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HIGH TEMPERATURE BRAZING OF INCONEL AND STAINLESS STEEL COMPONENTS FOR A SATELLITE THRUSTER PROPULSION

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Abstract. *To manufacture propulsion systems of satellites it is necessary to develop and qualify special union procedures, such as high temperature brazing and laser or solid state diffusion welds. In particular this work describes the recent experience to qualify a brazing process for aerospace use, specifically for the fabrication of a 5N thruster propulsion system, working with hydrazine as monopropellant, for the multimission platform (PMM) of the Brazilian Space Agency. The brazed components were the capillary tube injector and the capillary tube of the pressure line test ground coupling injector, fabricated in Inconel 600 and austenitic stainless steel AISI 304. The brazing process was realized in high vacuum, lower than* 4.10^{-5} *mbar, at the temperature of 1100°C. Two Ni-based brazing alloys, BNi-1a and BNi-2, as paste and amorphous metallic foil were tested. Joint gap and brazing thermal cycle were adjusted to avoid the presence of intermetallic phases, which occurrence in a brazed Inconel600/BNi-2 union increased the hardness until 1142HV. Wetability and metallographic tests indicate the BNi-1a metallic foil, as the most adequate for this application. Leakage rates lower than* 4.10^{-7} *mbar l/s assured the tightness of the brazed unions.*

Keywords: *High Temperature Brazing, Propulsion Systems, Inconel 600, stainless steel, intermetallics*

1. Introduction

The project of the propulsion subsystem for the multimission plataform (PMM), ordered by the Brazilian Space Agency (AEB), turned imperative the existence in this country of companies able to attend the demand of works of engineering and manufacture for the space sector. The propulsion subsystem has the function to provide the necessary impulse for the PMM after the separation of the launch vehicle and, moreover, it can be used to unload accumulated angular momentum on reaction-wheel controlled spacecraft.

In this scenario the present work describes the initial results of a collaboration congregating the experiences of the Fibraforte Company and Labsolda, the welding laboratory of the Federal University of Santa Catarina. The objective was to qualify for space use the brazing process, used in the manufacturing of 5N hydrazine thrusters. The Fibraforte Company is involved with the development of liquid propulsion components for about seven years, dominating all applied technological processes. It contributed to programs such as the Sub-Orbital Platform (PSO) for which 2N hydrazine thrusters, fill and drain valves and the propellant tank had been supplied; also a 200N bipropellant thruster, with an optimized propellant injection system, was supplied to INPE. The optimized propellant injection system reduces the internal stress in the catalyses bed and creates favorable conditions to use of less mechanical resistance catalytic.

In order to attend to the strict specifications demanded by the PMM project, the propulsion systems must be submitted to an extensive qualification program, that involves manufacturing processes, functional performance, special environment (thermal, vacuum and vibration) and durability tests in rigid operation conditions. In this context it is still necessary to develop and to qualify special manufacture procedures, for laser, electron beam or diffusion welds, which apply more advanced resources and are not so widespread in Brazil. Also the high-vacuum brazing process represents an interesting alternative for union of stainless steel and high temperatures resistant metallic components.

Precious metals filler alloys, as 82Au-18Ni, due to their excelent ductility are commonly fabricated in the form of foil or ring and represent a safe and confortable, although much more expensive choice for this special kind of union. In this work Ni-based filler alloys were applied, whose basic knowledge and brazeability were described in various papers in the 1980's (Lugscheider and Iversen, 1980, Bose, Datta and DeCristofaro, 1981, Lugscheider and Partz, 1983, Lugscheider and Pelster, 1983, Rabinkin, 1989). Due to their high metalloids content, the use of the Ni-alloys requires a more strictly control of the process parameters, in order to avoid intermetallic precipitation and consequent brittleness of the joint.

2. Materials and Experimental Procedures

2.1 Filler metal composition and application form

The brazed components were the capillary tube injector and the capillary tube of the pressure line test ground coupling injector, fabricated in Inconel 600 and austenitic stainless steel AISI 304 (figure 1). Two Ni-base brazing alloys, BNi-1a and BNi-2, as paste and amorphous metallic foil were tested. Their nominal composition according to AWS is given in table 1. The employed metallic foils von Metglas / Allied Chemical are 20 µm thick. The filler metals in form of paste consisted of i) commercial BNi-2 paste from Degussa; ii**)** BNi-1a powder mixed in Labsolda with a commercial white glue as binder agent. It was also tested the application of BNi-2 braze powder (Firma Vitta) plus ethyl alcohol as binding agent.

The application of the filler metals in form of pastes requires that the base metal components had to be beveled in an angle of 45^o, what was unnecessary by the application of solid filler metal. In this case small foil discs with 5 mm in diameter were previously punched and the so straight bored discs could than be applied as "rings" around the capillary tube (figure 2a). Prior to brazing, the base components were cleaned in an ultrasonic bath of acetone. After cleaning the components, as visualized in figure 2b, were manipulated, during assembling and positioning in the furnace, only with gloves or pinch, to avoid any oil or grease contamination.

Preliminary coating brazing tests were performed with both filler alloys (BNi-1a and BNi-2) on discs in the dimensions of 40 mm diameter and 5 mm thickness of the base metals AISI 304 and inconel 600. The degree of wetability for each system was visually evaluated. For the joining brazing tests a special auxiliary device was fabricated bei Fibraforte in steel 304. Figure 3 illustrates the assembling and the components after brazing.

tube injector	coupling injector

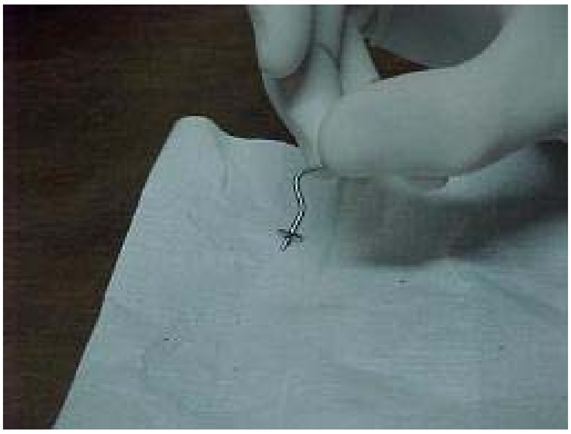
Figure 1- Capillary tube injector and the capillary tube of the pressure line test ground coupling injector

Table 1: Nominal composition of AWS B-Ni filler metals

Filler metal	Chemical composition (weight %)					
	Cr	B	Si	Fe	C	Others
BNi-1a	13,0 -15,0	2,75 - 3,5	4,0 - 5,0	4,0 – 5,0	0,06	0,5(max)
BNi-2	6,0 – 8,0	2,75 - 3,5	4,0 - 5,0	2,5 - 3,5	0,06	0,5(max)

2.2 Thermal cycle and brazing atmosphere

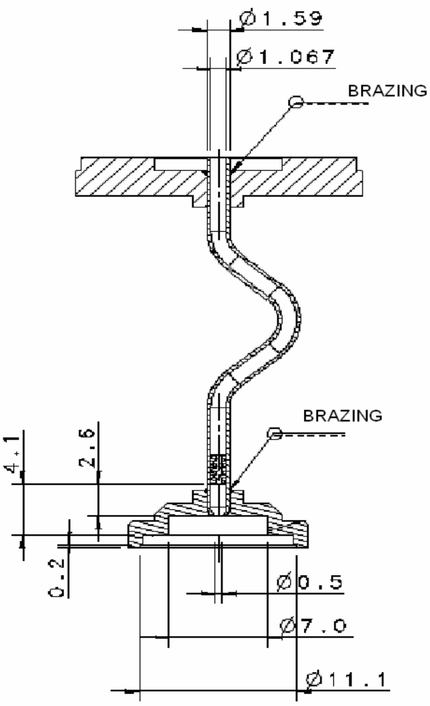
The brazing tests were performed at the temperature of 1100°C in a resistance heated furnace under a vacuum atmosphere better than 4.10^{-5} mbar. The recommended brazing cycle with the respective solidus-liquidus temperatures for the BNi-alloys is given in table 2. The thermal cycle, selected to satisfy the conditions for both filler metals, consisted of one soaking step prior to stabilization at the brazing temperature, respectively 930°C/10' e 1100°C/20' (Figure 4). The heating rates until the soaking and brazing temperature achieved 280°C/h. Cooling rate was controlled until 900°C at a rate of 180°C/h.



a

b

Figure 2 - a) capillary with filler metal foil in form of straight bored disc; b) brazing components after ultrasonic cleaning in acetone bath.



a

b

Figure 3 a) schematic of brazing components; b) capillary joints in auxiliary device after brazing

Table 2: Solidification interval and recommended temperature range for Ni-base filler metals.

Alloy (AWS)	Solidification interval (°C)		Brazing range (°C)
	Solidus	Liquidus	
BNi-1a	977	1077	1077 - 1205
BNi-2	971	999	1010 - 1180

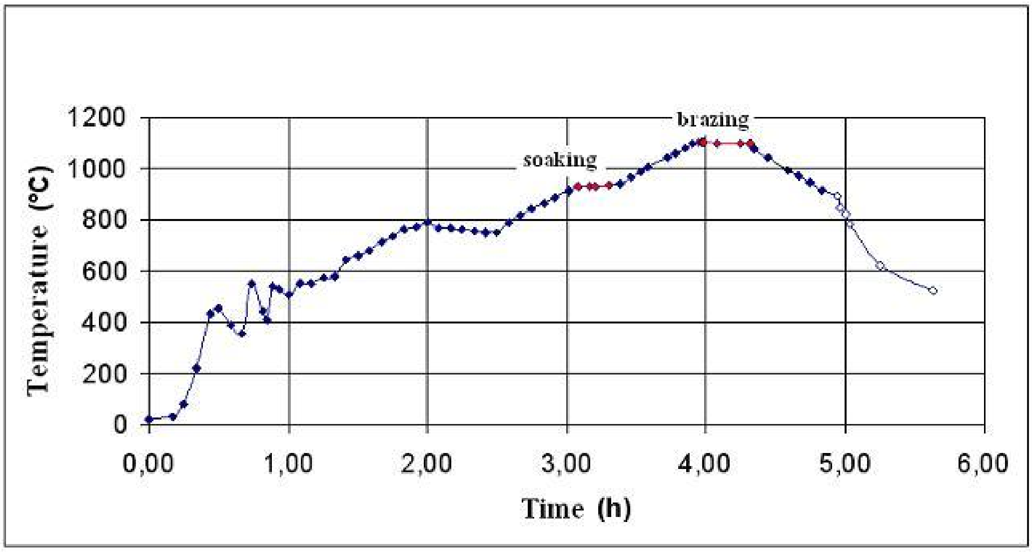


Figure 4 - Brazing cycle

2.3. Microstructural analysis and characterization tests

Microstructural characterization of the coating and joint brazes took place by optical microscopy using a Olympus microscope connected to a digital image acquisition system. To that end, samples were sectioned using a diamond blade and mounted in cold setting polyester resin. Next, the joints were ground using SiC paper (sequence 220, 320, 500, 800, 1000 mesh) and polished in diamond solution (1µm) and alumina slurry 0.1 µm. Vickers microhardness measurements were made in Shimatzu equipment with the load of 200 g.

Leakage tests were carried out using a Edwards Spectron 3000 helium leaking detector. These tests consisted in blasting He onto the outer region of joints placed under vacuum and measuring the mass of helium that penetrated the joint using a spectrometer. The leakage tests were done at the “Integration and Tests Laboratory” (LIT) of Brazilian National Spacial Research Institute (INPE).

3. Results and Discussion

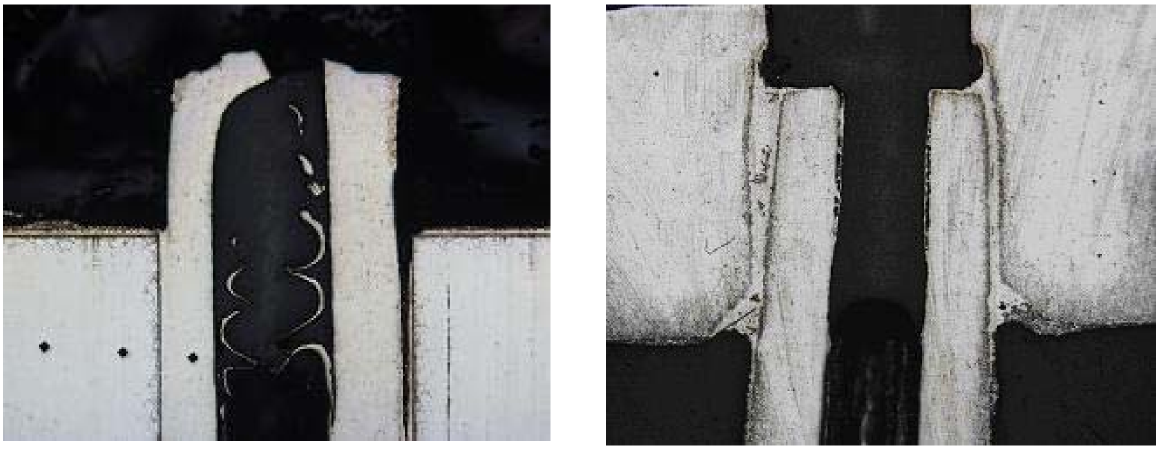
3.1 Observations about wetting and the presence of intermetallics

The BNi-1a and BNi-2 filler metals have good wetability, as the brazing coating tests resulted in low contact angles on stainless steel or inconel base materials, so that alone according to this criteria these alloys could be indistinctly applied for brazing both substrates. Further observation indicated in samples coated with BNi-1a an homogeneous microstructure and low hardness, in the range from 180 to 230HV, what means little higher than that from the original base metals (142 and 144HV, respectively for stainless steel and inconel.)

Nevertheless a distinct microstructural behavior was verified in samples brazing coated with BNi-2, where in regions containing coarse intermetallics crystals higher surface hardness values were detected: in the range between 275 and 356HV for stainless steel and until 805HV for inconel. These results indicated the system BNi-2/inconel as closer temperature dependant and so the alloy BNi-1a as a better filler metal for the applications in view.

Preliminary joints brazing tests revealed the strong influence that an inaccurate preparation procedure, i.e. poor dimension control of the parts has on the incidence of failures and so on the final quality of the union. Figure 5 show typical examples of defects associated with an excessive brazing-gap width: a) lack of filling due to failed parallelism and also probably low amount of filler metal BNi-1a applied as amorphous foil; b) stabilization of intermetallics and high hardness (716HV) in the central region of the seam. The local gap of 160µm was well above the critical brazing clearance for the couple BNi-2/stainless steel, which lies in the order of 50 µm (Lugscheider 1980, Dorn 1985)

Figure 6 is a detail of the system stainless steel/BNi-1a/inconel (lower part of joint in figure 5a), where the gap achieved 65 µm and besides brittle phases (silicides and borides) stabilised in the ductile nickel-base filler metal solid solution, also inter- and transcristaline precipitation occurred in the transition zone from seam to base material. Particularly for stainless steel the grain growth is evident near the seam, where the grain borders were penetrated by liquid constituents of filler metal: boric compounds can be found even in the interior of grains, as previous reported (Lugscheider and Partz, 1983 and Sakamoto et al, 1989). As illustrated in figure 7, along the capillary seam the Ni-base solid solution has low hardness and is essentially free from second phases.



a b

Figure 5 - Failures associated with excessive brazing gap: a) lack of filling / BNi-1a applied as foil; b) stabilisation of intermetallics in central zone of seam / BNi-2 paste . (50X)

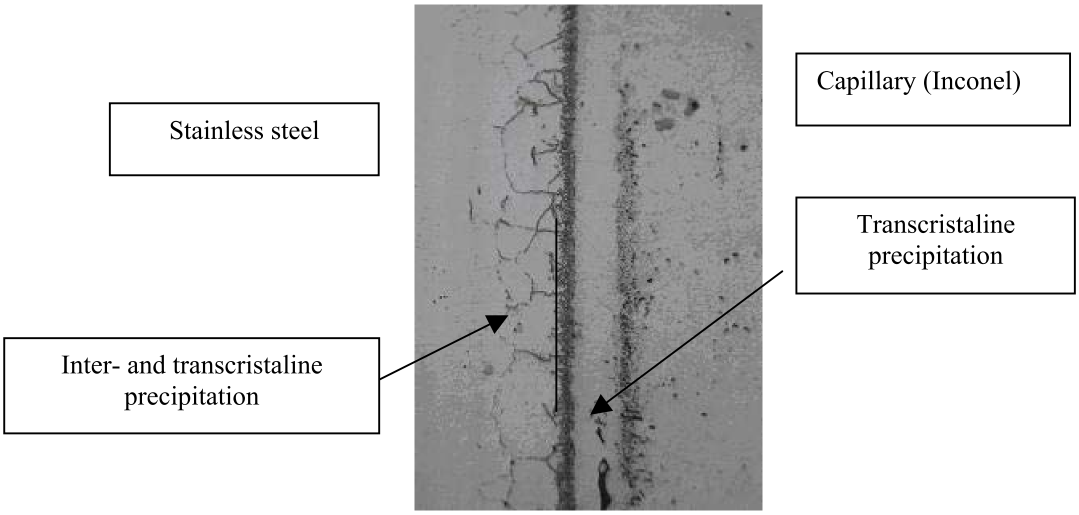


Figura 6 – Brazing system stainless steel/BNi-1a/inconel (200X).

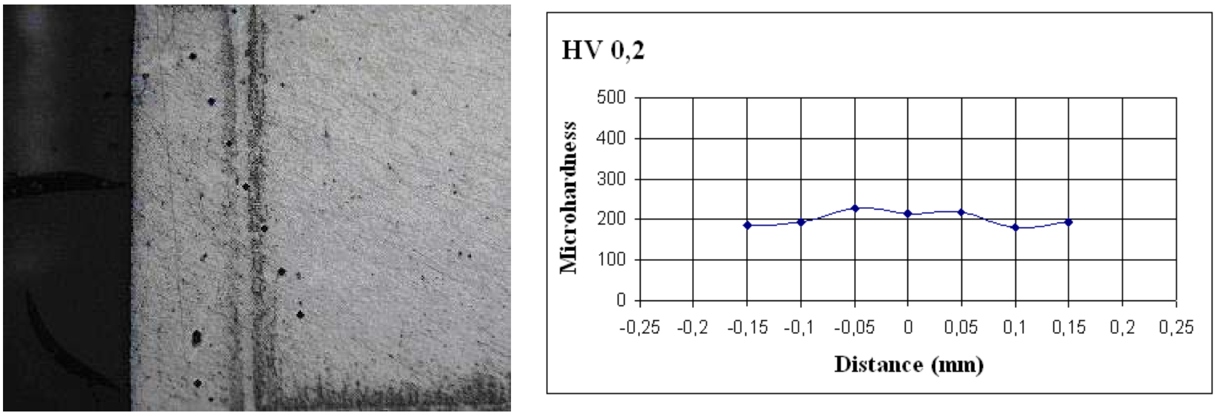


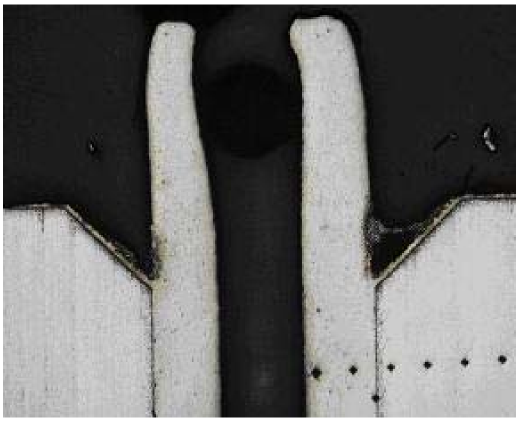
Figure 7 - Detail of capillary seam (left /100x)brazed with BNi-1a foil showing low hardness profile (right).

3.2. Selection of filler metal application form for capillary brazing joints

The above described results imposed more strict requirements on the preparation procedures and a second series of test was performed, where the gap clearance was maintained under 50 µm in order to avoid the stabilization of brittle intermetallics. In the purpose of selecting the best application form, the filler metals BNi-1a and BNi-2 were tested in 4 different states.

3.2.1. Brazing with BNi-2 (powder + ethyl alcohol as binding agent)

The poorest experience was with the filler metal BNi-2 as powder and ethyl alcohol as binding agent. Alcohol proved to be an inadequate carrier, the mixture was much more difficult to handle than a paste. Besides that, because of the packing characteristics and lower density of powders care must be taken in estimating the filler metal volume. Low amount of filler metal could explain the extensive lack of filling in Figure 8, where the gap size was below 18 µm. Further the same figure shows the localized erosion of base material (inconel tube) in inferior part of the bevel, which is an indication of the low level of melted powdered filler metal.



50X

Figure 8 - Filler alloy BNi-2 applied as powder with ethyl alcohol: lack of filling and erosion of base metal

3.2.2. Brazing with pastes

Better results were achieved by the application of the filler metals as pastes, as illustrated in figures 9a-d, for BNi-1a (applied as powder plus a commercial white glue as binder agent) and BNi-2 (commercial paste from Degussa). Although in both cases the wetting was very good, the BNi-2 paste has a better capillary gap-filling ability, what can be expected from its lower melting range (table 2). An indication of lack of filling (figure 9a) was verified by the BNi-1a . Although in the accumulated amount of filler metal inside the 45º beveled joint the presence of intermetallics is evident, the brazing seams were free from brittle phases. A maximum hardness of 1142 HV could be measured on a coarse crystal precipitated in the very softer BNi-2 matrix (192 HV), while for the BNi-1a these values were respectively 684 and 267 HV.

3.2.3 Brazing with amorphous BNi-1a foil

Excellent results were obtained by the application of filler metal BNi-1a as amorphous foil. The capillary gap filling was complete and as illustrated in figure 10, the use of solid filler metal has the additional advantage that the beveling of joints turns unnecessary. It is important to note that the brazed seam has low hardness and is essentially free from brittle phases, which are stabilized only around the superior neck of the joint, what can be acceptable for most applications. With respect to the amount of filler metal, complete filling was verified by the application of for 4 discs of BNi-1a foil.. Although in the case of 2 discs of filler metal small indications of uncompleted filling were visualized, the joints had an excellent performance and were qualified in the sealing tests. These results are reproduced in table 4.

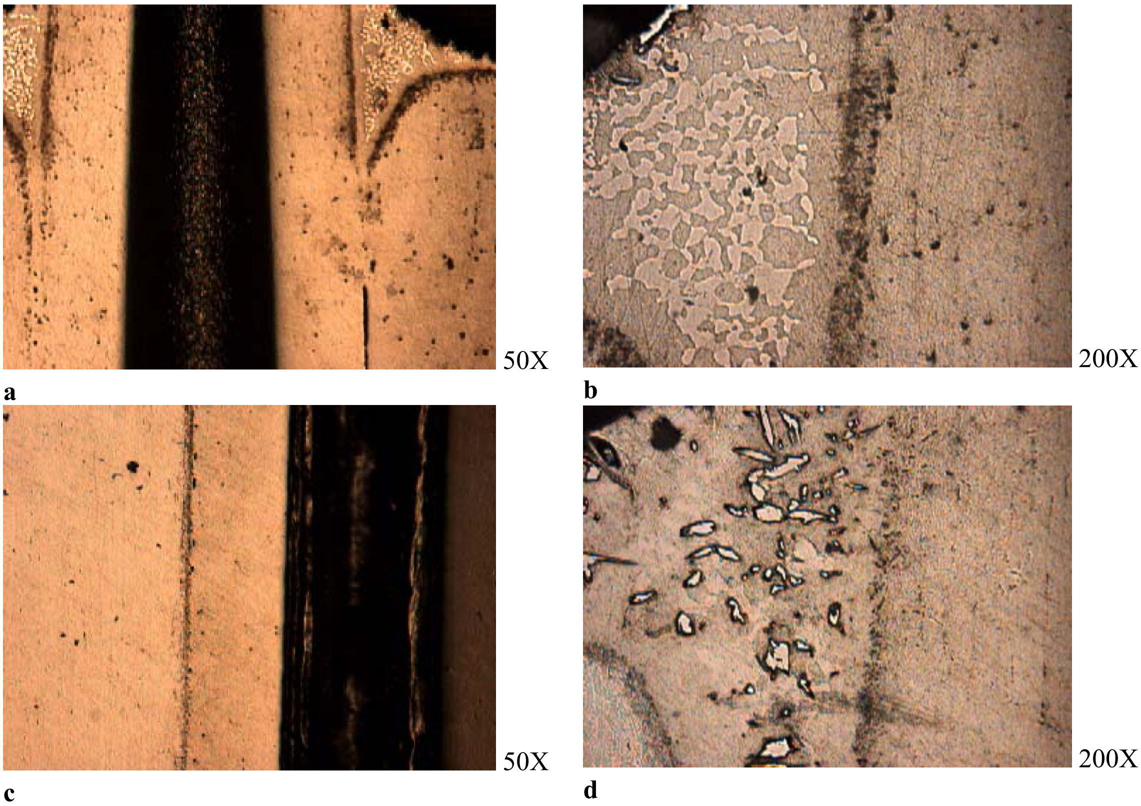


Figure 9 - Typical microstructure of brazed capillary joints with filler metal as paste: BNi-1a (a and b) and BNi-2 (c and d).

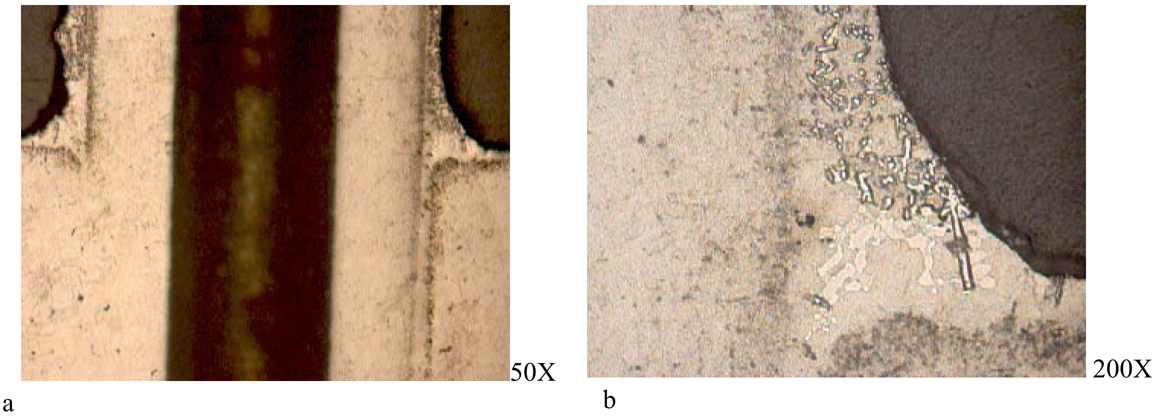


Figure 10 - Brazing with amorphous BNi-1a foil : a) complete capillary gap filling ; b) hard phases around superior neck of the joint.

Table 3 – Leakage Tests Results

	Specimen brazed with *paste BNi-2*	Specimen brazed with *metallic foil BNi-1a*
Detector Sensibility	0,20 x 10^{-9}mbar.l/s	0,20 x 10^{-9}mbar.l/s
Pressure in Specimen	8,00 x 10^{-3}mbar	7,00 x 10^{-3}mbar
Leak Rate	2,45 x 10^{-7}mbar.l/s	4,05 x 10^{-7}mbar.l/s
Atmospheric Pressure	949 mbar	949 mbar

4. Conclusions

Both filler metals BNi-1a and BNi-2 have good wetability on the base metals AISI 304 and inconel 600, as verified in coating and in capillary joint brazing tests.

The metallographic examination and the results of leakage tests qualify brazing joints for both filler metals.

With respect to the stabilization of intermetallics the system BNi-2/inconel was closer temperature dependant, as the precipitation was more extensive and associated with higher hardness on the braze.

The application of BNi-1a as metal foil was the better alternative, as the use of solid filler metal has the additional advantage that the beveling of joints turns unnecessary.

Furthermore, the thrusters manufactured with the brazed injectors has been already submitted to firing tests and had not presented any problems. In total the thrusters operated in firing tests four times longer than the expected life time of the mission.

5. Acknowledgements

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6. References

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