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Evaluation of the Microstructure of 600 and 617 Nickel Alloys Subjected to Arc Welding

Abstract: The paper presents the results concerning the assessment of the microstructure 600 and 617 nickel alloys. Test alloys delivered as plates were exposed to welding arc applied in the TIG method. The assessment involving the microstructure of the fusion zone, heat affected zone and of the base material was performed using light microscopy and scanning electron microscopy. The results revealed significant differences in the structures of the fusion zone in 600 and 617 alloys resulting from various chemical compositions as well as from the significant segregation of the alloying elements between dendrites and interdendritic zones.

Keywords: nickel alloys, welding, microstructure

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Introduction

Equipment and machinery operated at higher temperatures and in the corrosive environment require to be made of materials characterised by high mechanical properties and creep resistance, e.g. steels having martensitic-bainitic structure, where the growth of grain can be inhibited by the use of microalloy agents (np. P91/92, T22 OR T24) or agents having austenitic structures (e.g. 304H or 310) [1]. Other materials meeting the above named requirements are solution or precipitation hardened nickel alloys [2]. Because of their high price, nickel alloys have rarely been used in the power industry. The development of modern technologies and the necessity of satisfying environmentally-friendly requirements increasingly often necessitate the use of nickel alloys in structural elements exposed to corrosive conditions [3]. In such cases, nickel alloys are used to make complete products or are applied as surfaced coatings significantly reducing manufacturing costs without compromising functional properties. Solution hardened alloys are characterised by significantly lower susceptibility to hot cracking than precipitation hardened alloys, therefore the former are more often used in welding practice. Most commonly used alloys include nickel alloys 600 and 625, for which the most of leading producers offer filler metals (bars and wires). Less frequently used is nickel alloy 617 characterised by greater susceptibility to hot cracking, yet by very good het resistance and high-temperature creep resisting properties.

The article presents the results concerning the assessment of the microstructure of solution hardened nickel alloys (600 and 617) exposed to welding thermal cycles during TIG welding-triggered fusion penetration.

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Test Materials

The tests involved the use of solution hardened nickel alloys designated 600 and 617. Test specimens were cut out of 5 mm thick sheets. Microstructural observations involved the use of light and scanning electron microscopy as well as metallographic specimens subjected to electrolytic etching in the 10% aqueous solution of chromium oxide (CrO_3).

The chemical composition of the alloys was identified using flash spectroscopy. The analysis results are presented in Table 1. The values in bold indicate different contents of primary alloying agents; alloy 600 has a greater iron content whereas alloy 617 has greater contents of chromium, molybdenum, cobalt, tungsten and aluminium.

Table 1. Chemical compositions of alloys 600 and 617, % by weight; flash spectroscopy

Alloy	**Cr**	**Fe**	**Mo**	Co	C	Mn	S	Si	Cu	Al	Nb	Ti	B	W
600	**16.1**	**8.1**	**0.023**	0.006	0.048	0.14	0.0023	0.17	0.001	0.08	0.041	0.12	0.0022	<0.005
617	**22.95**	**0.8**	**8.95**	11.36	0.065	0.03	0.0001	0.05	0.015	**0.78**	0.046	0.24	0.0017	**0.97**

Microstructural Characteristics

The assessment of the microstructural changes in the areas characteristic of the welded joint were performed on specimens subjected to welding thermal cycles. The specimens with fusions were made using method 141 (TIG), a current of 100 A and an arc voltage of approximately 16.8 V (welding linear energy of approximately 0.24 kJ/mm). Electric are was conducted manually on the surface of metal. The shielding gas (argon 5.0) was fed at a flow rate of 12 l/min.

The visual and macroscopic tests performed on the metallographic specimens revealed the significant width of the weld face (approximately 8 mm) and only a slight penetration depth of up to 1.5 mm (nickel 600) (Fig. 1). In terms of alloy 617, the depth of penetration amounted to less than 1 mm (Fig. 5); this resulted from the low thermal conductivity of the alloy and high viscosity of the liquid metal (impeding the heating of the metal at the bottom of the weld pool due to the limited circulation of the liquid metal).

The microstructures of the characteristic areas of the fusions are presented in Figure 2÷4 (for alloy 600) and 6÷8 (for alloy 617). Both materials were characterised by the equiaxial grain of phase γ (crystallising in the lattice of A1). The base material revealed annealing twins and fine-dispersive precipitates on the boundaries of the grains and within them (Fig. 2 and 6), i.e. $M_{23}C_6$, M_6C and MC type carbides. The MC carbides were present as large primary precipitates of titanium carbonitrides. In alloy 617, aluminium and titanium formed the precipitates of phase γ' $Ni_3(Ti,Al)$ coherent with phase γ, hardening the alloy and improving its tensile strength, yet reducing the plasticity of the weld.

The heat affected zone revealed the growth of grains (Fig. 3 and 7). In the HAZ of alloy 617, approximately up to 100 µm, the equilibrium partial melting of grain boundaries was observed. The intensity of the partial melting grew along with an increase in the HAZ temperature, i.e. the closer to the fusion zone, the wider partially melted zones (Fig. 8a). In both alloys, the structure of the fusion area was dendritic and dendritic-cellular (Fig. 4, 8). Because of significantly differing chemical compositions of liquidus and solidus at a given temperature, the fusion area was characterised by the diversified chemical composition of dendrite cores and interdendritic spaces.

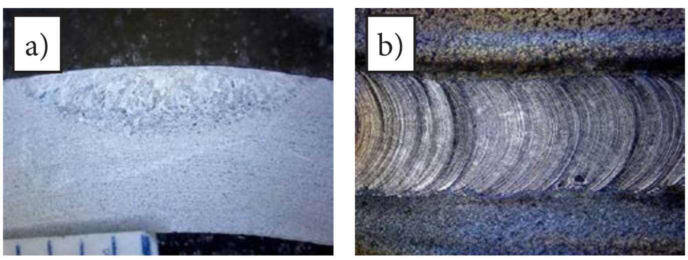

Fig. 1. Fusion in nickel alloy 600; current: 160 A:
a) fusion macrostructure, b) weld face

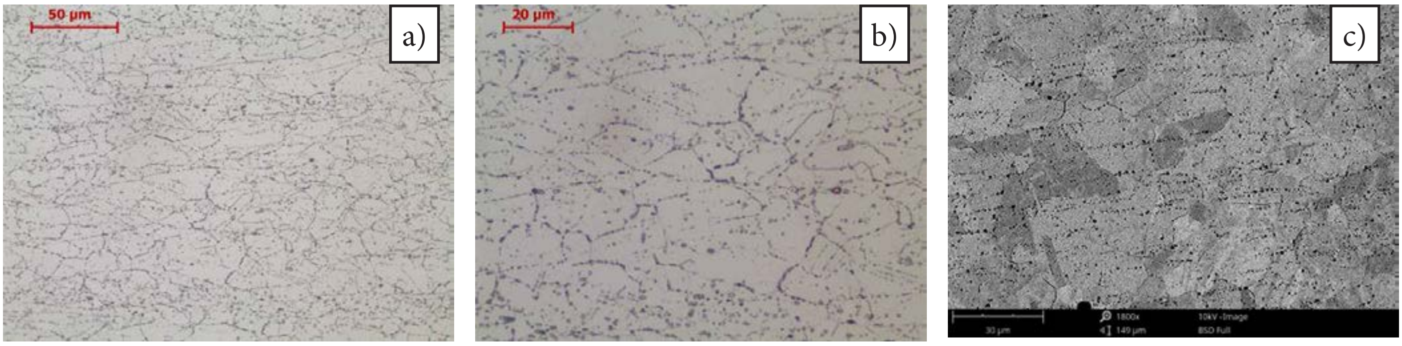

Fig. 2. Alloy 600; microstructure in the base material area (as-delivered state): a-b) light microscopy, c) SEM; structure of phase γ with carbide precipitates on the grain boundaries in within the grains

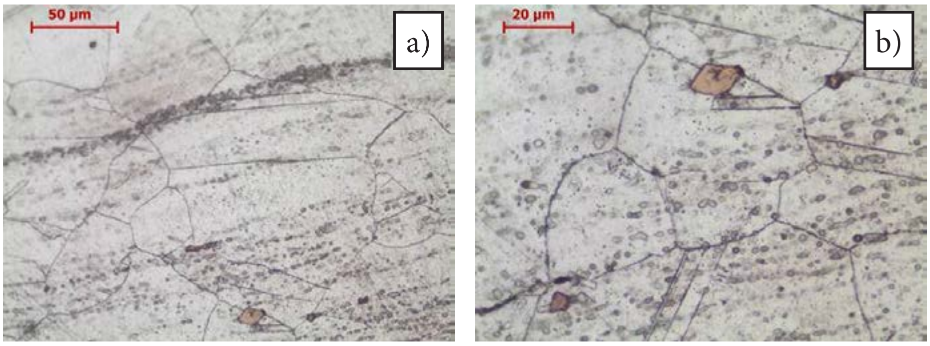

Fig. 3. Alloy 600; microstructure of the heat affected zone, visible grain growth – phase γ and carbide precipitates on the grain boundaries in within the grains

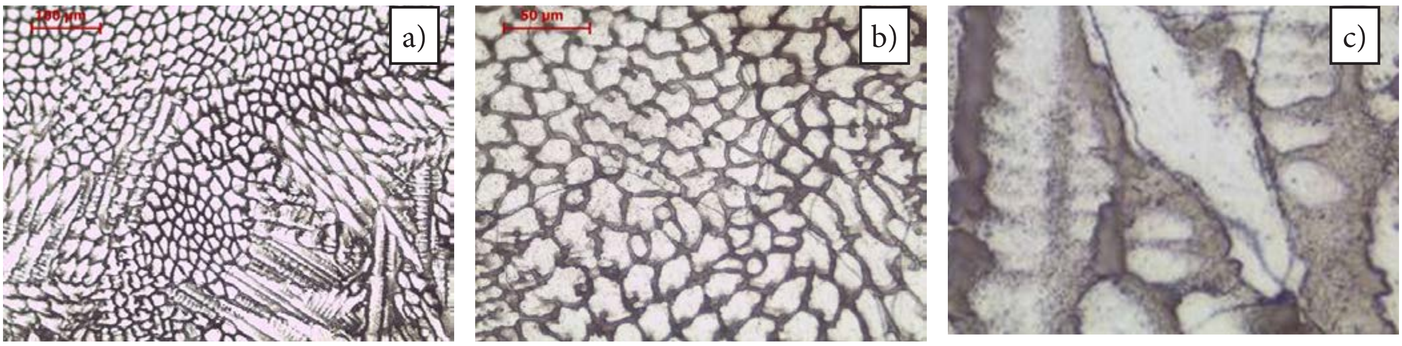

Fig. 4. Alloy 600; microstructure of the weld, cellular-dendritic structure; dendrite cores having the structure of phase γ

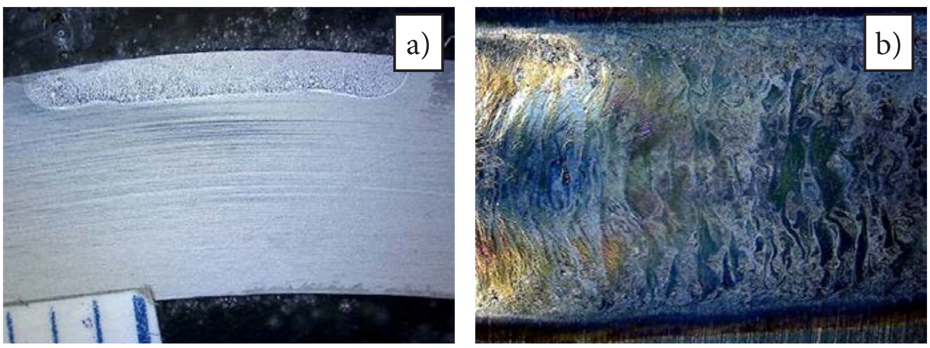

Fig. 5. Fusion in nickel alloy 617; current: 160 A: a) fusion macrostructure, b) weld face

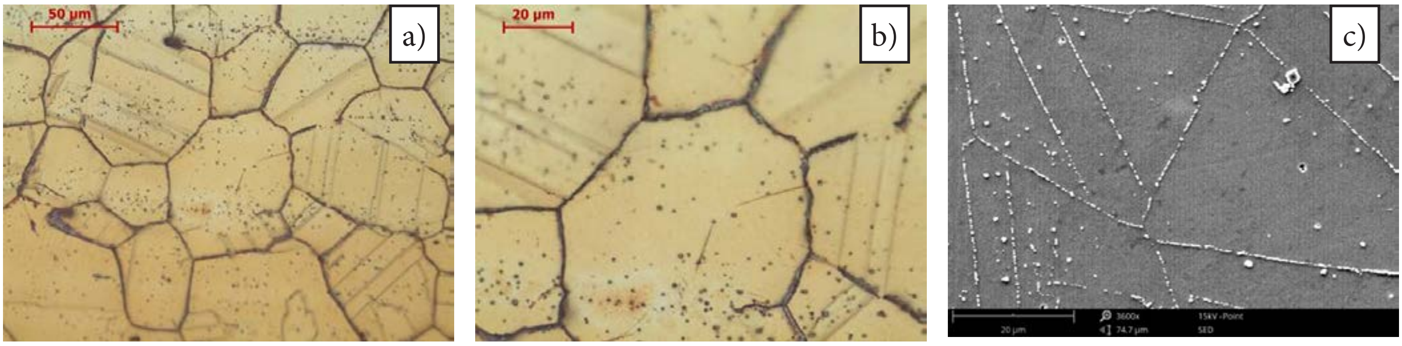

Fig. 6. Alloy 617; microstructure in the base material area (as-delivered state): a-b) light microscopy, c) SEM; visible decorated twin boundaries (annealing twins); structure of phase γ with carbide precipitates forming the lattice on the grain boundaries in within the grains

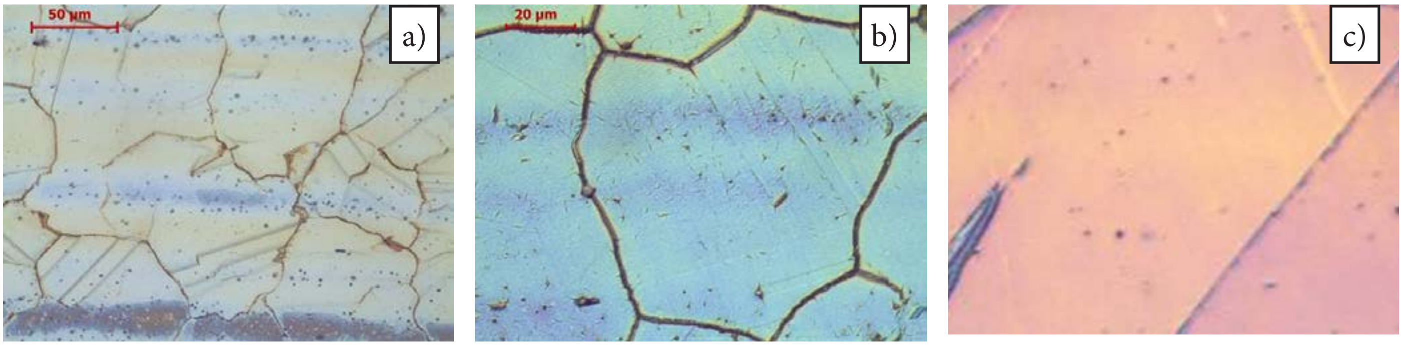

Fig. 7. Alloy 617; microstructure in the heat affected zone, visible grain growth; visible banding and twin boundaries (annealing twins); visible lattice of precipitates on the grain boundaries

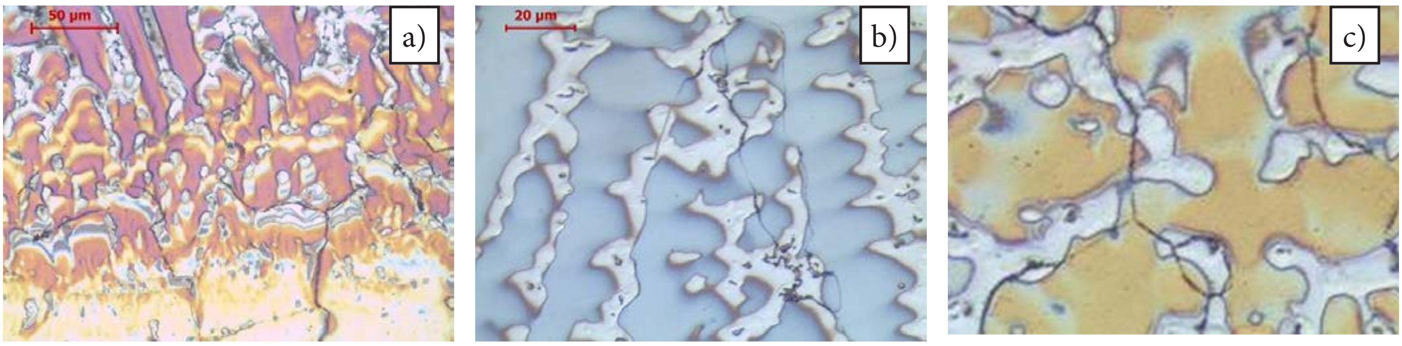

Fig. 8. Alloy 617; microstructure of the weld, visible grain growth; easily visible segregation of constituents in the interdendritic spaces with the formation of precipitates and other phases; dendrite cores having the structure of phase γ

Summary

The tests and analysis revealed that nickel alloys 600 and 617 in the as-delivered state have the structure of nickel austenite (phase γ) and differ significantly in terms of the size of grains. A significant amount of carbide-forming elements is responsible for the lattice of their precipitates within the grains and on grain boundaries. The elevated temperature in the HAZ is responsible for the partial dissolution of the carbide-forming elements, which in turn, leads to the growth of grains.

The welds of the alloys subjected to the tests had a dendritic or dendritic-cellular structure. The weld revealed the very significant segregation of alloying elements between the cores of dendrites and interdendritic spaces. The tests revealed structural differences resulting from chemical compositions. The complex chemical composition of alloy 617 was responsible for the presence of precipitates and phases affecting the mechanical properties of the joints and their corrosion resistance, particularly at elevated temperatures. The verification of the behaviour of the materials in industrial practice requires the performance of the metallographic tests of welded joints.

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