THE INFLUENCE OF LONG-TERM TEMPERATURE ON THE PROPERTIES AND STRUCTURE OF THE INCONEL 617 WELDED JOINT

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Abstract

The Inconel 617 alloy is used in the construction of boiler pressure elements with ultra-supercritical performance parameters. The paper presents the results of microstructure testing after 10,000 h ageing at 750 °C. Microstructure research was performed using scanning electron microscopy. The influence of ageing time on the changes in microstructure and the precipitation process in the native material, heat-affected zone and weld, which were referred to the changes in basic mechanical properties was described. The presented research results are an element of the material characteristics of the new generation alloys, which are used in design of pressure devices of steam boilers and diagnostic work during operation.

Keywords: Inconel 617, microstructure, precipitations, mechanical properties

1. INTRODUCTION

Approx. 40% of electric power all over the world is produced by burning coal. It results in further intensive works over design and construction of highly efficient steam boilers. It is also caused by the requirements of broadly defined environmental protection. Additionally, the development of new materials for operation at high temperatures is stimulated by the fact that it will take a long time before the alternative energy sources become the basic source of energy not only in Europe, but also in the world. The above data clearly show that the works on development of modern steels and alloys for the high-performance energy engineering cannot be neglected [1-4].

Inconel 617 is a nickel alloy (the so-called nickel superalloy), which contains approx. by wt. % chromium 20, cobalt 10 and molybdenum 8 and titanium, while the remaining content is nickel. This alloy was developed by Sumitomo Metal Ind.

Inconel 617 is used for components of ultra-critical steam boilers (700-800 °C, approx. 35 MPa). This alloy shows high creep strength as compared to other nickel alloys, which is 121 and 69 MPa at 750 °C for 10,000 and 100,000 h, respectively [5]. This is the effect of strong solid-solution hardening by adding molybdenum and cobalt and of solid-solution hardening with $M_{23}C_6$, MC, M_6C, Ni_3Mo and γ'. High oxidation resistance in the steam atmosphere and hot corrosion resistance of the Inconel 617 alloy is ensured by wt.% chromium 20 content.

Pressure components of power units, and thus the materials used for their construction should not only be characterised by sufficiently high creep or corrosion resistance in steam and combustion gas atmosphere but also with high mechanical properties at both room and elevated temperatures [6-9]. The process of changes in the performance of these materials, and thus changes in their microstructure, is described by the materials characteristics which, in combination with methods for the assessment of their exhaustion degree, are used in approving them for further safe operation both within and beyond the design service time [10, 11].

The research results and their analysis presented in this study supplement the publications on the service life of the Inconel 617 alloy and its similar welded joints, which do not refer to the effect of the long-term impact of elevated temperature on the stability of performance [12-14].

2. MATERIAL FOR INVESTIGATIONS

The material for investigations was a sample of ϕ 31,5x5,0mm pipe of Inconel 617 (NiCr23Co12MoB) with a similar welded joint. The chemical composition of investigated alloy with reference to the requirements of the standard is presented in **Table 1**.

Table 1 Chemical composition of investigated alloy (wt.%)

	C	Mn	Cr	Ni	Ti	Mo	Co	B	Al
Test material	0.06	0.02	21.70	REST	0.37	8.43	11.42	0.005	0.68
acc. to [5]	0.05 0.10	≤0,7.	20.00 23.00	REST	0.20 0.50	8.00 10.00	10.00 13.00	≤0.01	0.60 1.50

The similar welded joint was made by the 141 (GTAW) method using Thermanit 617 welding rod.

3. RESEARCH METHODOLOGY

The microstructure of the Inconel 617 welded joint was observed with Inspect F scanning electron microscope (SEM) on conventionally prepared electrolytically etched metallographic microsections. Hardness measurements were performed by Vickers method with Future - Tech FM - 7 hardness testing machine using the indenter load of 10 kG. The quantitative analysis of precipitates was carried out with NIKON EPIPHOT200 & LUCIA G v.5.03 image analysis system. The image analysis system was calibrated using the scale marker as in the photos. Calibration coefficient: 1 pixel= 0.040 μm. The above-mentioned investigations were performed on material in the as-received condition and after long-term ageing at 750 °C for 10,000 h.

4. RESULTS AND DISCUSSIONS

The microstructure of the Inconel 617 alloy and similar welded joint in the as-received condition observed with the scanning electron microscope is shown in **Figure 1**. The tested base material and the material in the heat-affected zone are characterised by the austenitic matrix with annealing twins and numerous primary precipitates of varying size arranged in bands both within the grains and at the grain boundary. The uniform cellular and dendritic columnar structure with locally visible effects of micro-segregation of chemical composition at the dendrite boundaries and band eutectic precipitates at the dendrite boundaries were found in the material of the weld made with Thermanit 617 filler metal. The measured average grain diameter of the base material is 5-3 according to PN-EN ISO 643:2013-06 [4]. A slight grain growth effect was observed in the heat-affected zone.

The long-term ageing of the Inconel 617 affects the development of precipitation processes as well as changes in the morphology coherent with the matrix of γ' intermetallic phase (**Figure 4**) and $M_{23}C_6$ carbides (**Figure 3**), as evidenced by the recorded microstructure images (**Figure 2**). Numerous uniformly arranged γ' phase precipitates inside the austenite grains and $M_{23}C_6$ carbide precipitates forming precipitation chains at the austenite grain boundary are observed in the base material, heat-affected zone as well as the weld itself. The measured average diameter of γ' phase precipitates is 93 nm.

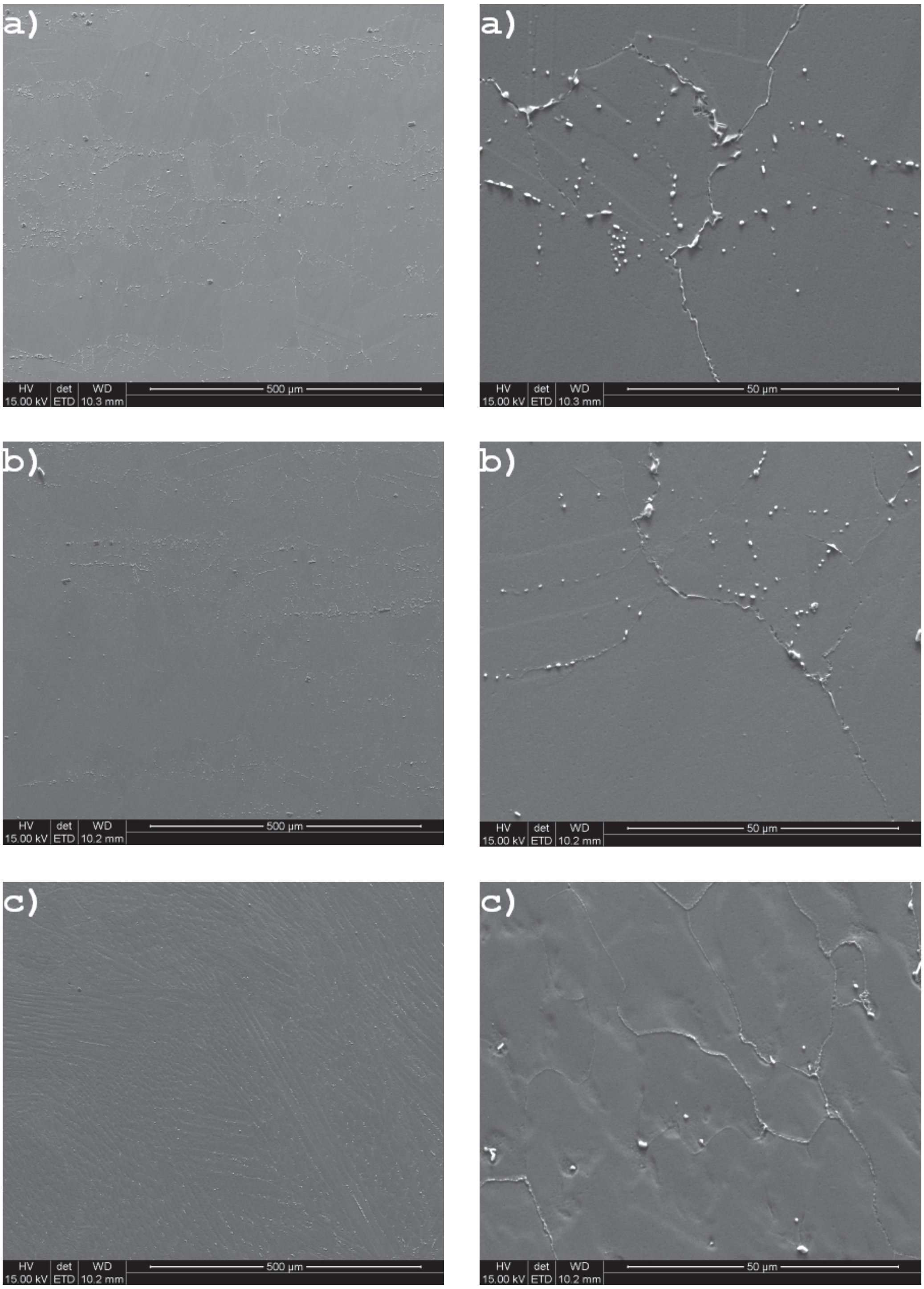

Figure 1 Microstructure of Inconel 617 welded joint in the as-received condition: a) native material, b) heat-affected zone, c) weld

The long-term impact of elevated temperature has changed hardness of both the native material and the weld material. The hardness increased by approx. 22% in the native material, 20% of the heat-affected zone and 25% in the weld (**Figure 5**).

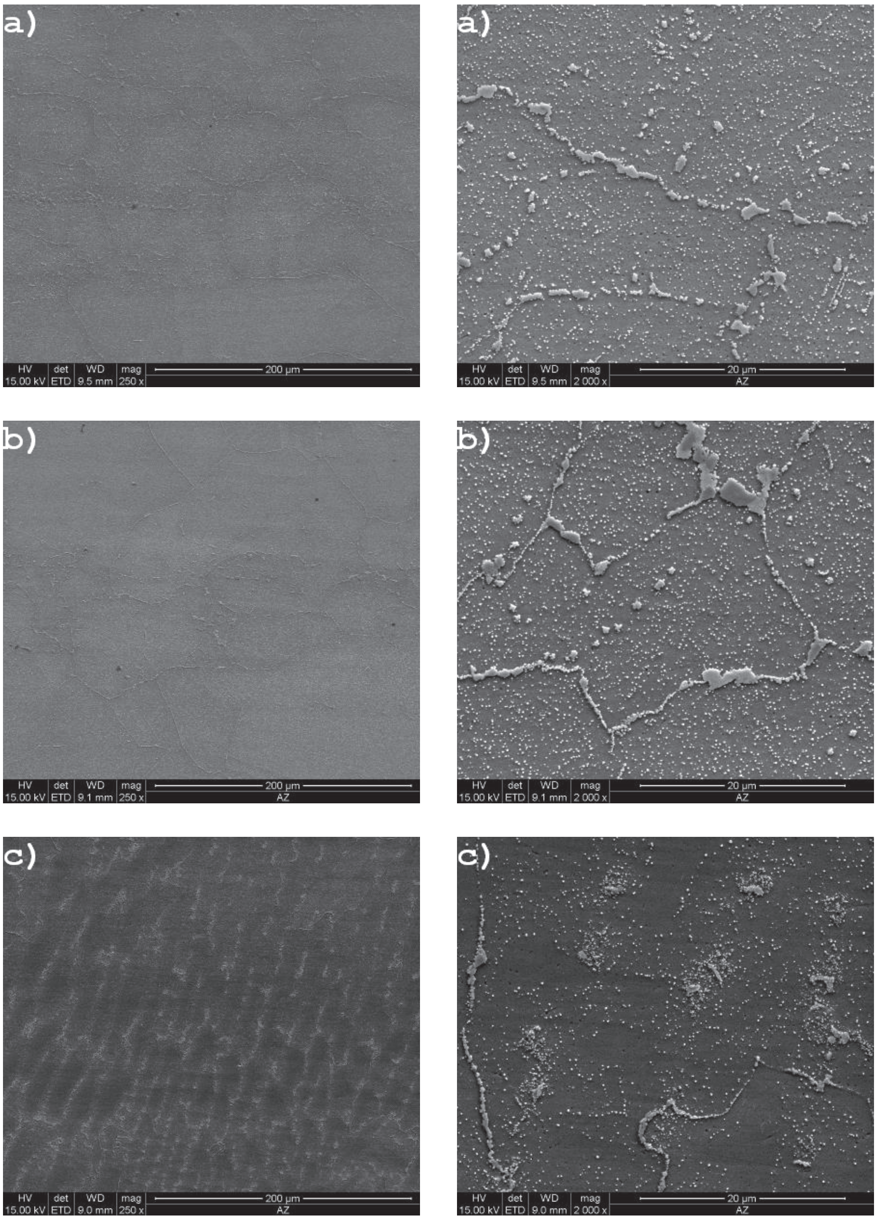

Figure 2 Microstructure of Inconel 617 welded joint after ageing at 750 °C for 10,000 h: a) native material, b) heat-affected zone, c) weld

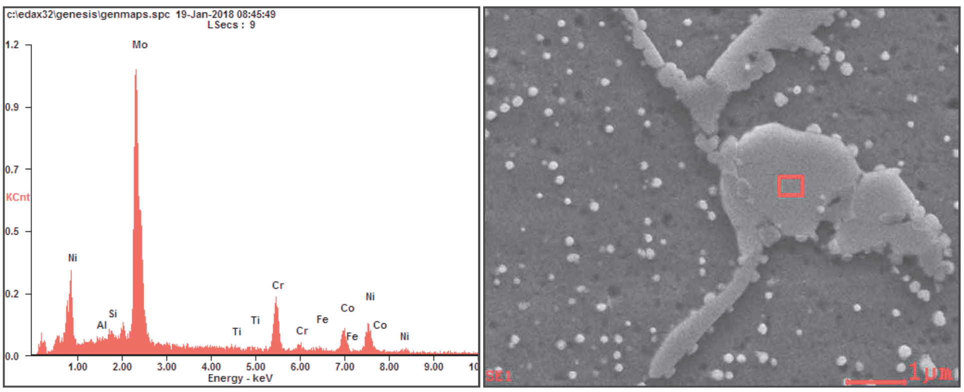

Figure 3 $M_{23}C_6$ carbide precipitate at the austenite grain boundary after 10,000 h ageing at 750 °C

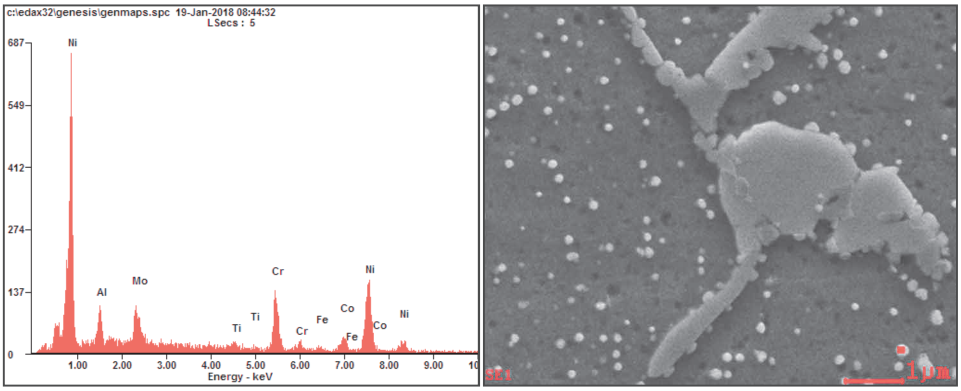

Figure 4 γ' phase precipitate within the austenite grain boundary after 10,000 ageing at 750 °C

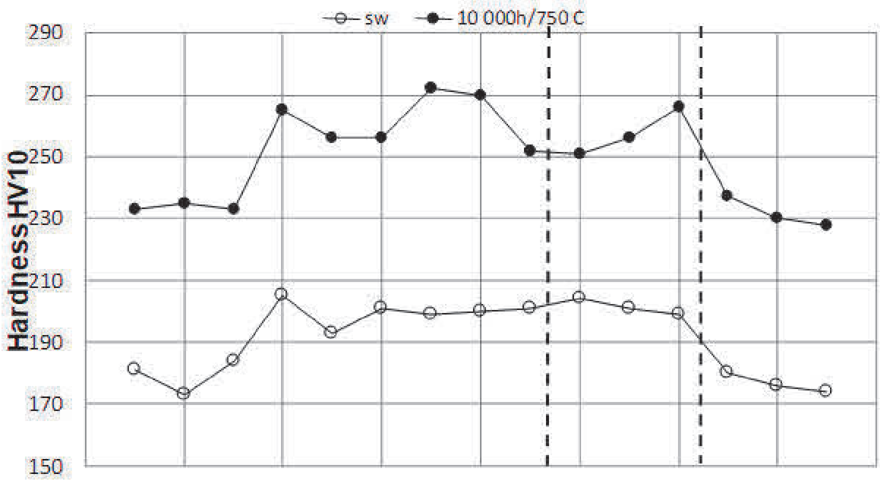

Figure 5 Comparison of Inconel 617 hardness HV10 in the as-received condition and after 10,000 h ageing at 750 °C

5. CONCLUSION

Due to its high creep strength at elevated temperatures and very good resistance to hot corrosion and steam oxidation, ensured by the formation of passivating Cr_3O_2 chromium oxides, the Inconel 617 mod. alloy is recommended for long-term service under creep conditions at 700-800 °C.

The characteristics of steels and heat-resistant alloys, which determine their suitability for applications at specific temperatures, also include the results of testing stability of microstructure and mechanical properties under laboratory ageing conditions at a temperature similar to the expected operation one. The ageing tests of the Inconel 617 mod. welded joint carried out at 750 °C for up to 10,000 h revealed changes in the microstructure of the base material, heat-affected zone and weld material involving mainly a tendency for forming uniformly arranged γ' phase within the grains the average diameter of which increased with ageing temperature and time. The measured average diameter of γ' phase after 10,000 h ageing at 750 °C was approx. 98 nm. [15]. In addition, the $M_{23}C_6$ precipitates were observed in the microstructure, and they were arranged mainly at the austenite grain boundaries and the annealing twins whose size also increases with test temperature.

The hardness measurement shows a significant, above 20%, increase in hardness of test welded joint after ageing as compared to the as-received condition, which indicates significant precipitation hardening.

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