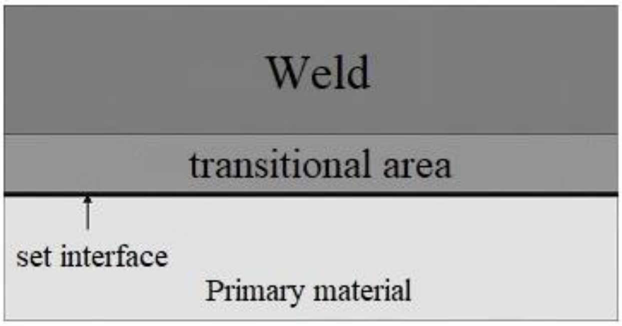

Fig. 1Microstructure zones in weld layer [1]

2 Materials and methods

2.1 Experimental materials

Base material (substrate) is the low alloyed steel for use at softly elevated temperature – 16Mo3 (tab. 1). Inconel 625 (tab. 2) was selected as a weld layer thanks to its very good corrosion resistance even at high temperatures, good creep resistance also weldability. The thicknesses of the weld and the base material are in ratio 3: 7,

* Corresponding author. Tel.: +421 915 423 281
E-mail address: patrik.kluciar@tnuni.sk

where the weld with higher mechanical properties acts as a bearing element and the resulting yield strength of the whole system is higher as the tensile strength of the base material.

Tab. 1 Basic chemical composition and mechanical properties of 16Mo3 steel

Material	Steel 16Mo3			
wt.%	Min.	Max.	Tensile strength R_m [MPa]	440
C	0,1	0,2		
Mn	0,5	0,8	Yield point $R_{p0,2}$ [MPa]	380
SI	0,15	0,37		
Al	--	0,015	Ductility A [%]	30
P	--	0,04		
S	--	0,04	Hardness HV	150
Fe	Bal.			

Tab. 2 Basic chemical composition and mechanical properties of Inconel 625alloy used for experiment

Material	Inconel 625 (NiCr22Mo9Nb)			
wt.%	Min.	Max.	Tensile strength R_m [MPa]	965
Cr	20	23		
Mo	8	10		
Co	--	1		
Nb	3,15	4,15	Yield point $R_{p0,2}$ [MPa]	490
Ti	--	0,4		
Fe	--	5		
C	--	0,1		
Mn	--	0,5	Elongation(at 20 °C) A [%]	50
Si	--	0,5		
Al	--	0,4		
P	--	0,015	Hardness HV5 (before cold rolling)	200
S	--	0,015		
Ni	Bal.			

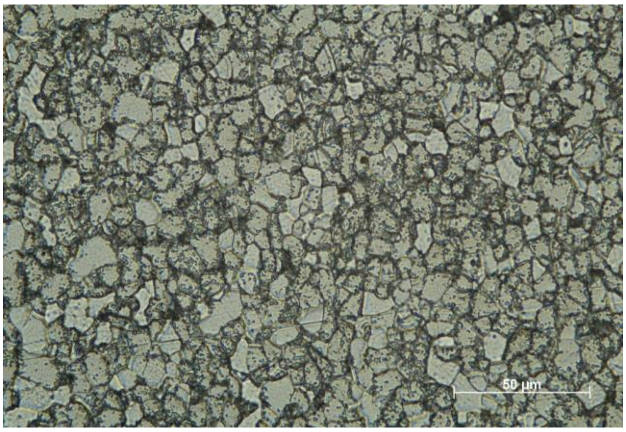

Fig. 2 Microstructure of primary material - 16Mo3 steel

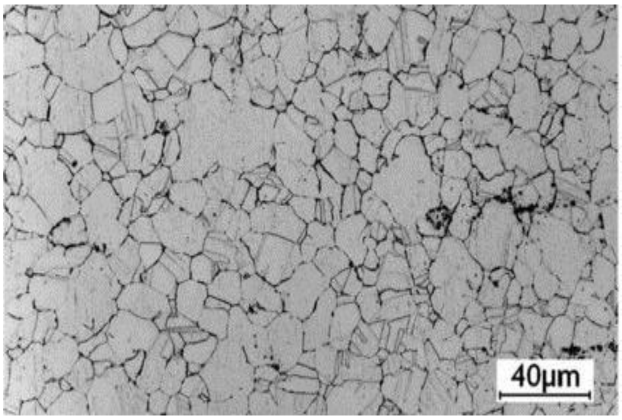

Fig. 3 Microstructure of Inconel 625

The microstructure of the primary material (16Mo3 steel) is shown in Fig. 2. It is a ferrite-perlitic structure consisting of ferrite grains with perlite on their borders. Furthermore, it is possible to observe fine precipitated carbides at or near the grain boundaries. The microstructure of Inconel 625 is in Fig. 3. It is a simple homogenous structure based on grains of γ phase with randomly distributed fine precipitates.

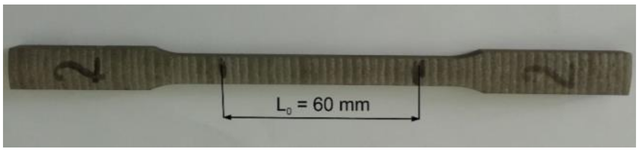

Fig. 4 Testing sample for tensile test

The shape of the test sample, used for performed static tensile test is in Fig. 4. Basic dimensions of the samples, then used for calculation of mechanical characteristics are listed in table 1.

Tab. 3 Basic dimensions of samples

Label of sample	Thickness [mm]	Width [mm]	Cross section S_0 [mm^2]	L_0 [mm]
1	6,1	8	48,8	60
2	6,1	8	48,8	60

Inconel coating was applied using Ar shielding gas. Tubes were cooled with water flow (10 l/min) through their inside during the process. The thickness of the clad layers was approximately 2,5 mm [7,8].

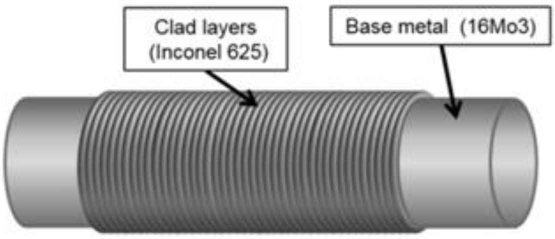

Fig. 5 Schematic illustration of tubes of16Mo3 steel with Inconel 625 welding overlay

2.2 Tensile strength test

The static tensile test is prescribed by EN ISO 6892-1 standard. The principle of the test is the static loading of the test sample by tensile stress to its fracture. The sample must have a standardized shape and size. The sample axis and axis of applied force are in coincidence. The stress-strain curve is then measured as a basis for strength mechanical characteristics evaluation from its characteristic points tensile strength, yield point etc.). From the size of the sample before and after the test is possible to calculate plasticity characteristics (ductility, contraction) [9].

The experimental sample consists of a combination of alloy Inconel 625 weld on 16Mo3 steel. Both materials have significantly different mechanical properties. The tensile strength of the alloy Inconel 625 is at an ambient temperature almost double compared to 16Mo3 steel. Measured mechanical characteristics are a certain combination of the properties of both mixed materials. Both materials also differ in yield point nature. At ambient temperature, Inconel 625 has a non-visible yield point in the stress-strain curve, but 16Mo3 steel yield point is visible. For that reason, the yield strength values of experimental samples were evaluated by the methodology for the determination of contractual yield strength (proof stress) [9].

3 Experimental results

3.1 Strength properties

Tensile strength, yield strength and ductility of test samples were evaluated by tensile strength test. The resulting experimental values are listed in table 4. Yield strength was evaluated as proof stress of 0,2%, because materials Inconel 625 have non-visible yield point in ambient temperature, while 16Mo3 steel point is visible in the stress-strain curve.

Tab. 4 Experimental results from the tensile test

Label of sample	R_m [MPa]	$R_{p0,2}$ [MPa]	A_{60}[%]
1	573,70	425,02	35
2	577,55	430,10	32
average	575,62	427,56	33

The corresponding stress strain curve obtained from the tensile test of samples no. 1 is in Fig. 6 as an example.

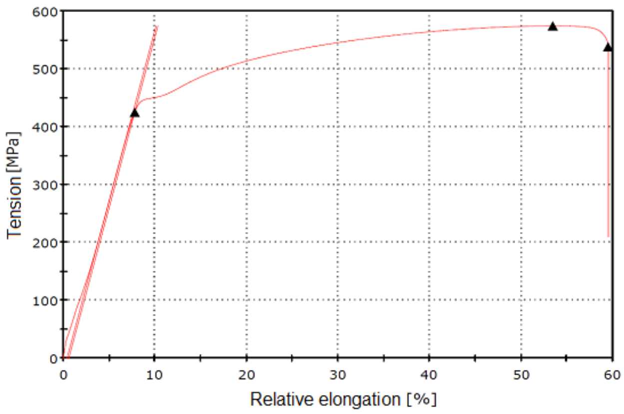

Fig. 6 Strass-strain curve for sample 1

Sample with weld consists of two homogeneous materials. The basic mechanical characteristics of the weld (Inconel 625) are significantly higher as the characteristics of steel 16Mo3. Their mutual comparison with values of the sample with weld, which was obtained by experiment, is in Fig. 7.

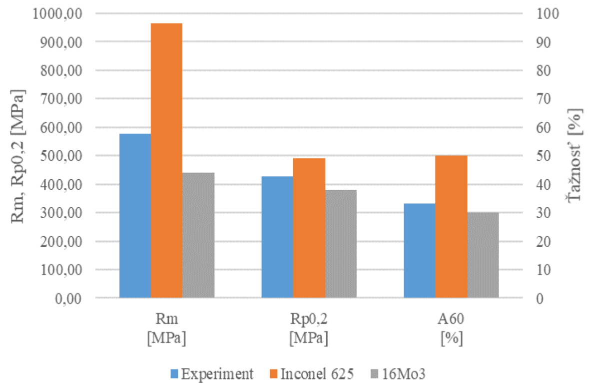

Fig. 7 Mutual comparison mechanical characteristics of basic material, weld and experimental sample with weld

Inconel 625 has very high plastics properties (ductility) and relatively low hardness. For this reason, any cracking was not observed during the experiment at any stage of the loading. For this reason, no cracking or other damage mechanism and separation of the layer from the base material was observed at any stage of the sample loading during the test, which is characteristic of e.g. for very hard nitrided layers.Although the thickness of the weld and base material is in ratio 3:7, the weld with higher mechanical properties acts as a supporting element and the resulting yield strength of the whole system is higher than the tensile strength of the base material itself. The failure of the entire cross-section of the sample occurred at the 30% higher stress value than the tensile strength of the base material itself. The total tensile strength of the experimental sample does not reach the tensile strength of the Inconel 625 alloy at the ambient temperature. After fracture the base material, there will be a significant reduction in the sample cross-section, which at the same acting load means a significant stress increase. This stress is higher as the tensile strength of Inconel 625 alloy. Therefore, the layer breaks immediately after the damaging of base material and total fracture of the sample occurs.

3.2 Microstructural analysis of primary material

General view of the interface weld layer – basic material is shown in Fig. 8. The interface is formed by three basic areas, which are at the figure marked as A, B and C. Areas A and B form a transition area, whereas C is the basic material. A more detailed view of the first section (A) is in Fig. 9. This is the area of partial or complete melting, where the basic material has been heated to the area of stable austenite above temperature A_1. After the welding, there was a rapid cooling, therefore martensite needles are visible in the structure together with ferrite grains. Perlit of original ferritic-perlitic structure austenitized during heating of the material and subsequent rapid cooling caused its martensitic transformation. Temperature of heating was not high enough for the overall reverse transformation of ferrite to austenite and because of this, original ferritic grains are also visible in the structure.

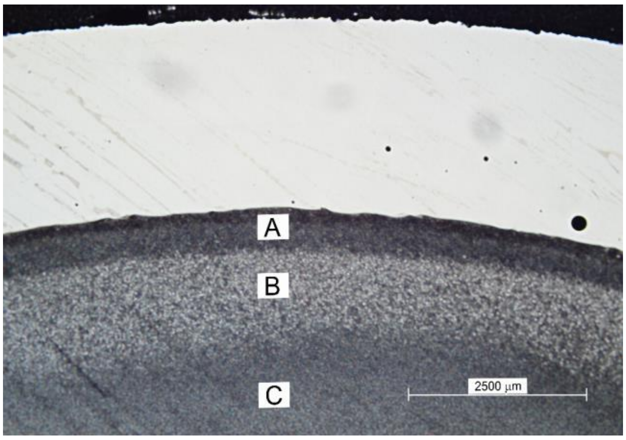

Fig. 8 General view on basic material and weld interface and his three basic areas

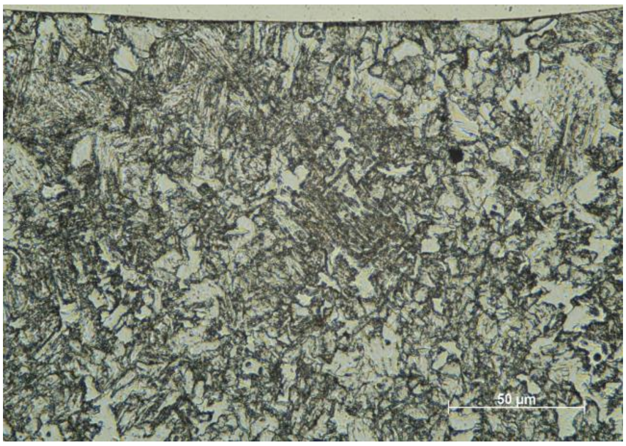

Fig. 9 Interface of weld - basic material-melting zone (A)

Figure 16 shows the more detailed view of the second part of the interface of weld – basic material (B). This is an area of overheating where the material has not melted, but only has been heated to temperatures below A1 and subsequently held at this temperature as the electrode passes over the surface during welding. Structure in this area didn't undergo phase transformation but significant coarsening ferrite grains has occurred. At the ferrite grain boundaries, perlite and carbides are segregated.

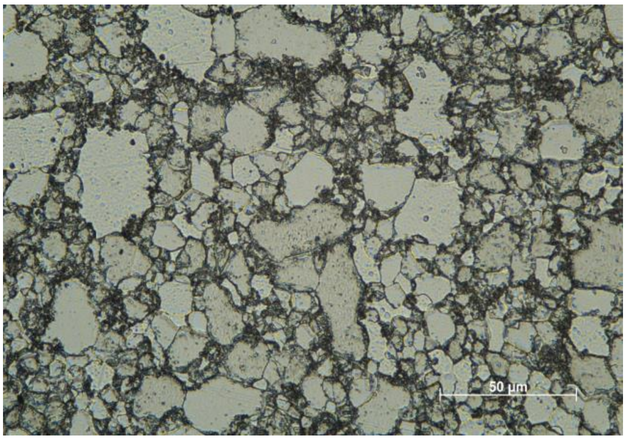

Fig. 10 Interface of weld - basic material-overheating zone (B)

4 Conclusion

The subject of the research was a weld of heat resistant alloy Inconel 625 on primary material 16Mo3 steel. The first part is focused on weld layer behavior during tensile loading as well as mechanical properties of Inconel coated samples. The second part deals with the microstructure investigation of the interface between the overlay and the substrate. The experiments can be concluded as follow:

- Strength properties of the system are approximately 30% higher than properties of primary material (16Mo3).
- Due to the high plastic properties, the weld did not crack during the tensile test until the rupture.
- The microstructure of the interface can be divided into three zones. Zone with partial melting where the martensite was observed with preserved ferritic grains. The overheated zone without phase transformation but with grain coarsening. The third zone corresponds with the base material structure.

5 Acknowledgement

This publication was created in the frame of the project: Advancement and support of R&D for "Centre for diagnostics and quality testing of materials" in the domains of the RIS3 SK specialization, ITMS2014+:313011W442, based on the Operational Programme Integrated Infrastructure and funded from the European Regional Development Fund.

6 References

[1] X. Xing, X. Di, B. Wang, The effect of post-weld heat treatment temperature on the microstructure of Inconel 625 deposited metal,J. Alloys Compd. 593, 110-116 (2014).

[2] S.A. David, J.A. Siefert, J.N. DuPont, J.P. Shingledecker, Weldabillityand weld performance of candidate nickel base superalloys for advanced ultra supercritical fossil power plants part I: fundamentals, Sci. Technol. Weld. Joining. **7**, 532-550 (2015).

[3] J.C. Lippold, Welding Metallurgy and Weldability, A John Wiley& Sons, Inc, New Jersey, 2015.

[4] J.N. DuPont, J.C. Lippold, S.D. Kiser, Welding Metallurgy and Weldability of Nickel-Base Alloys, A John Wiley & Sons, INC., Publication, 2009.

[5] J.N. DuPont, Microstructural evolution and high temperature failure of ferritic to austenitic dissimilar welds, Int. Mater. Rev.**4**, 208-232 (2012).

[6] J.N. DuPont, C.S. Kusko, Technical Note: Martensite formation in austenitic/ferritic dissimilar alloy welds, Weld. J. 51-54 (2007).

[7] EN 10028-2, FlatProducts Made of SteelsforPressurePurposes - Part 2: Nonalloyand alloySteelswithSpecifiedElevatedTemperatureProperties, vol. 3,2000.

[8] SpecialMetalsCorporation, Corporation-informationmaterials, http://www.specialmetals.com/assets/smc/documents/alloys/inconel/inconel-alloy-625

[9] I. Barenyi, M. Ličková: Náuka o materiáloch II, FŠT TnUAD, Trenčín 2015, ISBN 978-80-8075-689-5

[10] M.D. Rowe, T.W. Nelson, J.C. Lippold, Hydrogen-induced cracking along the fusion bound-

ary of dissimilar metal welds, Weld.J., 31-37 (1999).

[11] A.A. Omar, Effects of welding parameters on hard zone formation at dissimilar metal welds, Research Developments, 86-93 (1998).

[12] B. Zhihui Wang, B. Xu, C. YE, Study of the martensite structure at the weld interface and the fracture toughness of dissimilar metal joints, Weld. Res. Suppl. 397-402 (1993).

[13] C.C. Silva, H.C. de Miranda, M.F. Motta, J.P Farias, Influence of welding in operational conditions on the partial mixed zone formation in Ni-based dissimilar weld overlay, Trends in welding research, The Materials Information Society pp. 336-344, 2012.

[14] B.T. Alexandrov, J.C. Lippold, J.W. Sowards, a. T. Hope, D.R.Saltzmann, Fusion boundary microstructure evolution associated with embrittlement of Ni-base alloy overlays applied to carbon steel, Weld World **57**, 39-53 (2012).

[15] G. Li, J. Huang, Y. Wu, An investigation on microstructure and properties of dissimilar welded Inconel 625 and SUS 304 using high-power CO2 laser, Int. J. Adv. Manuf. Technol. **76**, 1203-1214(2015).

[16] M. Rozmus-Górnikowska, M. Blicharski, J. Kusiński, L. Kusiński,M. Marszycki, Influence of boiler pipe cladding techniques on theirmicrostructure and properties. Arch. Metall. Mater. **58**, 1993-1996(2013).

[17] M. Rozmus-Górnikowska, M. Blicharski, J. Kusiński, MetalicMaterials **52**, 141-147 (2014).