The evaluation of welded joints type cracking tube-weldolet composed of Ni-Cr based super alloys

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1. Introduction

Ni-Cr based super alloys are an unusual class of metallic materials with an exceptional combination of high temperature strength, toughness, and resistance to degradation in corrosive or oxidizing environments. These materials are widely used in aircraft and power-generation turbines, rocket engines, and other environments, including nuclear power and chemical processing plants. Intensive alloy and process development activities during the past few decades have resulted in alloys that can tolerate average temperatures of 1050°C with occasional excursions (or local hot spots near airfoil tips) to temperatures as high as 1200°C[1], which is approximately 90% of the melting point of the material.

Nickel-based superalloys have relatively high yield and ultimate tensile strengths, with yield strengths often in the range of 900 - 1300 MPa and ultimate tensile strengths of 1200 - 1600 MPa at room temperature [2]. Ni based superalloys have been developed more or less empirically over the past 60 years from a simple Ni-Cr matrix to the present multi element and phase systems [2], having a fully austenitic face centred cubic (fcc) structure which maintains a superior tensile, fatigue and creep properties at high temperature to a body centred cubic (bcc) alloy [3].

From the point of view of microstructure, Ni superalloys are complex [4]. The fcc matrix, known as γ, mainly consists of nickel, cobalt, iron, chromium and molybdenum. The strength of superalloys are conferred by the hardening precipitates known as γ'. In some nickel – iron superalloys such as IN718 and IN706, which contain niobium, they are hardened by γ'' (Ni_3Nb based D022 structure) [5].

This paper presents the evaluation of welded joints type cracking tube-weldolet which has fractured during operation. The cracking tube and the weldolet are manufactured from Ni based superalloys.

2. Experimental procedure

2.1. Materials and welding procedure

The materials used for the realizations of the welded joint are Ni-Cr based super alloys, namely KHR35C (cracking tube) with a dimension of ø 114.32 x 12 mm and Incoloy 800 HT (P-45) (weldolet). The filler material was ERNiCr3, and the welding was realized manually.

2.1.1. Chemical composition

The chemical composition of the KHR35C and of Incoloy 800 HT alloys is presented in Table 1 (according to the materials quality certificates).

2.1.2. Mechanical properties

The mechanical properties of the cracking tube and of weldolet respectively are presented in Table 2 (according to the materials quality certificates).

2.1.3. Structural and hardness investigations

The welded joint was structurally examined (macroscopic and microscopic) by means of optical microscopy. The macroscopic examination was performed according to EN ISO 17639: 2014 and EN ISO 6520-1: 2007 and microscopic examination was performed according to SR 5000-97, respectively STAS 5500-

Table 1. Chemical composition of KHR35C and Incoloy 800 HT alloys.

Service	Material	C [%]	Ni [%]	Cr [%]	Nb [%]	Mn [%]	Ti [%]	Mo [%]
Cracking tube	KHR35CT	0.45 - 0.55	33 - 36	24 - 27	0.60 - 1.50	-	-	< 0.50
Weldolet	Incoloy 800 HT	0.075	30.78	19.47	-	1.02	0.48	-

Table 2. Mechanical properties.

Service	Material	Tensile strength [MPa]	Yield strength [MPa]	Elongation [%]
Cracking tube	KHR35CT	440	225	8
Weldolet	Incoloy 800 HT	520	210	35

74. The hardness of the investigated materials was determined by Vickers method, at a load of 10 kgf (HV10).

3. Examinations

3.1. Macroscopic examinations

The macroscopic aspect of the welded joint is presented in Figure 1.

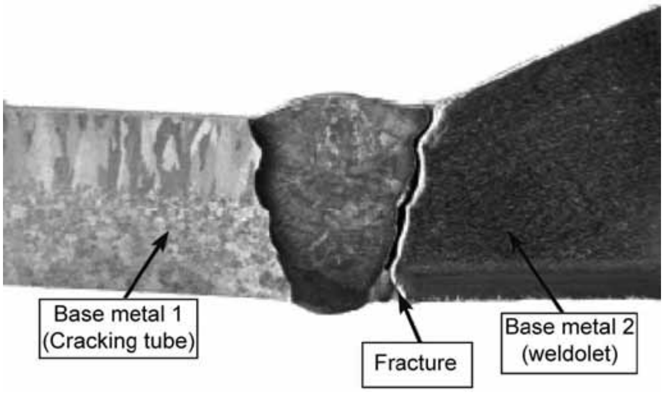


Figure 1. Welded joint [Lepito etched].

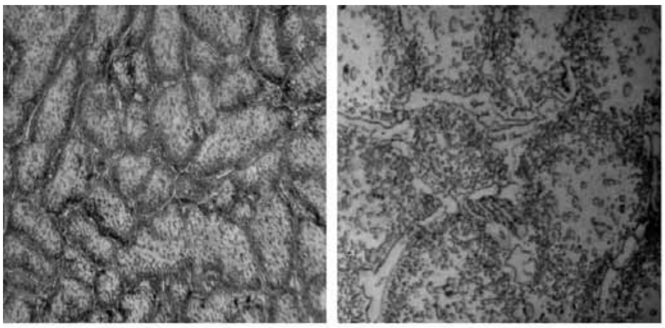
As it can be observed from Figure 1, the fracture of the welded joint occurred at the root joint, by the detachment of the weldolet, following the fusion line of the welding process.

The fracture at the weld root, with the detachment of the weldolet, occurs in the inner layer of this component, as it can be seen in Figure 1, which has a structure different from the rest of the material, clearly revealed by the macroscopic attack.

Regarding the layer of the interior zone of the weldolet, it can be observed that this layer has 2 zones, an exterior one, with a thickness of 1.60 mm, (strongly etched by the reagent, dark zone) and an interior zone with a thickness of approx. 0.8 mm (lighter).

3.2. Microscopic examinations

The microscopic examination of the welding specific zones (base metal, heat affected zone, and weld) highlights specific microstructures, namely:

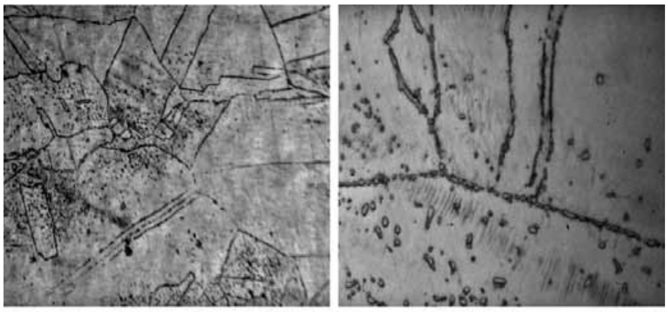


a) [100X, etched Aqua Regia] b) [500X, etched Aqua Regia]

Figure 2. The microstructure of the base metal (cracking tube)

• the structure of the base metal 1 (cracking tube) is composed of a Ni-Cr based solid solution and precipitation of metallic fine particles, placed at the grains boundaries, which is a normal structure for the Ni-Cr based alloys (see Figures 2a, 2b) . No cracks were detected in the examined areas.

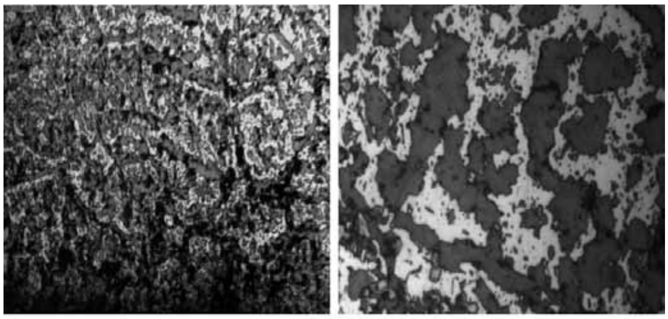
• In weldolet (base material 2), the microstructure is composed of Ni-Cr based solid solutions and precipitation of coarse metallic particles (Figures 3a and 3b).



a) [100X, etched Aqua Regia] b) [500X, etched Aqua Regia]

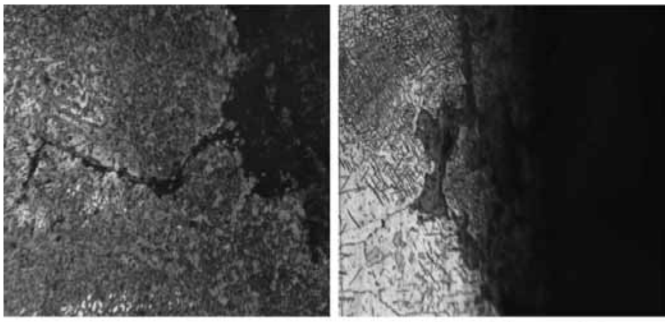
Figure 3. The microstructure of the base metal 2 (weldolet).

• At the inner zone of the weldolet, it is observed a layer with a different structure than the weldolet structure (Figure 4a and 4b).



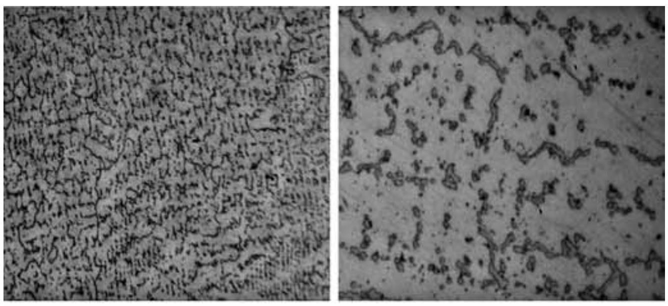
a) [100X, etched Aqua Regia] b) [500X, etched Aqua Regia]

Figure 4. The microstructure inner zone of the weldolet.



a) [100X, etched Aqua Regia] b) [500X, etched Aqua Regia]

Figure 5. The microstructure of the fracture zone.



a) [100X, etched Aqua Regia] b) [500X, etched Aqua Regia]

Figure 6. The microstructure of the weld.

• In the fracture zone, it can be observed micro-cracks placed perpendicular to the weld zone (Figure 5 a, 5 b).

• The weld presents a casting dendritic microstructure, based on Ni and Cr, and metallic precipitation placed uniformly within the matrix (Figures 6a and 6b). The weld doesn't present defects such as microcracks.

3.3. Hardness investigations

The hardness of the investigated materials was determined by Vickers method, with a load of 10 kgf (HV10). The hardness values obtained in the specific areas of the welded joint are:

- Between 230 and 238 HV10 in base metal 1 (cracking tube);
- Between 207 and 240 HV10 in base metal 2 (weldolet);
- Between 227 and 325 HV10 in weld zone.

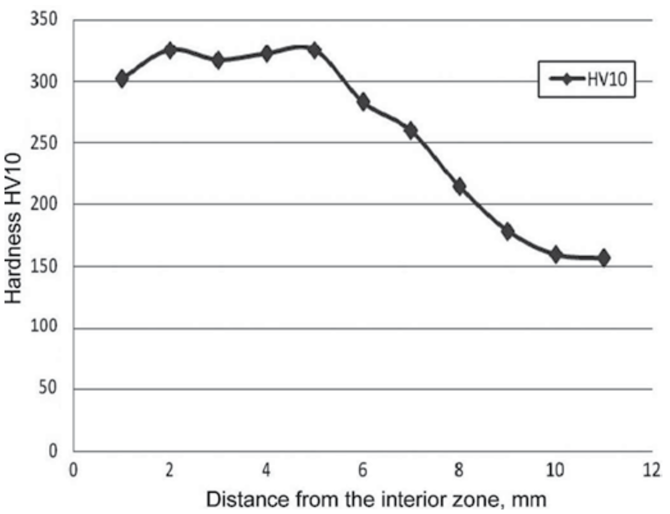


Figure 7. HV 10 hardness variation.

Figure 7 shows the hardness variation of the weldolet inner layer which has a different structure compared to the structure of the base material. The first six values are determined in the layer and the rest toward the base metal, which reaches the value of 157 HV10. This hardness variation may lead to the conclusion that this layer is a diffusion layer developed in time.

3.4. Macro fractographic examination

The fracture of the welded joint (cracking tube-weldolet type) has occured at the interface between the Weldolet and the deposited metal. The macroscopic aspect of the fracture shows no plastic deformation in the separation zone, as it can be observed from Figure 1.

4. Conclusions

4.1. The macroscopic examination of the welded joint, type cracking tube-weldolet, highlights a fracture at the interface between the deposited metal and the weldolet. The fracture follows a route that enters in the root zone of the weld and in the base metal (weldolet), where it can be observed a layer with a completely different structure and hardness.

4.2. The structure and hardness of the cracking tube composed of KHR 35 CT alloy is normal for this class of materials (nickel based alloys).

4.3. The structure and hardness of the weldolet made of Incoloy 800 HT is normal for this class of materials. It is noted, however, at the inner zone of the weldolet a layer consisting of two areas, with a total thickness of 2.4 mm having high hardness values of up to 325 HV10.

4.4. The macrofractographic examination revealed no plastic deformation in the fracture zone, which indicates a possible intergranular fracture.

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