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Characteristics of Multimaterial Joints of Nickel-Based Superalloys

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Abstract. In the process of designing advanced constructions, it is extremely important to choose not only materials but also methods of joining them. The brazing technique allows for obtaining high-quality combinations of materials radically different in chemical composition and properties. In turn, the welding method guarantees obtaining a weld whose composition is a resultant combination of materials and is characterized by a low degree of deformation. In this study, a microstructure SEM+EDX analysis and hardness test for welding and brazing multimaterial joints of Inconel® 625 and Inconel® 718 were performed.

Introduction

Due to the application, nickel-based alloys are divided into structural alloys and alloys with special physical properties such as magnetically soft alloys, high-temperature alloys, corrosion-resisting alloys. Furthermore, nickel superalloys are used as shape memory alloys (NiTi) and alloys with special purpose in plastic forming [1-3]. However, the most important feature of all nickel superalloys is their heat resistance, corrosion resistance and the ability to work in extreme environmental conditions. For this reason, these materials are most often used in the aerospace industry for the construction of combustion chambers, gas turbines and flue gas exhaust, i.e. elements that require high-temperature and heat-proof materials [4-5]. Due to the occurrence of vibrations within these elements, they must also be characterized by high fatigue strength and corrosion resistance due to their interaction with combustion products. In the aerospace industry, the most commonly used nickel alloys are the following: Inconel 718, Inconel 625, Hastelloy X, Udimet R41 and Nimonic 90 [6]. In this study, the authors focused on the characteristics of Inconel® 625 (Ni-Cr-Mo alloy) and Inconel® 718 (Ni-Cr-Fe alloy) alloys.

In addition to the selection of appropriate construction materials, the choice of the method of joining is important. Both factors affect the efficiency of the structure. Glue, rivet, welded, threaded and brazed are the most commonly used joints in the aerospace industry. In the recent years, there has been a significant development of beam techniques (lasers and electrons) in the processes of joining materials [7-8]. The choice of joining method depends on such factors as type of materials to be joined, geometrical dimensions of elements, operational requirements and conditions of connections [9]. This paper presents issues in the field of welding and brazing. Brazing allows to obtain high-quality joints of materials that differ in chemical composition and properties or work in difficult operating conditions [10]. The process intended for the joining of nickel alloys is high temperature brazing and vacuum brazing. However, in the aerospace industry, mainly vacuum brazing is used for these types of alloys [11]. Joints soldered with this method are characterized by high precision, high strength, no oxide inclusions, dissolved gases and blisters. The necessity to

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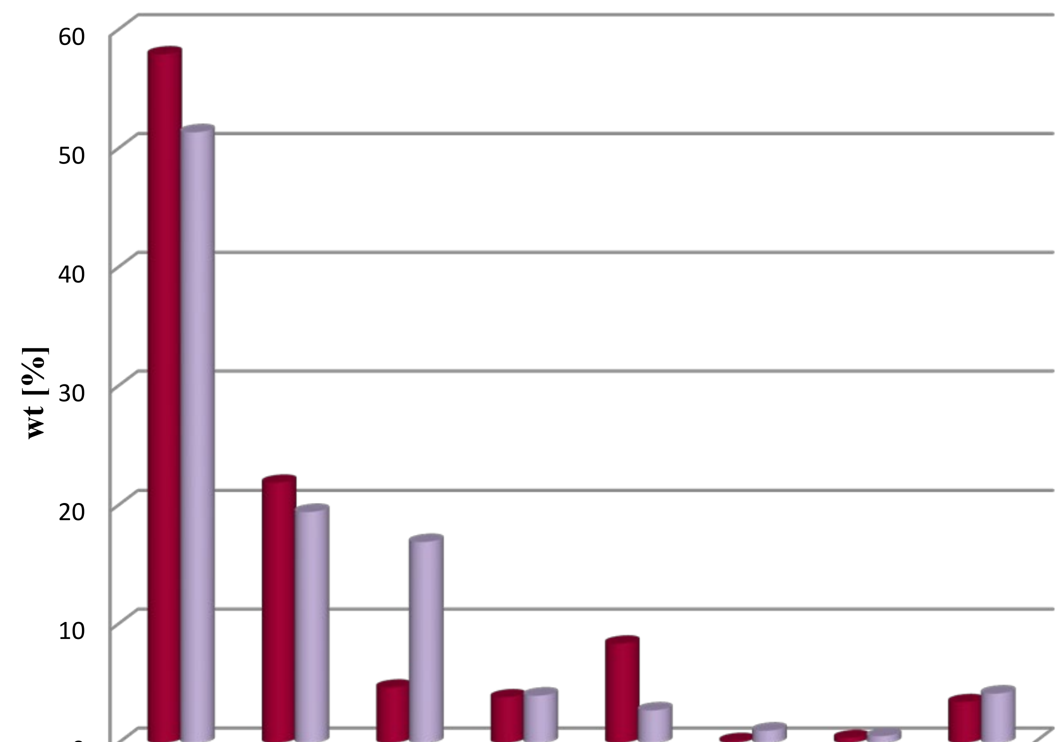
maintain a gap between the brazed elements and conducting the process in a vacuum furnace constitute limitations of this method. [12].

In the electron beam welding technique, the diffusion processes in the weld pool and mixing of molten nickel- based superalloys (Inconel 625 and Inconel 718) lead to the homogenization of the chemical composition of the liquid metal. During the solidification of the weld metal, the segregation of niobium and molybdenum occurs, which leads to the formation of eutectics at 1150°C and 1250°C. As a result of the eutectic formation taking place at 1150°C, austenite, brittle and intemetallic Laves phase are formed [13], while at the temperature of 1250°C niobium carbide and austenite are formed. The presence of carbides and the Laves phase leads to deterioration of crack resistance and plasticity of the material. Susceptibility to cracking during solidification as well as fracture cracks increases [14-16]. In order to reduce the impact of these phenomena, an oscillated electron beam is used instead of an unoscillated one during the welding process. Such a solution results in a faster cooling rate of the weld, and thus less niobium segregation and a smaller volume of the Laves phase. The finer, unrelated particles of the Laves phase, the better the properties of the welds [17].

Materials and methods

The research was carried out for specimens of welded and brazed Ni-based superalloys – Inconel® 625 and Inconel® 718. Compositional specification of both Inconel superalloys is included in Figure 1.



	Ni	Cr	Fe	Nb	Mo	Ti	Al	C
Inconel 625	57.91	21.88	4.64	3.82	8.33	0.16	0.41	3.42
Inconel 718	51.34	19.41	16.88	3.96	2.72	1.02	0.56	4.13

Fig. 1. Chemical composition of Inconel® 718 and Inconel® 625 (in wt. %).

Inconel® 625 in the form of a tube was brazed into a hole made in an Inconel® 718 plate. The surface of the materials was cleaned and chemically degreased. The solder consisted of 20% nickel and 80% gold. The brazing process was carried out in a vacuum oven. The multimaterial weld was obtained by oscillated electron beam welding, as a result of welding of two plates. The structure and shape of the joints were determined using an Olympus SZ61 stereoscopic microscope. Microstructural investigations were performed using an Axiovert 45 optical microscope and a Joel JSM 5400 scanning electron microscope with an EDS analyzer. A Vickers microhardness tester Shimadzu HMV-G -21DT with the load of 980.7 mN was used for the specimens.

Results and discussion

The stereoscopic images of welded and soldered multimaterial joints are shown in Figures 2a and 2b respectively.

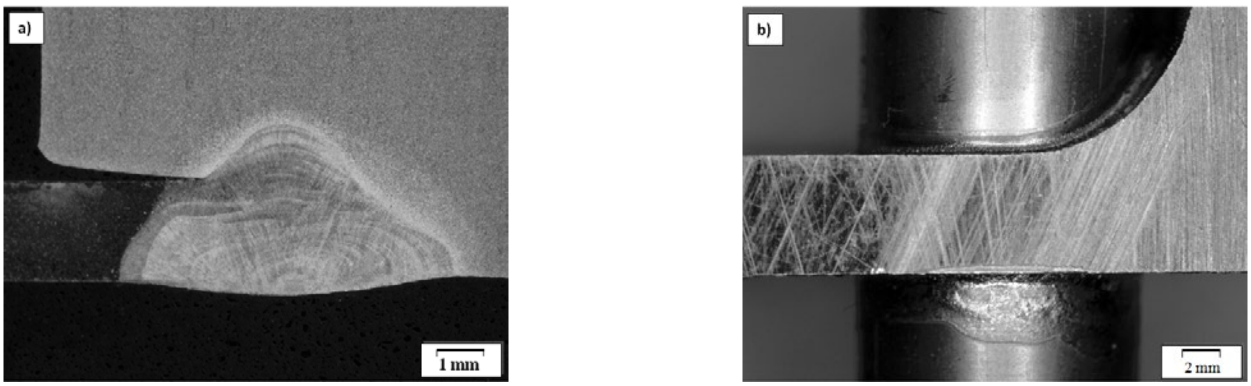


Fig. 2. a) stereoscopic image of the welded joint b) stereoscopic image of the brazed joint

In the image of the weld joint, the lack of the flash weld, crystallization cracks and microcracks in the Heat-Affected-Zone (HAZ) are evident, while in the case of the brazed joint, there is no dissolution of solder, cracks and porosity.

The microstructure of the parent metal Inconel® 625 is presented in Figure 3. In some grains, annealing twins are present, which is a characteristic defect for metals and alloys with a face centered cubic structure. The microstructure of the second native material Inconel® 718 is characterized by fine graining and the presence of the δ phase. The precipitation of the δ phase is always preceded by the precipitation of the γ'' phase. Due to the fact that niobium is the main component of both phases, the increase of the δ phase takes place with the γ'' phase depletion. Therefore, the presence of the δ phase causes loss of hardenability of the alloy.

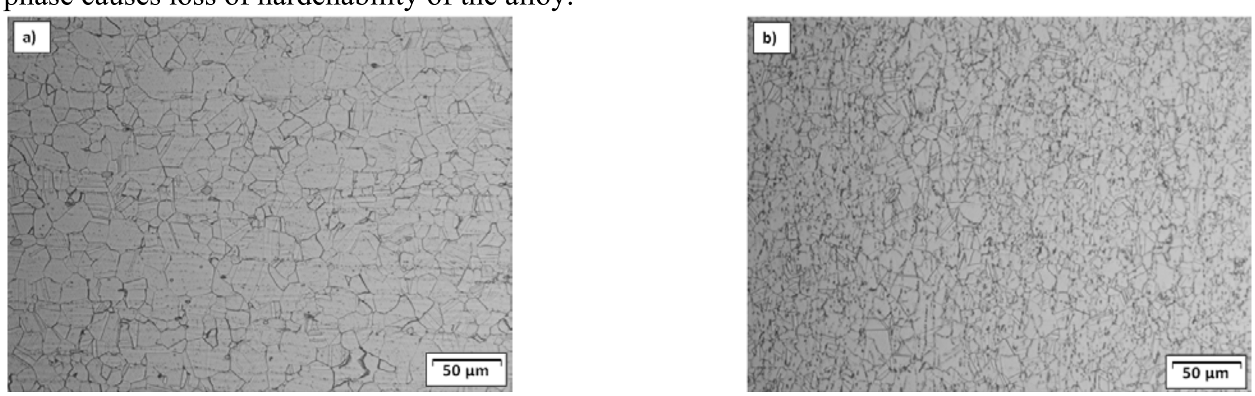


Fig. 3. The microstructure of a) Inconel® 625 b) Inconel® 718

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Using a scanning electron microscope, a linear EDS analysis of both connections was made. The points in which the measurement was made are marked with points in the microstructural images. In each case, 11 points were taken into account for the analysis (Figure 4).

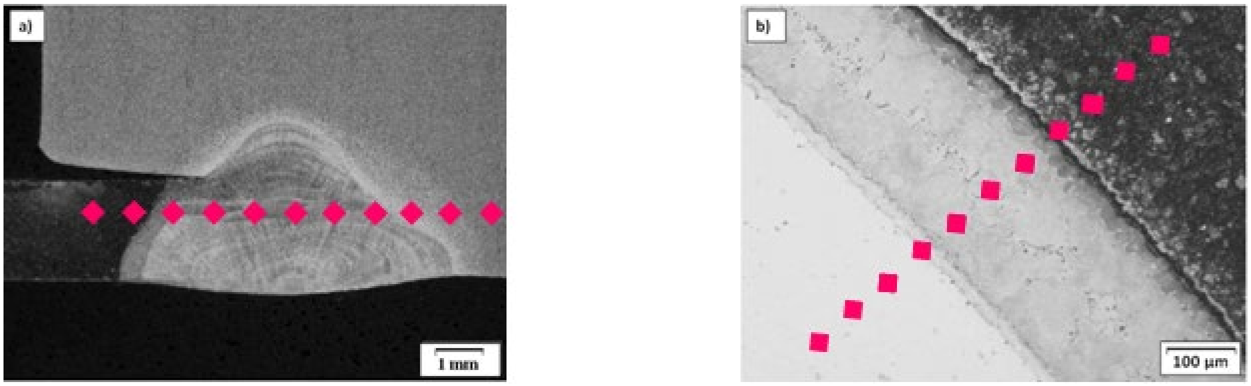
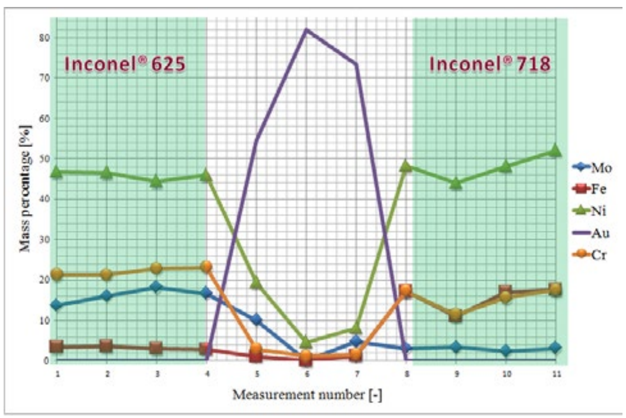


Fig. 4. The microscopic image of a) weld joint b) brazed joint. The place of performance of SEM / EDS analysis are indicated in the figure points.

a)



b)

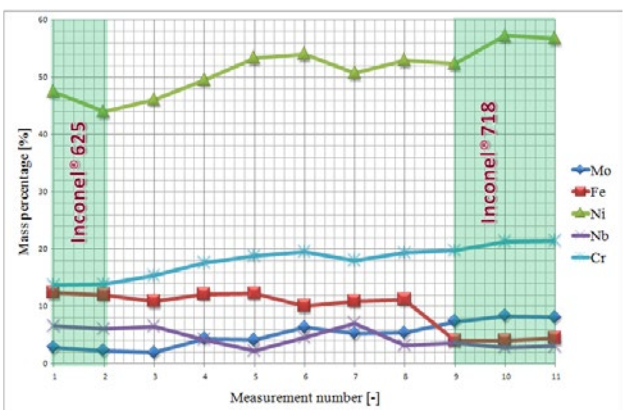
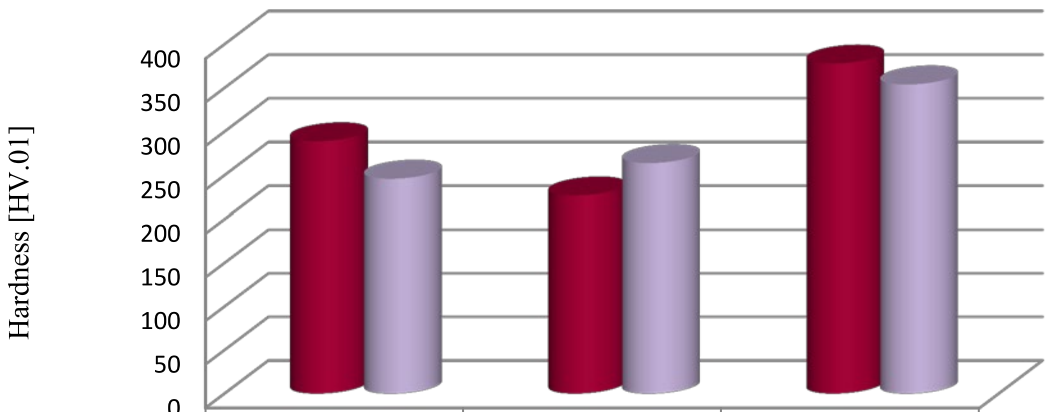


Fig.5. Diagram of linear SEM / EDS analysis of a) brazed joint b) weld joint

In the brazing process, iron, chromium and molibdenum diffused into the solder consisting of 80% Au and 20% Ni (Figure 5). The average molybdenum content in the solder is 4.91%, chromium - 1.83% and iron - 0.78%. The presence of gold in parent materials after the soldering process is not revealed. In the case of electron beam welding, the composition of the welded joint is a resultant combination of nickel superalloys.

The hardness of parent materials and multimaterial joints was measured using the Vickers method (Figure 6).



	Inconel® 625	multimaterial joint	Inconel® 718
weld joint	289	227	378
brazed joint	246	264	354

Fig. 6. Average hardness of parent materials and multimaterial joints

For each joint, Inconel® 718 is the material with the highest hardness value. The brazed joint has the lowest hardness value compared to the parent materials. This value is the result of only the joining of nickel superalloys with the use of a solder of a different composition. However, the weld has an intermediate value between the parent materials. The test hardness for the weld revealed that its hardness is the resultant value for individual hardness of the joined materials.

Conclusion

The brazed joint is characterized by the lack of solder dissolution, cracks and porosity, whereas in the welded joint, no defects such as flash weld, crystallization cracks and microfissuring in the Heat-Affected-Zone are revealed.

The linear SEM/EDS analysis conducted for both joints indicated the presence of diffusion phenomena of molybdenum, chromium, and iron into the structure of the brazed joint. The structure of the electron beam welding joint is a result of a combination of parent materials and diffusion phenomena is not observed.

The Vickers hardness test proved that Inconel® 718 has the highest hardness value. The brazed joint has a lower hardness value than parent materials, because only the phenomenon of joining with the solder occurs. The weld connection is characterized by an indirect value of strength properties with reference to the parent materials.

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