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Ni-Co Alloys for Steam Turbine Blade Restoration by Welding Application

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Abstract – **Ni-Co alloys boron doped were fabricated by induction melting technique. The deposition of the alloys with and without boron was applied by using the TIG welding method (tungsten inert gas). Microstructure analyses of the deposited alloys in the cross-section were performed under SEM techniques. Interface displayed directionally solidified fine equiaxed grains, while columnar grains where observed in the filler with some diffusion degree inner the metal base superior zone. Tension tests have shown that welded samples Ni-Co boron doped present improved resistance, moreover, the samples present good cohesion at the interphase since the fracture occurs in filler material. Numerical analyses were performed and zones of maximum stresses and strains can be detected. These modeling results support with high approximation degree the experimental analyses.**

Keywords – **Gas Turbine Blade, Welding, Mechanical Testing, Restoration.**

I. Introduction

Restoration of damaged turbine blades is an option for increase the service life of the component instead of replacing it with a considerable economic benefit. Among the common damages are found micro-cracks, bubble in casting, impact and corrosion- erosion, these are the usual problems generated in turbine blades which affect directly its performance. In welded joints are presents six zones developed after the welding process, which are, unaffected zone, over aged zone, partially annealed zone, solid solution zone, fusion zone and welded zone, where the critical zone is the solid solution zone. There are extensive information about laser-based deposition technologies for reparation of gas turbine components [1-5] however, the use of the technique involve a considerable cost due to the investment in the equipment acquisition, considering that this process in some times present very low depth of the metallurgical union. Several authors have investigated the turbine blades restoration by different welding techniques Plasma spraying [6], Plasma transferred arc (PTA) welding [7] among others. It is very well known that gas turbine blades are exposed to high temperatures, therefore the ideal material that can be used for such condition are the nickel-base super alloys, due to their excellent hot corrosion resistance and good mechanical properties at elevated temperatures. However, Ni-base super-alloys with high Ti/Al composition exhibit high cracking susceptibility in fusion-repair, because these alloys are hardened by the precipitation of γ’ phase [5]. In this work we are try to obtain a coherent interface in the Hot Affected Zone (HAZ) to minimise the micro-cracking and porosity formation. Therefore, the aim of this study is to investigate the possibility to produce Ni-Co alloys Boron doped and to explore the application as welding material deposited on a turbine blade by tungsten inert gas (TIG) welding. Until now, no information in literature concerning to the turbine blade restoration with this alloy is available.

II. Experimental Procedure

Alloys with different Ni, Co and B (as dopant) elements (99.99% purity) were used to produce alloys as filler material by induction melting technique in 10^{-2} torrs vacuum atmosphere to weld the metal base turbine blade 410 martensitic stainless steel.

A gas turbine blade was repaired by using TIG (Tungsten Inert Gas) welding method, as is showed in Fig. 1, with a 0.317 cm diameter Thoried electrode (2%) at 125 A, travel speed of 5cm per minute, beam angle of 30° and a shielding gas of 25% He-75 % Ar (flux of 5 ml/min.)

Fig.1. Alloy deposition of a sectioned turbine blade by TIG welding before finishing process.

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Metallographic preparation was performed in welded samples were obtained by cutting around of interphase, ground up to 600 paper grinding and then polished with 1.0 µm alumina powder. After that, specimens were etched with 30ml HCl, 20 ml glycerol and 10 ml HNO_3. Microstructure images analyses were performed in a LEO-1450VP scanning electron microscope, as well chemical composition analysis was performed by using the Energy Dispersive X-Ray Analysis (EDAX) system of the equipment. Vickers microhardness profiles were performed on a polished cross-section using a 0.2 Kg load and a holding time of 15 s, using a Leco micro-hardness tester. Specimens for tension tests were sectioned from the welded zone, with dimensions in agreement to the ASTM E8- 13a *Standard* Test Methods for Tension Testing of Metallic Materials. In order to elucidate and to obtain a better understanding about welding effect, numerical analyses were performed based on ANSI/AWS B4.0 on the welded samples.

III. Results and Discussions

3.1 Microstructure

In Fig. 2 it is presented the microstructure of the welded sample where it can be observed the three regions, namely metal base, inter-phase or Heat affected Zone (HAZ) and filler material. It is well known that when solidification process occurs, two types of grain morphologies may exists, namely equiaxed and columnar.

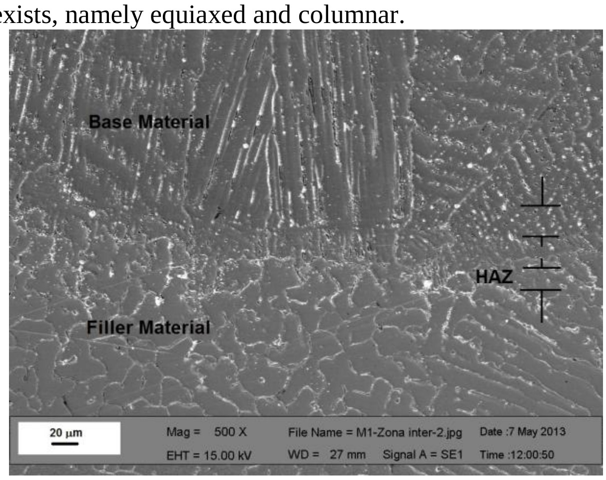

Fig.2. Inter-phase of the Heat affected Zone (HAZ) and filler material

The first one it is produced after crystals nucleation in an undercooled isothermal melt, producing a polycrystalline structure with grains no specifically oriented. The second one (columnar) occurs when the heat flux is unidirectionally oriented. In our case, in both regions coexists columnar structure, in filler material zone it is observed a combination of equiaxed and columnar grains, being the last ones in a major proportion. While in base zone are observed principally columnar grains, also, few micro-cracks were observed in this zone, principally onside to the columnar grains (marked by an arrow), however in filler material only very few microporous are present on the surface sample, this effect it is produced by the low cooling rate that it is being developed when the electrode is traveling over the welding zone at a moderate speed which is one of the most important parameter to be considered to obtain a successful welded union. These similar structure and low porosity degree, may ensure that base material metallurgicaly accept the filler material creating a homogeneous crack free coherent interphase.

3.2 Mechanical properties.

3.2.1 Hardness

Fig. 3 present the hardness evaluation performed on the cross section of the welded sample with the Ni-Co boron doped alloy. It is observed that in the metal base zone present a value of 250 kg/mm^2 and after this zone, it is present the welded interphase or heat affected zone (HAZ) where it is observed that hardness start to increase in exponential mode until reach the filler material zone with a hardness value of 430 kg/mm^2 approximately. It is clear to observe that the interphase zone present a 180 µm width, being this value relatively high, indicating that some diffusion process occurs on this zone, this is effect possibly occurs due to the atomic radii of Ni and Co (1.62 and 1.67 Å respectively) from the filler material are relatively smaller than the Fe atomic radii (1.72 Å) from the base material, thus it can establish that, during the heating process the atoms migration from the filler material to heat affected zone occurs generating mixed compounds with the elements present in the base material, producing some gradual strengthening on the interphase due to the structural difference.

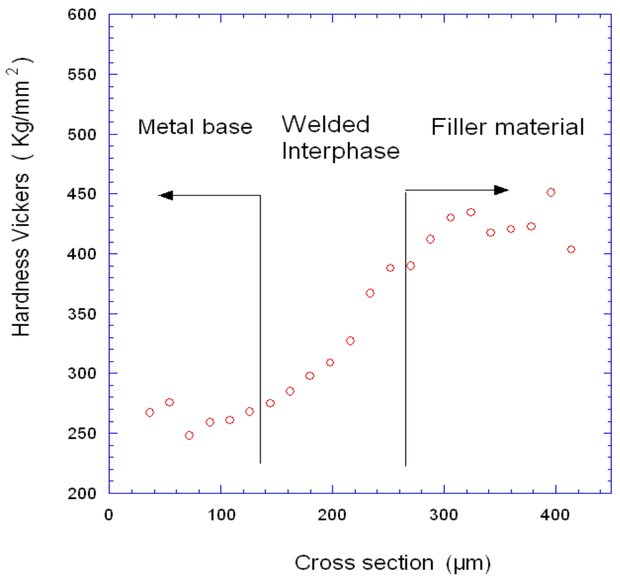

Fig.3. Hardness Vickers profile along the: base material-HAZ-filler material.

This can be observed in the region of the hardness slope (see Fig. 3) generated in this zone, which is not developed abruptly.

The transition zone present microhardness values up to 50% higher compared with the base alloy which may be associated with the tempering and aging processes in this welded zone (HAZ) and the release of dispersed intermetallic phases [8]. Generally if arc welding on materials which have been strengthened by precipitation hardening, then, in the HAZ may will experience cycles of heating and cooling during the welding process, in consequence its properties will change and may be different than that of the original base alloy.

3.2.2 Tension test evaluation.

Fig. 4 shows the plots obtained from tension tests on the sample without filler material (blade material), the welded samples with the Ni-Co and Ni-Co boron doped alloys. It is observed that sample without filler material present a very low deformation with high resistance in yielding point of about 340 MPa, which is in good agreement with the reported values for 410 martensitic stainless steel. The sample with Ni-Co no doped present a value of approximately 120 MPa in the yield stress which is lower in comparison with the welded sample by Ni-Co boron doped alloy which present a value of 145 MPa. This increment it is attributed partially to the boron presence in the alloy that may segregated to the welded inter-phase (no detected by SEM analyses), promoting a cohesion-strengthening between the base material and filler material.

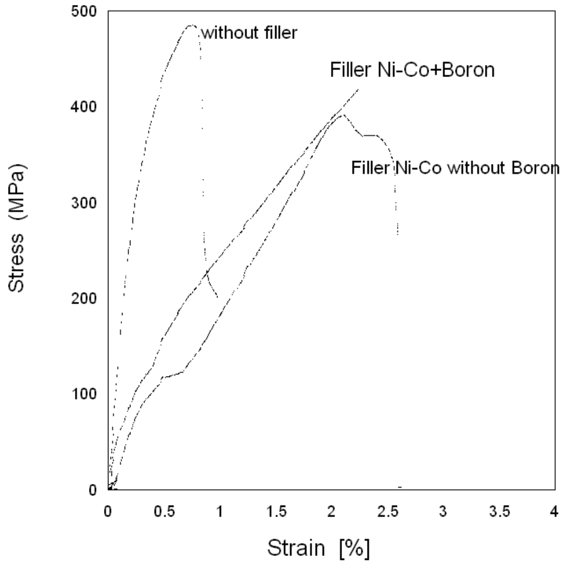

Fig.4. Tension tests plots of the samples without filler material (blade material), welded samples with Ni-Co and Ni-Co boron doped alloys.

It is important to note that the plastic region in the curves present a value of 250 MPa approximately, with low deformation which indicate good cohesion between the filler material and the base material. To demonstrate the strong bond between base material and filler material, in Fig. 5a it is presented the image of the resulting fractured sample after tension test, showing the filler material welded to the base material without no cracking presence in the HAZ, also it is observed that the fracture was developed totally in the filler material, which ensure that the turbine blade will not be fractured on the welding interphase zone.

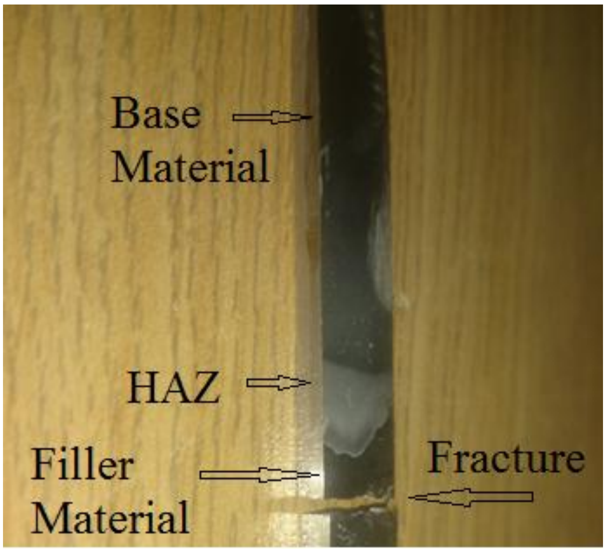

Fig.5a. Fractured sample after the tension test, showing that failure occurs on the filler material and not in the HAZ interphase.

Fracture surface of the Ni-Co boron doped sample image is presented in Fig. 5b where it is observed the fracture near to the central surface region, this image exhibited a complete ductile fracture having small and uniform dimple morphology which indicate an inherently heat treated material type, product of the heat generated during the welding process.

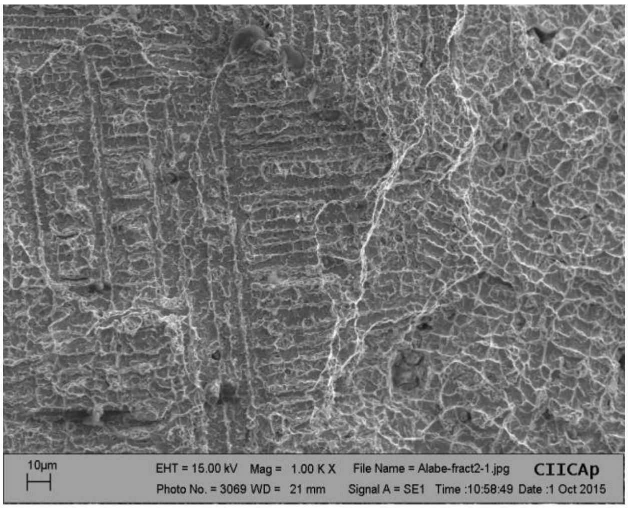

Fig.5b. Fracture surface of the Ni-Co boron doped sample exhibiting ductile dimple morphology.

3.2.3 Modeling tensile behavior.

A numerical analysis allow to evaluate the quantitative and qualitative behavior of the specimens under a fixed load and the results of the presented method may be compared in detail with experimental results. Therefore, in order to obtain a precise information ANSYS/ WORKBENCH® R14.5 software was used for numerical simulation analyses.

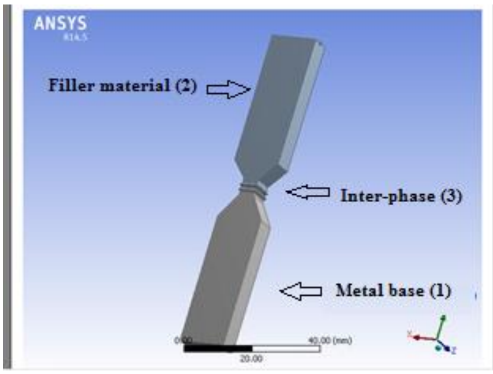

Fig.6a. Schematic representation of Metal base (1), Filler material (2) Inter-phase (3)

The Fig. 6a and 6b shown the obtained images from the modeling software illustrating the welding zones in the tension test specimen: metal base (1), the weld portion as filler material (2), and inter-phase or HAZ (3). It can be seen in the Fig. 4b the applied load from the finite element model with a tension load of 6010 N and the welding zone of two different materials with different mechanical properties.

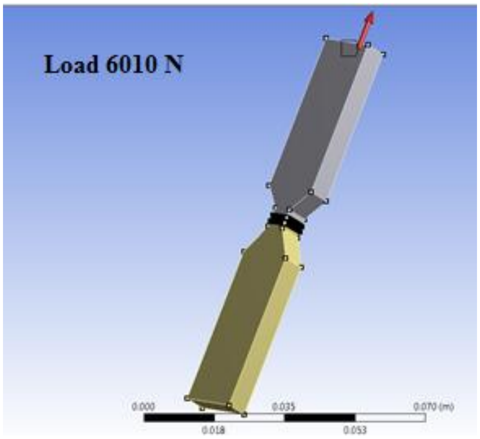

Fig.6b. Schematic representation of the applied stress direction with a load of 6010N.

After been specified the former parameters, Fig.s 7a and 7b shown the images with the corresponding stresses and strains respectively on the specimens Ni-Co Boron doped.

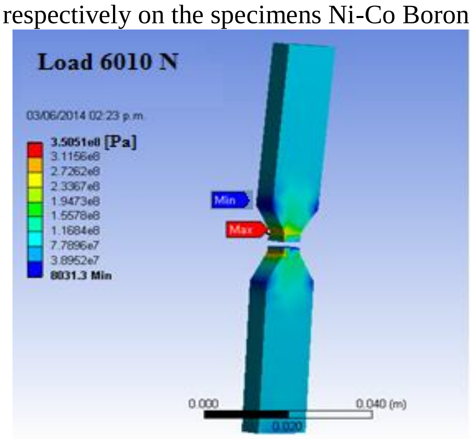

Fig.7a. Schematic representation of the maximum and minimum streses in sample boron doped.

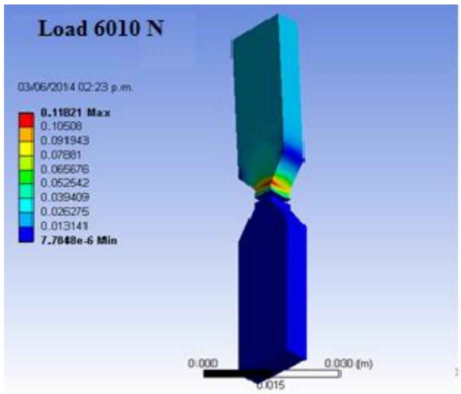

Fig.7b. Schematic representation of the maximum and minimum strains in sample boron doped.

It can be observed in Fig. 7a that the maximum operating stress it is developed near to the welded interphase in the order of 350 MPa, while in Fig. 7b it is observed that also the maximum strain concentration is near where filler material was deposited in approximately 0.118 percent.

Fig. 8a and 8b shown the stresses and strains in the specimens Ni-Co without Boron additions respectively. It can be observed in Fig. 8a that the maximum stress developed in this sample is very similar to the sample boron doped (350 MPa), however, the strain shows a slight variation in comparison with the sample boron doped (0.18 percent).

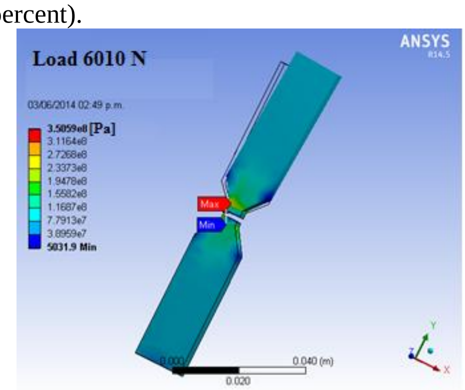

Fig.8a. Schematic representation of the maximum and minimum streses in sample without boron additions.

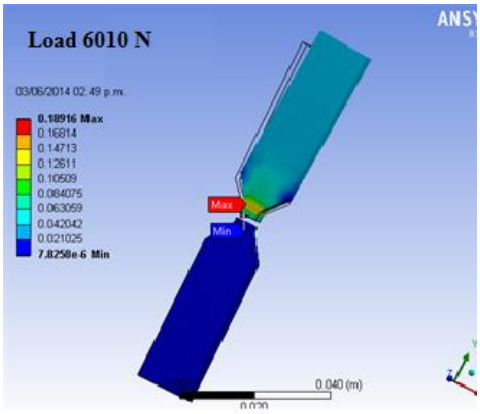

Fig.8b. Schematic representation of the maximum and minimum strains in sample without boron additions.

The maximum stress and strain concentration occurs near where filler material was deposited. The numerical results validate with high range of accuracy the experimental results, in such way that this calculations may provide a good approximation for predict the mechanical response of the turbine blade.

Fig. 9 present the numerical results from the mechanical behavior of the samples with and without boron additions, namely stress-strain curve in the elastic zone exclusively.

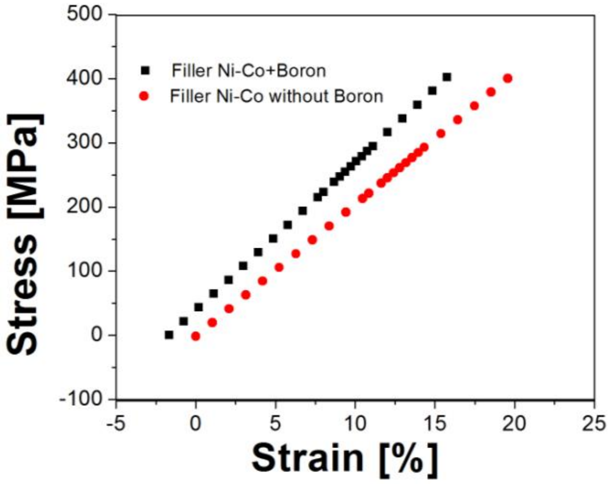

Fig. 9. Numerical representations of the stress-strain curve for samples in the elastic zone.

It can be seen that the alloy boron doped present a similar stress behavior up to the yielding zone, but shows less deformation in comparison with the sample without boron. This results may indicate that boron do not play an important role in elastic deformation by diminishing the deformation process before fracture.

The above modeling results presents an acceptable approximation with the experimental results, thus, it provide an important information about the mechanical properties of the welded interphase

IV. Conclusion

Ni-Co and Ni-Co boron doped alloy were successfully synthetized in order to be used as filler material in restoration welding process of damaged steam turbine blades. Hardness evaluations along the heat affected zone (HAZ) have shown that interphase region exhibit a moderate slope change, indicating a good metallurgical bonding between base and filler materials. Limited porosity and microcracking was found at the interphase (less than 10 % in area fraction) which suggest that material possesses good mechanical strengthening. Tension test indicates that boron additions slightly affect the yielding stress behavior, presenting a good correlation with the modeling analyses, where also confirm the assumption that crack propagation and therefore, failure may happen in the filler material not in the interphase zone. Fatigue analyses are currently carried out.

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