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Influence of erosion on the mechanical properties of Inconel 718 joints brazed with BFM NiCrP

R.P. Rezende[1], M.D.M. das Neves[1]
[1]*renato.rezende@usp.br*
[1]*mdneves@ipen.br*

[1]Instituto de Pesquisas Energéticas e Nucleares
Av. Prof. Lineu Prestes, 2242 - Butantã, São Paulo - SP, 05508-000

1. Introduction

Spacer grids are part of the Fuel Element (FA) set of the Pressurized Water Reactor (PWR) type. These spacer grids maintain the position of the fuel rods within the FA arrangement, maintaining between them the necessary spacing for reactor operation. The Spacer grids are manufactured from the union of the points of intersection of stamped strips of Inconel 718, by a joining process called brazing. For this process, these strips are coated with a thin layer of nickel by means of electrodeposition in order to protect against oxidation and allow a better fluidity and wettability of the brazing filler metal (BFM) in the strips during brazing. The BFM used is nickel-based NiCrP. During the brazing process the dissolution of the base metal (BM) by the molten BFM occurs, resulting in a reduction of the BM thickness. This work aims to evaluate the influence of dissolution of the BM (Inconel 718) on the mechanical strength of the joint brazed with NiCrP-based filler metal, under different processing conditions of temperature, brazing time and cooling mode.

2. Methodology

In this work, stamped strips of Inconel 718, 0.35 mm thick, called BM, were used. The strips were laminated and underwent thermal solubilization treatment. The BFM used was a brazing paste under the trade name Nicrobraz 50-S, with specification AWS A5.8 (2012) (BNi-7) from the manufacturer Wallcolmonoy. The solidus/liquidus temperature of the BFM is 890 °C. The nominal chemical compositions of BM and BFM are shown in Table I.

Table I: Chemical composition of BM and BFM (%wt).

Chemical composition of BM and BFM (% wt)								
Element	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Co**	**Mo**
BM	0.08 (max)	0.35 (max)	0.35 (max)	0.015 (max)	0.015 (max)	17-21	1.0 (max)	2.8 - 3.3
Element	**Nb + Ta**	**Ti**	**Al**	**Fe**	**Cu**	**Ni**	**B**	**Ta**
BM	4.75 - 5.5	0.65 - 1.15	0.20 - 0.80	Bal	0.30 (max)	50 - 55	0.006 (max)	0.05 (max)
Element	**Ni**		**Cr**		**P**		**C**	
BFM	Bal		14		10		0.06 (max)	

The straps were fitted keeping the joint gap fixed at 0.025 ± 0.020 mm. After applying BFM, the joints were subjected to the brazing process, as shown in Figure 1(a). The thermal cycle of the process is shown in Figure 1(b). The internal pressure in the furnace during brazing is in the order of 10^{-3} mbar.

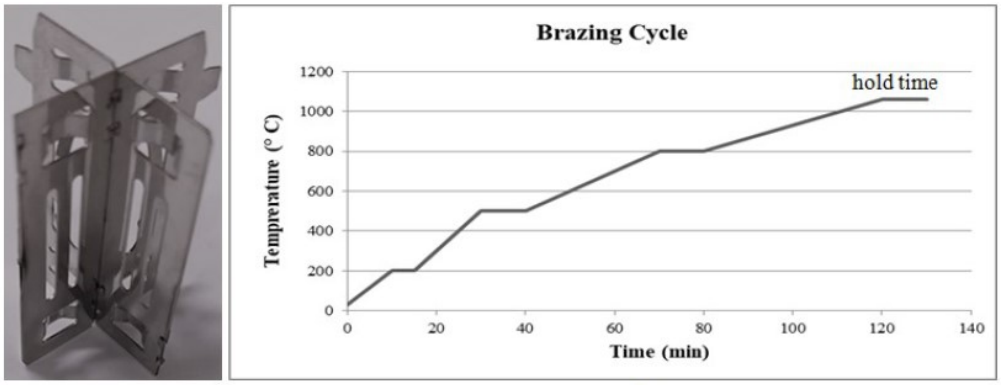

Figure 1: (a) Inconel 718 joint before brazing and (b) Characteristic brazing cycle.

Table II presents the different brazing and cooling conditions used in this study. The joints were brazed under different conditions of temperature, time and cooling. Six (6) specimens were brazed in each condition. The controlled cooling of the furnace was carried out at a rate of 1.5 °C/min up to a temperature of 300 °C and from this temperature, cooling inside the furnace to room temperature, with an average rate of less than 2.0 °C /min. The so-called rapid cooling was performed using argon inert gas at a pressure of 3 bar absolute and with an average cooling rate close to 77 °C/min up to a temperature of 300 °C, from this temperature the cooling was performed inside the furnace with an average rate of 2.0 °C/min.

Table II: List of test specimens brazed under different conditions.

Brazing Conditions	T (°C)	Hold Time (s)	Type of Cooling	Rate (°C/min)
1	950	300	Temperature controlled	1,5
2	950	300	Rapid with argon	77,0
3	950	1200	Temperature controlled	1,5
4	950	1200	Rapid with argon	77,0
5	1060	300	Temperature controlled	1,5
6	1060	300	Rapid with argon	77,0
7	1060	1200	Temperature controlled	1,5
8	1060	1200	Rapid with argon	77,0

The brazed joint samples were prepared by metallography, etched with the chemical reagent Kalling 1 and the microstructure was revealed. Afterwards, the samples were analyzed by optical microscopy (OM) Leitz - Metaloplan microscope, by scanning electron microscopy (SEM) using the semi quantitative technique of energy dispersive spectroscopy (EDS) to map the different regions and identify the elements present in each region. The measurement of the grain size of BM (strip) was performed in both directions (longitudinal and transversal) using the intercept method. The Vickers microhardness test was performed with an automatic Leitz-Miniload microhardness tester with a load of 980 mN and an indentation time of 20 seconds.

3. Results and Discussion

In Figure 2 it is possible to observe the brazed joints under different conditions. In Figure 2(a) the brazed joint at 950 °C and 20 min is observed and in Figure 2(b) the brazed joint at 1060 °C and 20 min, both cooled in a controlled manner at a rate of 1.5 °C/ min. In general, it appears that the conditions used in the brazing were adequate, as no discontinuities were observed, such as lack of fusion and penetration, pores or cracks in the brazed bead.

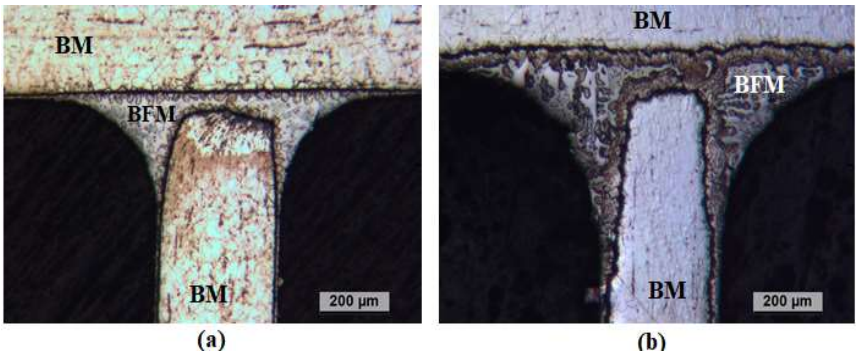

Figure 2: Brazed joint obtained by OM, (a) 950 °C and 1200 s and (b) 1060 °C and 1200 s.

In the brazed joint at 1060 °C (Figure 2(b)), a greater dissolution/erosion of the BM is observed, when compared to the brazed joint at 950 °C. The greater dissolution of the BM transfers to the region of the brazed joint elements of the BM alloy, which form a composite of the same material, proportionally reducing the amount of brittle phases of high hardness, increasing the mechanical resistance.

Time, temperature and chemical composition are the main variables that influence the BM dissolution process. The amount of BFM added to the brazing joint also has a great influence on the dissolution of BM Zhang et al (2004). As mentioned in Brazing Handbook (2003), the amount of BFM applied must be controlled to avoid erosion. A larger amount of BFM increases erosion in BM.

Under these brazing conditions, the geometric reduction of the joint caused by the dissolution of the BM was observed, which causes a reduction in its area and an increase in chemical elements in the joint region, modifying the phase balance in this region. At higher temperatures they facilitate diffusion processes motivated by the creation and migration of defects in the crystal structure resulting in greater atomic mobility of chemical elements present in the region. Elements present in the brazed joint region will form new phases due to greater availability and greater chemical affinity. Despite the greater dissolution in the joint, it had an average strength of 6 kN, indicating that the reduction in joint thickness does not directly influence its mechanical strength.

Figure 3 shows the result of the shear test on brazed joints under different conditions. The graph indicates an increase in load as a function of an increase in temperature. The hold time at the brazing temperature showed a small increase in strength, while the type of cooling did not significantly influence the increase in the mechanical strength of the joint.

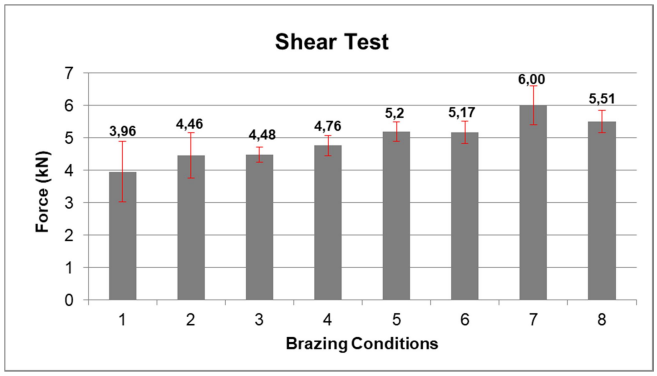

Figure 3: Shear Force.

It is possible to observe that the increase in temperature and time caused an increase in the values of the resistance strength of the brazed joint, when comparing the temperatures of 950 °C and 1060 °C. These results are in agreement with those found by Wu et al (2012), for brazing using a NiCrP-based BFM, in which lower shear strength values were obtained at temperatures of 980 °C, compared to values at temperatures of 1040 °C.

4. Conclusions

The manufacturing conditions of the brazed joints (temperature of 950 °C and 1060 °C, time of 300 and 1200 seconds and the cooling conditions) allowed obtaining joints with complete filling, without the presence of discontinuities in the analysis by visual inspection.

The results of the shear test indicated greater strength of the specimen brazed in a longer time and temperature with controlled cooling compared to the specimen brazed in a lower temperature.

The erosion process didn't affect the mechanical strength of the joint.

Acknowledgements

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