CONTRIBUTION TO INVESTIGATION OF THE INFLUENCE OF WELDING ON THE HARDNESS AND MICROSTRUCTURE OF SUPERALLOY NIMONIC 80A

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ABSTRACT
Because of their properties, superalloys are primarily used for the production of structural parts whose operating conditions correspond to elevated temperatures and often extremely aggressive environments. Because of that, they require a combination of high strength, good fatigue and creep resistance, and good corrosion resistance. Nimonic 80A is a nickel-chromium alloy, which is precipitation hardened with the addition of Al and Ti. The chemical composition of Nimonic 80A alloy has a dominant influence on its mechanical and technological properties. The combination of strength (max. tensile strength 1220 N/mm^2) and hardness (HB 370) at room and elevated temperatures with thermal stability at high temperatures makes this alloy most commonly used in extreme working conditions. Nimonic 80A has the widest application in the automotive industry where it is most often used for various parts of turbines, also, a significant part of the application is made up of industrial gas turbines, as well as the application of these materials in medicine. Standard methods and compatible filler metals can be used for welding Nimonic 80A alloy. In this work, TIG (tungsten inert gas) method used for welding samples with a different chemical composition. The aim of testing was investigate the effects of chemical composition on mechanical properties of welding joints superalloyNimonic 80A.

Keywords: Superalloys, Nimonic 80A, welding, experimental tests

1. INTRODUCTION

Nimonic 80A is a nickel-based superalloy containing approximately 20% chromium, which is precipitation-strengthened by the addition of Al and Ti, resulting in the formation of the ɣ'-phase precipitate (Ni_3Al). This phase is particularly significant for providing resistance to high temperatures and creep resistance.

According to the literature [1], the superalloyNimonic 80A has a hardness of 200-250 HV after recrystallization annealing and 290-370 HV after precipitation annealing. When welding such materials, it is crucial to carefully choose the welding conditions, i.e., the proper selection of filler material, the appropriate thermal treatment, and to define the welding conditions (heat input, current strength, etc.).

Increased requirements for the quality and safety of welded joints under certain operating conditions impose strict demands to achieve a series of properties in the welded joint.

Standards such as BS EN ISO 15614-1:2004+A2:2012 [2] and SIST EN ISO 9015-1:2012 [3] specify the conditions for performing tests on welded joints, including hardness testing according to locations provided in the standard. In many cases, hardness testing of the welded joint alone is not sufficient to determine the quality of the weld. For this reason, additional tests are often required, particularly microstructure testing. This approach can establish a connection between the hardness and the microstructure of the welded joint.
This paper provides an overview of the testing on welded joints of the superalloyNimonic 80A with a modified chemical composition, which is most commonly used for various turbine parts in the automotive industry. It is important to emphasize that the research and development of these materials have a significant impact on specific technological advancements, which in many cases are limited by the lack of new materials.

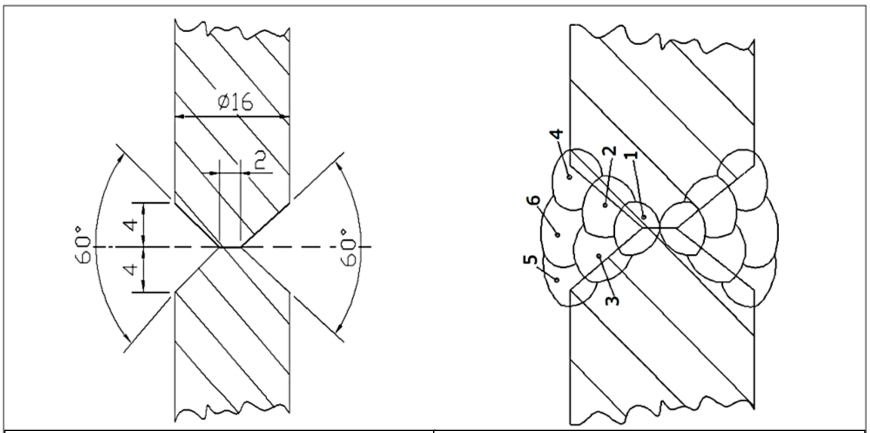
2. EXPERIMENTAL RESEARCH

For the practical part of the work, precipitation-strengthened rods of the Nimonic 80A superalloy with a diameter of Ø 16 mm were used. Table 1 shows the modified chemical composition of the experimental melts produced at the "Kemal Kapetanović" Institute in Zenica.

Table 1. Chemical composition of Nimonic 80A superalloy in wt. % (balance Ni) [4]

Sample number	C	Si	Mn	S	Al	Co	Cr	Cu	Fe	Ti	residual
	0,04÷ 1,00	max. 1,00	max. 1,00	max. 0,015	1,0 ÷1,8	1,0÷2,0	18÷21	max. 0,2	3,00	1,8÷2,7	
5	0,09	0,08	0,01	0,009	1,2	0,89	20,1	<0,01	0,21	1,9	P=0,008
9	0,05	0,02	<0,01	0,007	0,93	1,90	19,3	<0,01	0,10	1,69	P=0,008
10	0,06	0,19	0,01	0,008	1,53	0,87	19,7	<0,01	0,12	1,86	P=0,007

Welding of the machine-prepared samples Ø 16 mm, made of Nimonic 80A superalloy, was performed at the "METACOMM" process equipment factory in Jajce, using the TIG welding procedure - 141 (EN ISO 4063) [5]. The welding of the test samples was carried out in the BW/X/PC-vertical-wall position (EN ISO 6947 [6]), manually/semi-automatically. During the TIG-141 welding process, protection was provided by the flow of argon shielding gas (grade 4.8). The TIG welding process enables good root weld formation with minimal surface and internal defects. The joint preparation shape and the welding sequence according to the WPS are shown in Figure 1.



Tolerance +/- 1 (mm) (EN ISO 13920) Acceptance level of the welded joint "B"	Groove preparation (sketch) (EN ISO 5817)

Figure 1. Joint preparation shape and welding sequence

Non-Destructive Testing (NDT) and metallographic tests were conducted on the welded joint samples at the "Kemal Kapetanović" Institute in Zenica. Figure 2 shows the tested samples, and Table 2 provides the test results. As can be seen, all test samples meet the requirements, i.e., no cracks were present on the surface of the welded joint.

Figure 2. NDT testing of welded samples with penetrants

Table 2. Results of NDT testing of welded samples

Type of Testing	Testing Standard	Scope of Testing	Findings
Visual Inspection	EN 970	100%	Meets standards
Penetrant Testing	EN 571-1	100%	Meets standards

2.1 Hardness Testing HV10

Hardness measurements were performed across the welded joint cross-section according to the BAS EN 1043-1 standard [7], and the microstructure at the hardness testing locations was analyzed in order to obtain a more complete picture of the quality of the welded joint. The testing surface was ground, polished, and etched with the appropriate Adler reagent according to the ASTM E 407 standard [8].

Hardness testing HV10 is specified by the BAS EN 1043-1 standard for testing the hardness on the cross-section of an electrogas-welded joint of metallic materials using the Vickers method in accordance with the BAS EN ISO 6507-1 standard [9], with a load of HV10. Hardness testing is carried out under ambient conditions at a temperature of 18 °C. The applied hardness measurement method is a series identification, covering the base material (BM), heat-affected zone (HAZ), and weld metal (WM) at a distance of ≤2 mm from the surface and 0.5 mm from the fusion line. A schematic representation of the welded joint with the locations and hardness values of sample number 10 is shown in Figure 3. The average hardness values measured in the welded joint, according to the mentioned standard, are provided in Figure 4 for all test samples.

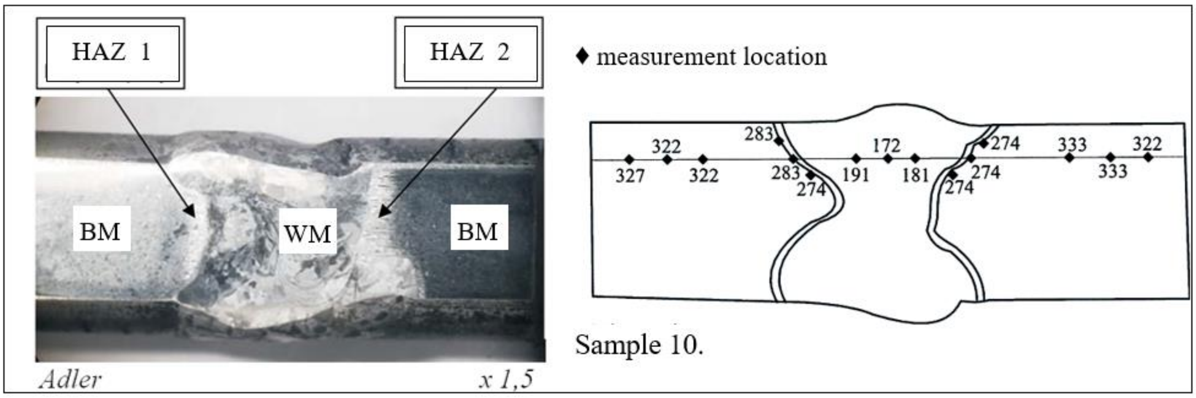


Figure 3. Microstructure testing zones and schematic representation of the welded joint with hardness test values for sample 10 [10]

From the diagram in Figure 4, it can be seen that the average hardness value of the base material ranges from 207 HV for sample 9 to 326 HV for sample 10. The lowest hardness value in the heat-affected zone is found in sample 9 (198 HV), while sample 10 has the highest value (278 HV). Additionally, the diagram shows that the average hardness value of the weld metal for all three samples ranges from 162 HV (sample 5) to 181 HV (sample 10). The analysis of the results revealed that the highest hardness values for all three measurement zones are found in sample 10.
In comparison to the other zones, the weld metal exhibits the lowest hardness, which can be explained by the use of pure nickel (98%) as the filler material during welding. Nickel has a lower hardness compared to the Nimonic 80A alloy.

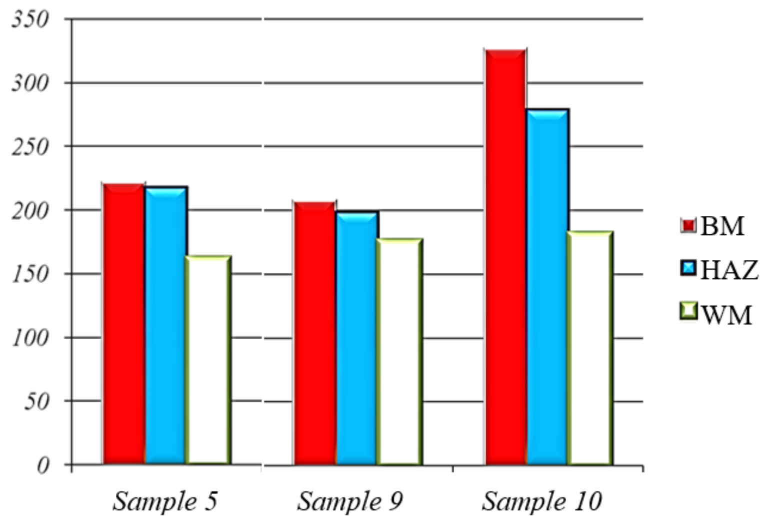


Figure 4. Hardness distribution diagram in multi-pass welded joints - average values

2.2. Macrostructure and Microstructure Testing

The microstructure testing was conducted using an OLYMPUS PMG3 light microscope, Figure 5. This testing included the analysis of the microstructure of the base material (BM), heat-affected zone (HAZ), and weld metal (WM). Microstructure testing of the HAZ under the light microscope was limited due to the narrow width of this part of the welded joint. Therefore, the microstructure in the HAZ was examined at the section of the welded joint where changes in the microstructure were clearly visible.

Figure 5. OLYMPUS PMG3 Microscope

The macrostructure of the cross-section of the multi-pass welded joint for all samples shows that welding was performed using multiple passes, with several layers of weld metal. The weld metal is free of porosity, cracks, and non-metallic inclusions. The heat-affected zone (HAZ) is 2 to 3 mm wide. Figure 6 shows the appearance of the microstructure for sample 10, including the base material, heat-affected zone, and weld metal. The image is taken as a representative snapshot for the other samples as well. As seen in the figure, the microstructure of the base material is austenitic, as is the microstructure of the heat-affected zone, while the weld metal region displays a characteristic cast microstructure.
Representative microstructure images are provided in Figure 6.

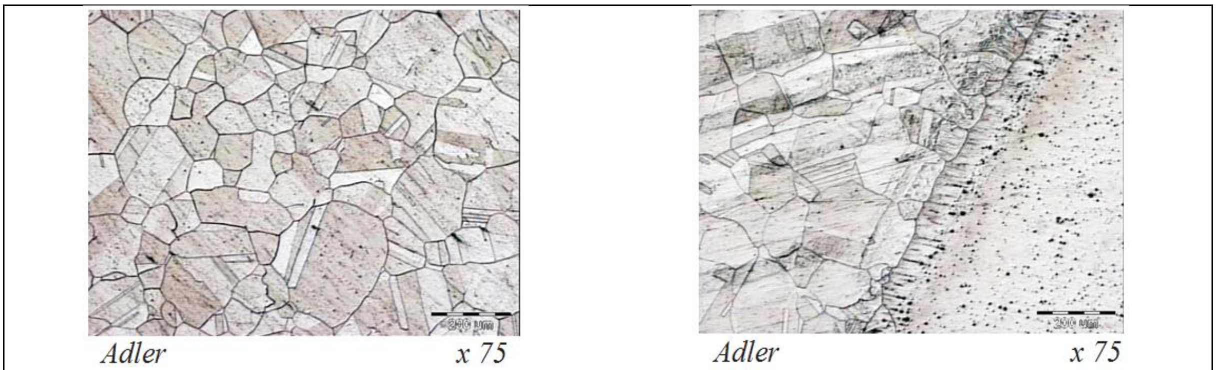


Figure 6. Representative microstructure images of sample No. 5

3. CONCLUSIONS

The results of the testing of the multi-pass welded joints of Nimonic 80A superalloy with a modified chemical composition show the following:

- No cracks were observed in the non-destructive tests.
- The hardness of the base material for all three tested samples ranges from 207 HV to 326 HV, the hardness of the heat-affected zone (HAZ) ranges from 198 HV to 278 HV, and the hardness of the weld metal ranges from 162 HV to 181 HV.
- The chemical composition of the samples has a significant impact on the microstructure and hardness of the welded joint. As the content of aluminum and titanium, which form the γ' phase, increases, the hardness also increases.
- The microstructure of the base material and the heat-affected zone is austenitic, while the weld metal has a cast microstructure.

4. REFERENCES

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