Research on the welding possibilities of dissimilar welded joints between two special alloys

C Rontescu, D T Cicic, D F Nitoi and C Petriceanu
Politehnica University of Bucharest, Materials Technology and Welding Department, 313 Splaiul Independentei, 060042 Bucharest, Romania
E-mail: corneliu.rontescu@yahoo.com

Abstract. Continuous development of the technological processes led to the necessity of using industrial equipment/installations made of high temperature resisting materials that provide the ability to work in heavily corrosive environments. The paper analyses two fusion welding options of dissimilar welded joints between two alloys, a cobalt based and a nickel based alloy. Here in are presented the results obtained after welding the two different materials using Tungsten inert gas (TIG) and Electron beam (EBW). Based on the results obtained after micrographic and macrographic examinations, it has been concluded that the two welding processes can be successfully used at dissimilar welded joints between the two types of material.

1. Introduction
Cobalt or nickel special alloys are used in many different industrial fields due to their superior properties, such as: good mechanical properties and non-corrodibility at high temperatures. Choosing the proper alloying elements used to develop special alloys, increases mechanical properties, improves creep resistance, high temperature corrosion, structural stability and fracture toughness, at operating temperatures [1 - 4].

Different welding processes can be used for welding cobalt or nickel special alloys, like: Shielded metal arc welding (SMAW), Gas metal arc welding (GMAW), Tungsten inertgas (TIG), Plasma arc welding (PAW), Electron beam welding (EBW) etc. In fusion welding processes, the welding thermal cycle influences, significantly, the welded beam and the heat affected zone by changing their chemical composition, mechanical properties and microstructure. When using fusion welding processes, a proper welding technology must be chosen so these changes don't cause major differences towards the base materials.

Also, the welding thermal cycle generates irregular heating and cooling of the welded joint adjacent areas, process that may insert high residual stress in the welded joint. It is well known that, in welding, residual stress influences the integrity of the welded joint by increasing the risk of hot cracking, cold cracking and stress-corrosion cracking [5 - 8].

The two alloys used for the experimental research presented in the paper, nickel alloy type AMS 5536 and cobalt alloy type AMS 5608, are alloys increasingly used in welding products used in different industrial fields because of the mechanical and thermophysical properties they possess.

Within the paper it is analyzed the possibility of welding the materials previously mentioned using two fusion welding processes: TIG (Tungsten Inert Gas) and EBW (Electron-beam welding).
The nickel alloy type AMS 5536 is an alloy resistant at high temperatures and corrosion. It also has very good oxidation resistance and remarkable strength at high temperatures. This alloy presents good weldability, formability and machinability. AMS 5536 is non-magnetic. This alloy is especially resistant to carburization and nitriding, conditions which cause failure in some high temperature alloys. It is used extensively in high temperature jet engine and chemical processing applications and is highly resistant to stress corrosion cracking in petrochemical applications [9].

The cobalt alloy type AMS 5608 is an alloy with an austenitic structure and high temperature resistance. The high chromium level coupled with small additions of lanthanum produce an extremely tenacious and protective scale. The alloy also presents good metallurgical stability displayed by its good ductility after prolonged exposure to elevated temperatures [10].

The AMS 5608 alloy is non-magnetic. This alloy performs well in continuous high temperature service and has excellent oxidation, corrosion resistance, achieved through the addition of chromium in combination with a small amount of lanthanum. The presence of lanthanum produces a tenacious, protective oxide scale at high temperatures. This alloy also maintains its ductility at cryogenic temperatures while strength levels are increased substantially [10].

2. Experimental data
The chemical composition and properties of the materials used for the dissimilar welded joints by fusion welding are presented in table 1 and table 2. The dimensions of the components used for the welded joints were 100x200x1.2mm.

| Table 1. Chemical composition of the base material. |
|-----------------------------------------------|
| **Weight Percentage (%)**                    |
| **Materials** | Ni | Cr | Co | Mo | W | Fe | Si | La |
| AMS 5536     | balance | 20.5-23.0 | 0.5-2.5 | 8.0-10.0 | 0.2-1.0 | 17-20 | 0.2-0.5 | - |
| AMS 5508     | 22.5-27.5 | 20.0-24.0 | balance | - | 13.0-16.0 | Max. 3 | 0.2-0.5 | 0.02-0.12 |

| Table 2. Mechanical properties of the base material. |
|-----------------------------------------------|
| **Materials** | **Tensile Strength (N/mm²)** | **Yield Strength (N/mm²)** | **Elongation (%)** |
| AMS 5536      | 720 | 324 | Min. 35 |
| AMS 5508      | 963 | 446 | Min. 50 |

| Table 3. Welding parameters used for TIG. |
|-----------------------------------------|
| **No.crt.** | **Parameter** | **Value** |
| 1           | Welding current (A) | 35±5 |
| 2           | Arc voltage (V) | 11±2 |
| 3           | Electrode diameter (mm) | 1.6 |
| 4           | Gas flow (l/min) | 10 |
| 5           | Travel speed (cm/min) | 12 |
| 6           | Type of gas protection | Argon |
Table 4. Welding parameters used for EBW.

| No.crt. | Parameter                        | Value   |
|--------|----------------------------------|---------|
| 1      | Beam current (mA)                | 30±1    |
| 2      | Focusing current (mA)            | 500±10  |
| 3      | Beam accelerating voltage (kV)   | 34±2    |
| 4      | Travel speed (cm/min)            | 40      |
| 5      | Beam Spot size (mm)              | 0.35    |

Before welding, the surface of the components was cleaned of impurities, oxides, grease and oils with degreasing and stripping substances recommended for these types of materials.

The parameters used for TIG and EBW welding (e.g. arc voltage, welding current, voltage, beam current, beam accelerating voltage etc.) are presented in table 3 and table 4.

3. Results and discussions

The welded joints resulted from the two fusion welding processes are presented in figure 1.

![Figure 1. Welded joints resulted: a – TIG bead b – EBW bead.](image)

To highlight the results obtained after welding the two types of materials the welded samples were cut and prepared for micrographic and micrographic examination and also for measuring the hardness in the characteristic areas of the beads. Also, measurements of the geometrical characteristics of the beads obtained were performed. The mean values of the geometrical characteristics measured at the beginning, mid and end of the welded beads are presented in table 5.

Table 5. Geometrical characteristics of the welded beads.

| Mean measured values(mm) | TIG bead | EBW bead |
|--------------------------|----------|----------|
| Width (B)                | 3.31     | 3.25     | 3.58     | 1.79     | 1.48     | 1.48     |
| Root width (B')          | 2.02     | 2.31     | 2.35     | 1.02     | 0.98     | 1.01     |
| Reinforcement (h)        | 0.21     | 0.23     | 0.23     | 0.04     | 0.05     | 0.04     |
| Root Reinforcement (h')  | 0.32     | 0.38     | 0.42     | 0.2      | 0.2      | 0.19     |

In order to perform the metallographic analysis the samples were cut using a special cutting system at low cutting speeds with continuous cooling in order to prevent the analyzed zone from being affected by the heat. After the cutting process, the samples were cleaned from impurities and subject to
a polishing process using metallographic paper with different granulations; finally, the samples were subject to polishing with abrasive diamond paste [11, 12].

Analyzing the micrographic images obtained (figure 2) deformations and different geometrical characteristics can be observed in the case of TIG welding. Another information resulted from the micrographic images presented in figure 2, is that the thermo-mechanic influenced area is narrower in the welded joint resulted in the case of EBW.

![Figure 2. Micrographic images of the welded joints obtained by: (a) TIG, (b) EBW.](image)

Based on the values of the geometrical characteristics presented in table 5, the variation graphics for the welded beads were drawn up and indicated in figure 3.

![Figure 3. Variation of the welded joint characteristics for the two welding processes - width, root width, reinforcement, root reinforcement.](image)
From the values presented in table 5 and the graphics presented in figure 3 it can be noticed that the values obtained for the TIG bead are higher than in the case of the bead obtained by EBW welding. Also, it can be observed that in the case of EBW bead the values of the geometrical characteristics vary very little on its length.

In order to highlight the quality of the obtained welded joints, hardness was measured in the characteristic areas: base material (BM), heat affected zone (HAZ) and welded bead (D). The hardness measuring points by Vickers HV 0.2 method are represented in figure 4. The hardness values obtained after measurements are presented in table 6.

**Table 6. Obtained hardness values.**

| Measurement points | BM AMS 5508 | HAZ | D | HAZ | MB AMS 5536 |
|--------------------|-------------|-----|---|-----|-------------|
| TIG                | 277 284 280 282 274 258 245 250 237 267 245 244 227 225 224 |
| EBW                | 288 284 285 244 240 231 243 231 244 233 223 221 214 210 |

The hardness values variation presented in table 6 are presented in the graphic form in figure 5.
Analyzing figure 5 it can be noticed that the hardness variation in the measured areas resembles for both beads obtained. A drop of the hardness value is observed in the AMS 5508 material area towards the welded bead and the AMS 5536 material, fact explained by the different composition of the two materials and the bead resulted.

4. Conclusions
The following conclusions can be drawn from the results obtained through the research:
- TIG and EBW welding processes can be used to weld the two type of alloys - AMS 5536 and AMS 5508, both processes providing the quality conditions required by the standards in force for welded structures;
- When using TIG welding the geometrical characteristics values of the welded bead vary on its length and are higher compared to those obtained when using the EBW process, due to the use of the manual method;
- In the case of EBW welding the geometrical characteristics values of the welded bead are constant its entire length and the width of the heat affected zone is much smaller compared to the one obtained when using the TIG welding process.

5. References
[1] Wang F 2012 Mechanical property study on rapid additive layer manufacture Hastelloy X alloy by selective laser melting technology The International Journal of Advanced Manufacturing Technology 5-8 545-551
[2] Abedi M R et al. 2016 The Effect of Repair Welding Number on Microstructure of Hastelloy X Fabricated via TIG Process International Journal of Materials Science and Applications 5(2) 43-48
[3] Graneix J, Beguin J D, Alexis J and Masri T 2015 Weldability of Superalloys Hastelloy X by Yb: YAG Laser Advanced Materials Research 1099 pp 61-70
[4] Lippold J C, Sowards J W, Murray G M, Alexandrov B T and Ramirez A J 2008 Weld Solidification Cracking in Solid-Solution Strengthened Ni-Base Filler Metal” 147-170.
[5] Rontescu C, Cicic D T, Bucur A D and Bogatu A M 2018 Technological methods to reduce welding stresses and distortions (Conference Paper) SGEM 2018 Vol 18 Issue 6.1 pp 481-488 18th International Multidisciplinary Scientific Geoconference Albena Bulgaria 2-8 July 2018 Code 142901
[6] Chen-Ming Kuo 2010 Comparison of the Mechanical Properties of Hastelloy X Material afterWelding by GTAW and Nd-YAG Laser Materials Science Forum January
[7] P. J. Withers and H. K. Bhadeshia 2001 Residual stress – I: measurement techniques Mater. Sci. Technol. 17 pp 355–365
[8] P. J. Withers and H. K. Bhadeshia 2001 Residual stress – II: nature and origins Mater. Sci. Technol. 17 pp 366–375
[9] https://www.upmet.com/products/nickel-alloys/alloy-x, accessed at 16.01.2019
[10] https://www.upmet.com/products/cobalt/alloy-188, accessed at 16.01.2019
[11] Rontescu C, Chivu O R, Cicic D T, Iacobescu G and Semenescu A 2016 Analysis of the Surface Quality of Test Samples Made of Biocompatible Titanium Alloys by Sintering (Bucharest, Romania: J.CHIM) 67(10) pp 1945-1947
[12] C Rontescu, D T Cicic, I M Vasile, A M Bogatu and C G Amza 2017 Reconditioning medical prostheses by welding ModTech International Conference 227(1) pp 413-418