FILLER MATERIALS FOR BRAZING WIDE CRACKS IN IN738 SUPERALLOYS

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Abstract

We report the results of a complex microstructural study of four selected filler materials to achieve efficient reparation of wide cracks in surface of IN738 superalloys. Filler materials studied were represented as a mixture of special metallic powder/paste and powder of Ni-base alloys. One of the mixture components has a low melting point, so that it will melt during the process ensuring good isothermal brazing. The filler material with the better adhesion to the substrate and microstructure was chosen to repair a wide crack on the surface of IN738 superalloy, with further study of the mechanical properties of the joint trough hardness measurements. The optimized compound displayed greater hardness of filler material in comparison with superalloy base, which is indicative of a strong metallurgical union between them. The suggested procedure by vacuum brazing allows achieving better repair for the case of wide cracks, which are difficult to handle with conventional techniques. In the similar way, one can also perform complete refurbishment of large surface area, which may be particularly useful in the large industrial gas turbines that contain many components manufactured of superalloys.

Keywords: Brazing, Ni-base superalloys, Gas turbines, IN738, Filler material.

Introduction

Industrial gas turbines require use of several types of superalloys to ensure stable operation under the aggressive environment, including high temperature and pressure. The materials used thus should feature superior mechanical properties, excellent stress resistance, hardness, ductility and resistance to high temperature corrosion [1]. Ni-based superalloys IN738 and IN939 are commonly mentioned as materials meeting these requirements, so that they found a pronounced application in blades and vanes for the gas turbines. These superalloys are obtained by precipitation hardening from γ' phase $Ni_3(Al,Ti)$ and MC type carbides. However, during the welding process IN738 suffers from micro-cracking in the zones affected by welding heat, resulting in precipitation and grain boundary liquation during [2,3]. These problems also appear for the other γ'-derived alloys with Al + Ti content exceeding 3 wt% [4]. Under operation in a gas turbine, one can also observe dimensional reduction of component thickness caused by erosion, sulfuring, oxidation, high

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temperature corrosion, damage by extraneous objects or a combination of all these factors. As soon as cracks and other surface defects are formed, they may eventually widen and propagate due to thermal fatigue effects.

Therefore, it is a timely and important task to optimize the parameters of repair materials used in brazing, aiming to increase the useful lifetime of turbine components, at the same time reducing production and/or acquisition costs associated with their replacement. Taking into account that IN738 and IN939 superalloys are susceptible to cracking if exposed to extremely high temperatures (such as those of welding process), which makes low-temperature brazing more attractive as an alternative effective technique to repair these components. To decrease melting point even more, brazing alloys are usually added with B or Si [5-7]. The common brazing process relies on wettability and ductility of the liquefied filler, which is generally sufficient to fix minor defects and narrow cracks. However, repair of a large surface defects poses another type of a problem, as generally-used methodology is insufficient in treatment of a damage extending beyond a certain size. On the other hand, the inter-diffusion of alloying elements between the base and the filler material, especially transmission of melting point depressants from the liquid into the base alloy causes composition change and subsequent isothermal solidification in the welded joints. In a contrast to the conventional process, one can apply increased holding time to carry out a proper solidification of transient liquid with phase bonding, avoiding formation of a brittle phases.

In addition, the brazing technique is highly tolerant to the presence of faying surface oxide layers, being free of common defects associated with fusion welding [8-10]. Due to this, diffusion brazing evolved into a successful and cost-effective alternative joining technique for industrial gas turbine components made from weld-sensitive alloys like IN738. In order to ensure the required properties to the joint, it is important to form the appropriate microstructure, which, in turn, depends significantly on inter-diffusion of the elements at the metallurgic boundary. This process can be significantly improved with proper optimization of diffusion parameters and proper choice of filler alloy. In summary this paper is dedicated to the solution of the aforementioned problems. We report the results of comparative analysis of four filler materials with different composition and structure, compounded with detailed investigation of microstructural and mechanical properties of the resulting repairs of IN738 matrix.

Experimental procedure

Filler materials were prepared by mixing IN738 alloy powder with commercial brazing alloys NB160, DF4B, DF3-325 (powder) and NB160 (paste). These materials are recommended for brazing of Ni-base superalloys for refurbishing cracks 0.12-0.25 mm wide. In this work the wt% of the mixture can be calculated by equaling their specific contact surfaces (SCS):

$$SCS_1 = 4/(\rho \cdot W), \tag{1}$$

$$SCS_2 = 0.75(1-B)/(\rho \cdot r \cdot B). \tag{2}$$

Here ρ and r are the density and the radius of the particles, W is crack width and B stands for composition of the brazing alloy. Each brazing mixture was prepared during one hour using Retch high energy planetary mill (model PM200) at 250 rpm, changing the rotation direction every 15 min. To determine the optimal temperature range for brazing process, differential thermal analysis (DTA) was made for each mixture with TA Q600 equipment (Thermal Analysis Co., USA). The DTA process included heating with 5 °C/min rate in Pt crucible, comparing the results with a reference Al_2O_3 sample. A commercial liquid binder (Nicrobraz-S, WallColmonoy Co.) was used as a binding agent for the powder. This binder volatilizes during the thermal cycle at approximately 540°C. The brazing mixture was placed over IN738 substrate and subjected to brazing process in a vacuum furnace (0.05 Torr) following the thermal cycle schematically depicted in Figure 1. After brazing, the plate was cut into samples, which were prepared by conventional metallographic techniques. Microstructural examination was conducted on Jeol JSM-6490 LV scanning electron microscope (SEM), equipped with Oxford electron dispersive spectrometry (EDS) system and INCA software. The hardness measurements were performed with Clemex CMT.HD equipment which is fully compliant with ASTM E-384 and DIN/ISO 6507 standards. For each sample, we carried out 20 measurements with 500gf (10 sec each) for the area covering both filler and base metal. The chemical compositions and properties of filler materials are summarized in Table 1. The mixture proportion and temperature of brazing process are presented in Table 2.

Table 1. Nominal chemical composition and properties of the filler materials.

Filler Material	**Chemical Composition (Wt %)**														**Density (g/cm^3)**	**Average Particle size (µm)**
	Ni	**Cr**	**Fe**	**Si**	**B**	**C**	**Co**	**Ta**	**La**	**Y**	**Al**	**W**	**Mo**	**Ti**		
NB160	Bal	11.0	3.5	3.5	2.3	0.5	-	-	-	-	-	-	-	-	7.8	20.2
DF3-325	Bal	20.0	-	-	3.0	-	20.0	3.0	0.1	-	-	-	-	-	10.4	14.4
DF-4B	Bal	14.0	-	-	3.0	-	10.0	2.5	-	0.1	3.5	-	-	-	4.5	65.8
IN738	Bal	16.0	-	-	-	-	8.5	1.8	-	-	3.5	2.6	1.7	3.5	9.9	10.1

Table 2. Mixture ratios for filler materials and brazing temperature.

Mixture of filler materials	**Calculated mixture ratio (Wt %)**	**Binder contents (Wt %)**	**Brazing temperature (°C)**
IN738/DF-4B	64/36	8.0	1150
IN738/DF3-325	35/65	8.0	1190
IN738/NB160	39/61	8.0	1160
IN738/NB160 Paste	50/50, 40/60, 30/70, 20/80	0.0	1160

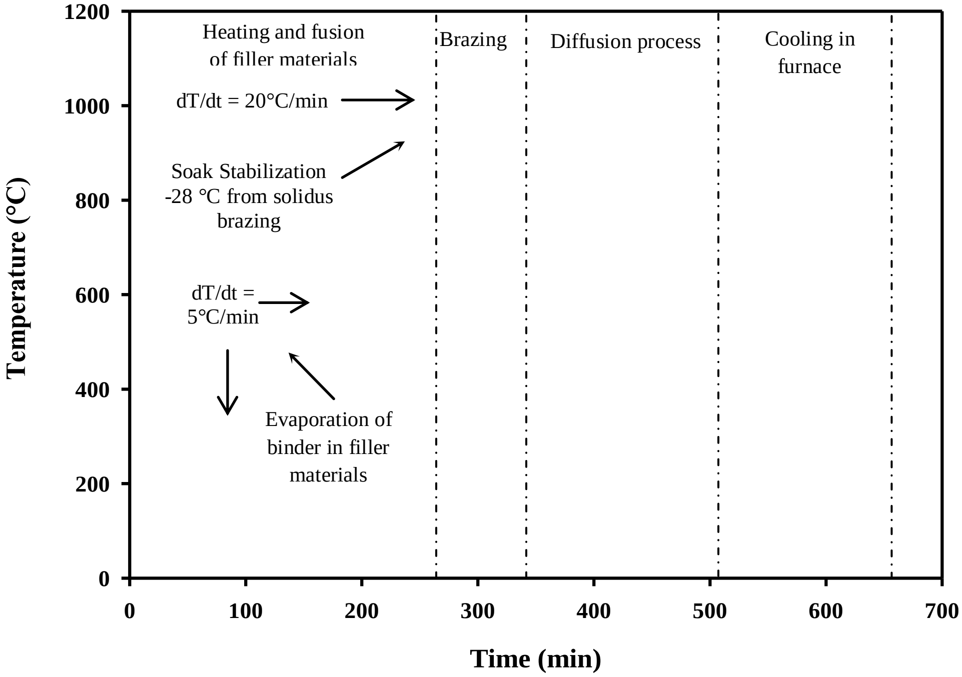

Figure 1. Schematic thermal cycle used for brazing.

Results

Thermograms obtained by DTA for each brazing composition are shown in Fig. 2, giving a clear and accurate indication of melting point for the filler materials. The exothermic peaks characteristic to liquidus state of the mixture can be useful to estimate the optimal temperature range for brazing. As NB160 filler metal contains Fe, Si, B and C acting as depressants of melting point, its DTA curves allow to observe the temperatures with the eutectics related starting elements begins melt compared to DF-4B which only contain B and DF3-325 which contain B and Al. Phase reactions play a crucial role in many aspects of the processing and service of high-strength nickel-base superalloys. As it can be seen in Figure 2(c); Al, Si and Fe forms eutectics reactions between them at temperatures between 800 and 950°C.

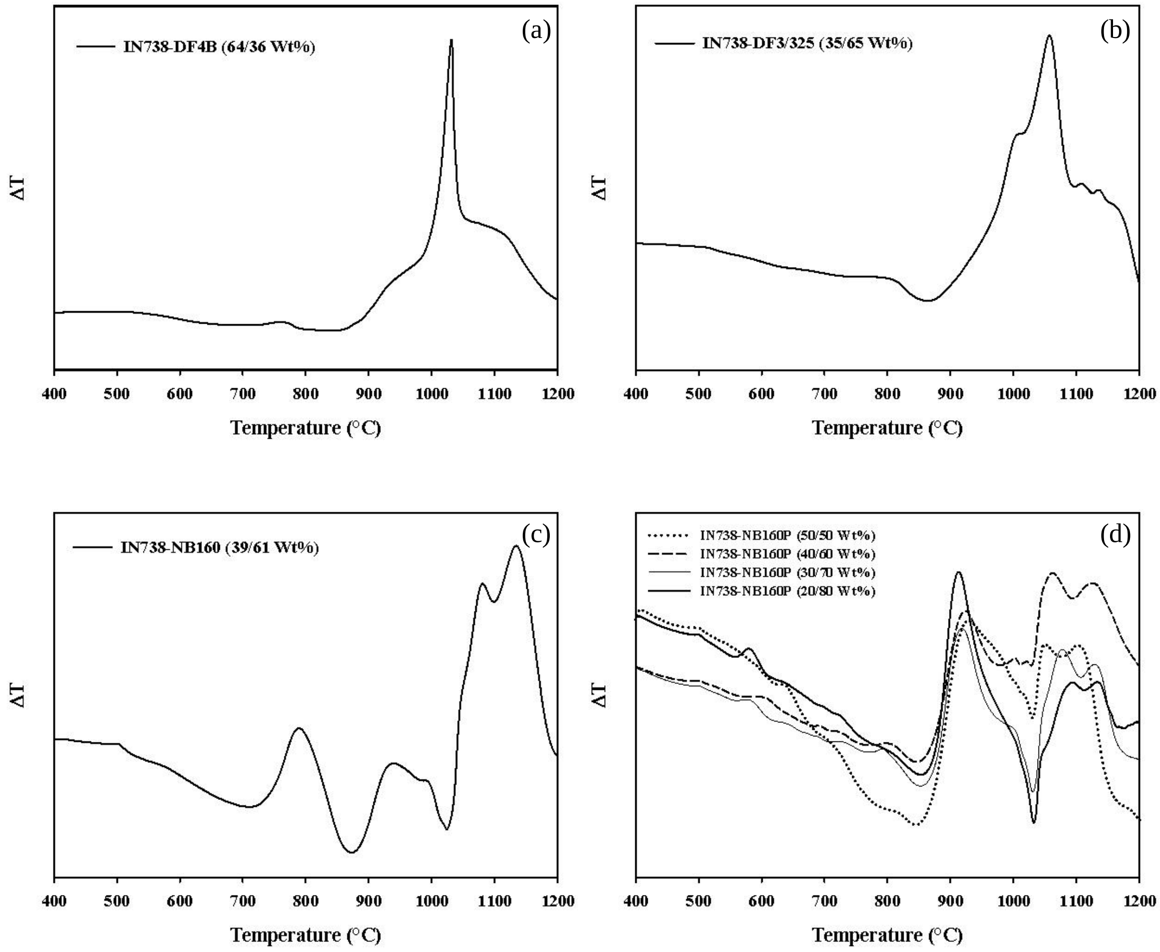

Figure 2. Differential thermal analysis curves for the mixtures of filler materials: (a) IN738/DF4B, (b) IN738/DF3-325, (c) IN738/NB160 and (d) IN738/NB160 Paste.

Figures 3 to 6 shows cross section photomicrographs of different mixtures of filler material after brazing process. In the case of IN738/DF4B mixture (Fig. 3) it can be seen that the boundary between the filler material and base metal is homogeneous and clear, without any traces of diffusion; it is hard to determine the exact extent of the reaction area. Some porosity can be noted at the interface between the metals. The EDXS spectrum revealed four main phases characteristic to the filler materials, which are listed in Table 3. Rich chromium boride phase, dispersed over the whole microstructure (Fig. 3.A), can be found as formations of different sizes. Other Cr-rich phase, containing considerable amount of W, is formed from IN738 additive metal. The matrix microstructure of Ni-base solid solution with two lighter globular morphological features marked C and D. Fine white particles (phase E) rich in Ta are scattered through the microstructure are probably introduced from filler material.

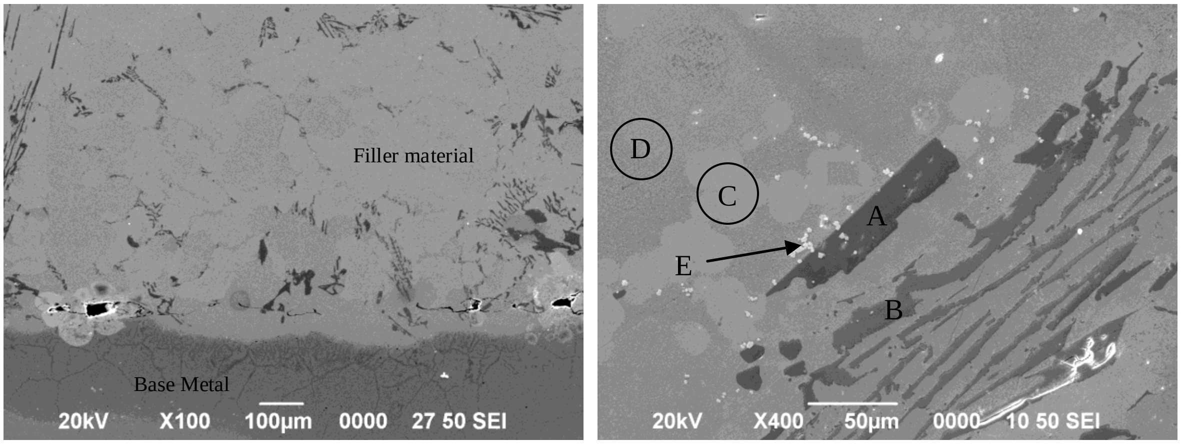

Figure 3. Photomicrographs of IN738/DF4B powder mixture showing main phases in filler material after brazing process.

Table 3. Average chemical composition of the main phases in IN738/DF4B mixture.

Phase	**EDXS average chemical composition (Wt%)**									
	Cr	**Co**	**Ni**	**Mo**	**W**	**C**	**Al**	**Ti**	**Ta**	**Nb**
A	74.56	4.56	4.59	9.12	7.17	-	-	-	-	-
B	76.29	3.24	4.12	-	16.36	-	-	-	-	-
C	2.88	6.36	70.02	-	-	4.02	5.10	5.38	6.25	-
D	8.76	13.96	71.99	-	-	-	1.39	3.89	-	-
E	1.69	-	7.33	-	4.33	7.67	-	15.98	57.95	5.05

As the chemical composition of DF3-325 filler material is almost similar to that of DF4B, it is natural to expect that the phases formed after solidification would yield related results (see Fig. 4 and Table 4). The DF3-325 filler shown moderate adhesion to the substrate, and also some porosity was observed at the interface.

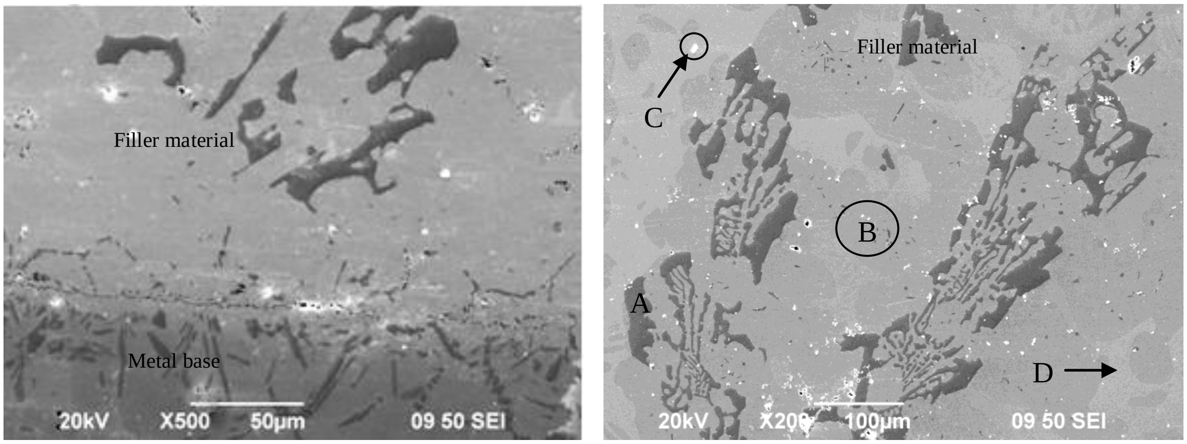

Figure 4. Microstructure of IN738/DF3-325 mixture filler material

Table 4. Average chemical composition of the main phases in IN738/DF3-325 mixture.

Phase	**EDXS average chemical composition (Wt%)**									
	Cr	**Co**	**Ni**	**Mo**	**W**	**C**	**Al**	**Ti**	**Ta**	**Nb**
A	81.77	5.48	4.61	3.18	4.95	-	-	-	-	-
B	16.61	17.27	62.01	-	-	-	1.44	0.53	2.13	-
C	1.87	-	8.34	-	4.12	8.52	-	16.54	55.66	4.95
D	6.10	19.67	69.96	-	0.84	-	-	3.43	-	-

To study NB160 filler material, it was decided to use EDXS analysis of the samples to reveal the interface between IN738 substrate and filler material in more detail. Figure 5 shows two main microstructure phases obtained with IN738/NB160 filler material. As it is evident from the spectra, the main phase in this filler material is the base Ni solid solution (A) with dark and blocky inclusions of boron carbide (B). The reaction zone is not very clear in the phoromicrographs, while faint porosity can be visible at the interface. The matrix material also contains Al, Si and Fe, as it follows from EDXS data

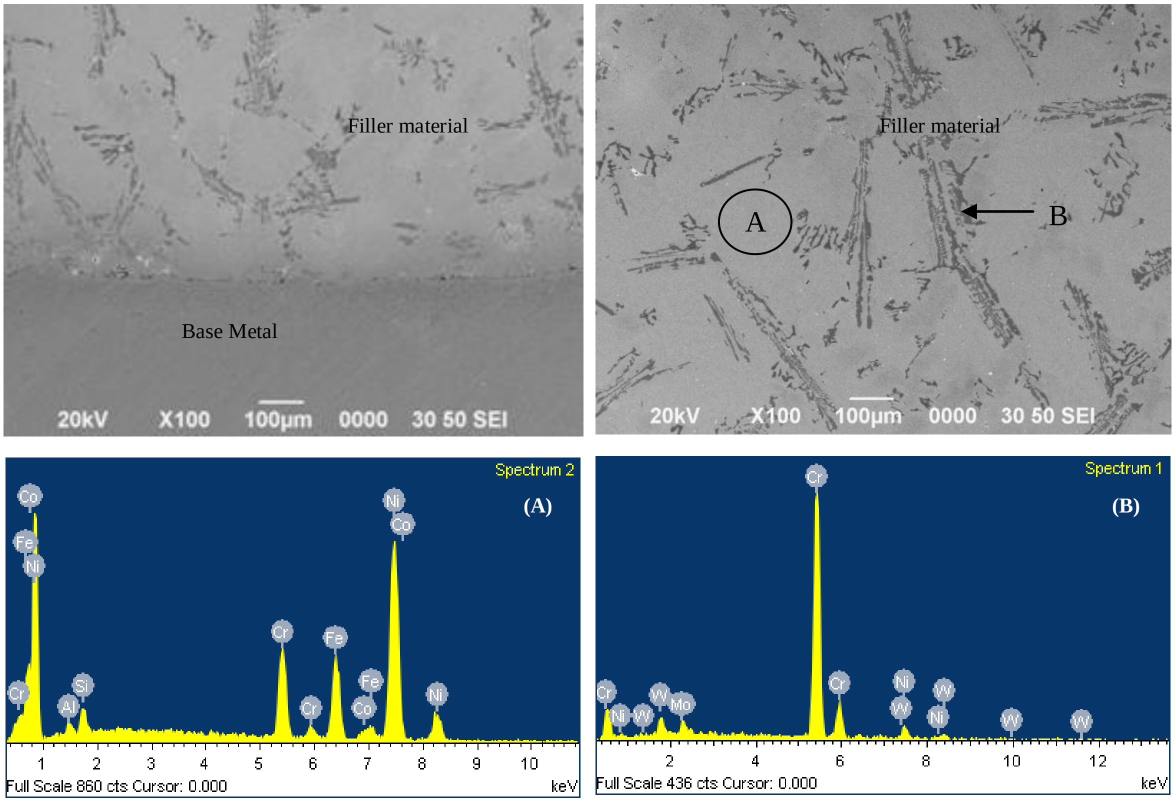

Figure 5. Photomicrographs of IN738/NB160 powder mixture and EDXS spectra of two main phases in the filler material microstructure.

Figure 6 presents microstructure of IN738/NB160 with paste, showing the same phases as those illustrated in Fig. 5. In contrast to previously discuss with other filler materials; in this case one can clearly see the reaction zone some 100 µm thick at the interface between base metal and filler, which is predominantly containing boron carbide. The filler material in a form of a paste definitely performed better in preventing porosity at the interface, resulting in more homogeneous microstructure. Therefore, we have chosen this material to make a test repair of a large crack (about 1.6 mm wide) in IN738 substrate. To optimize the process, the filler mixture was prepared in four different component proportions. The resulting microstructures are shown in Figure 7. As one can see, the wettabilty phenomena improve with increasing contents of NB160, which has a positive effect on obtained at the interface. Evidently, the best mixture ratio is 20/80 Wt% (IN738/NB160P).

Finally Figure 8 show hardness profile measured for 20/80 Wt% (IN738/NB160P), confirming that filler material has greater hardness in comparison to the base metal, which is indicative of a strong metallurgical union between them.

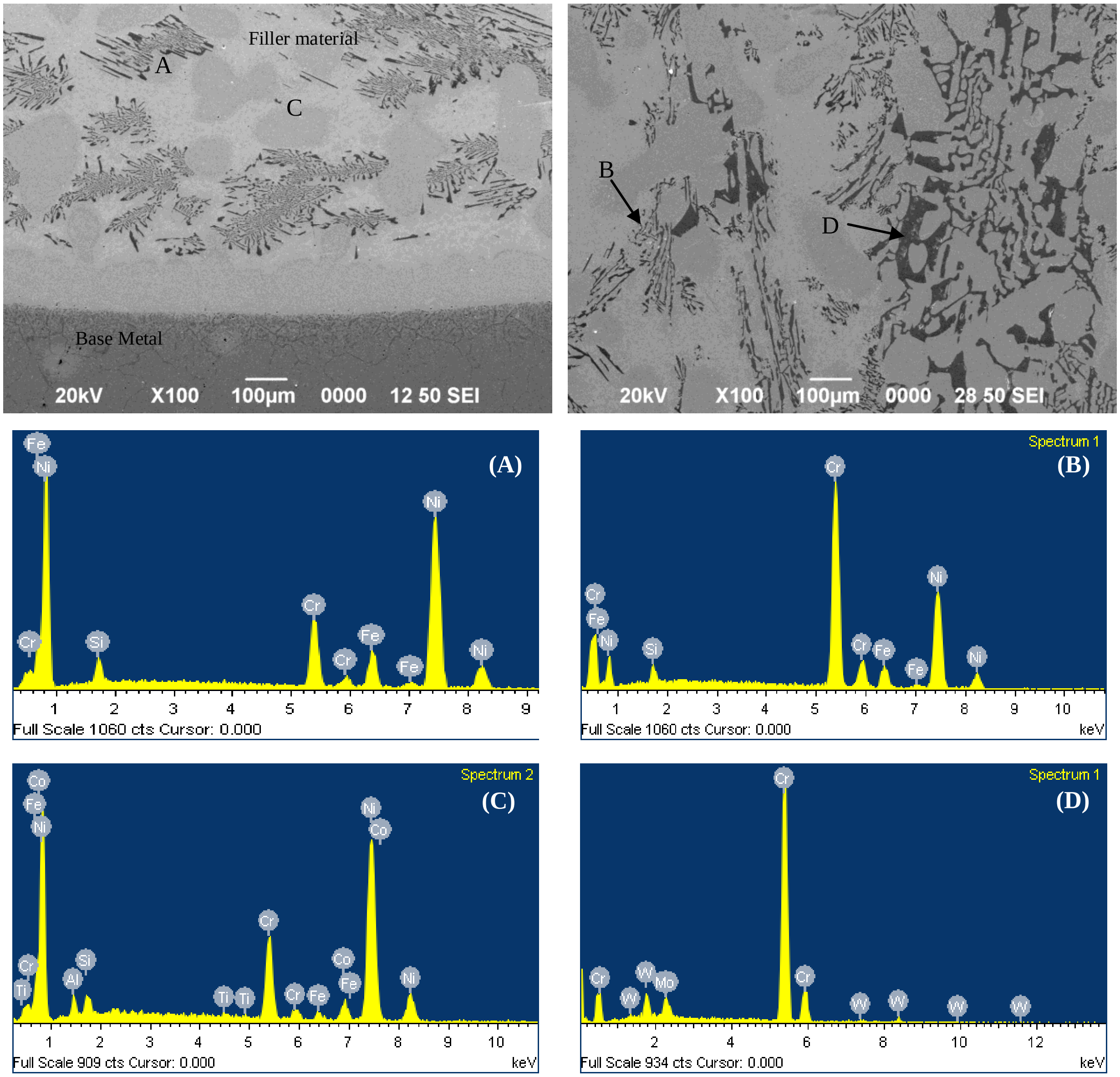

Figure 6. Photomicrographs of IN738/NB160 Paste mixture and EDXS spectra of two main phases in the filler material.

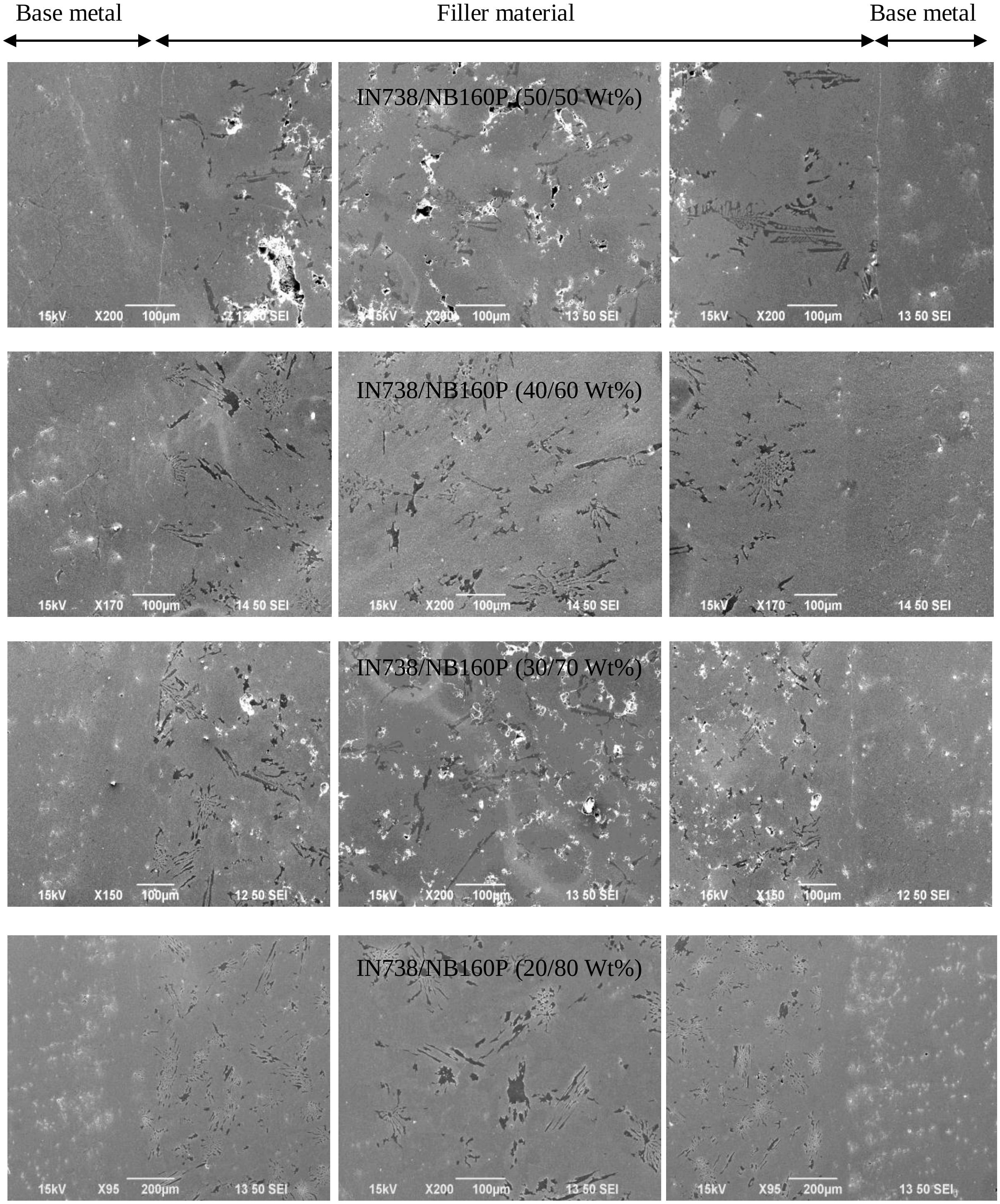

Figure 7. Cross section microstructure of IN738/NB160 Paste filler material of different composition.

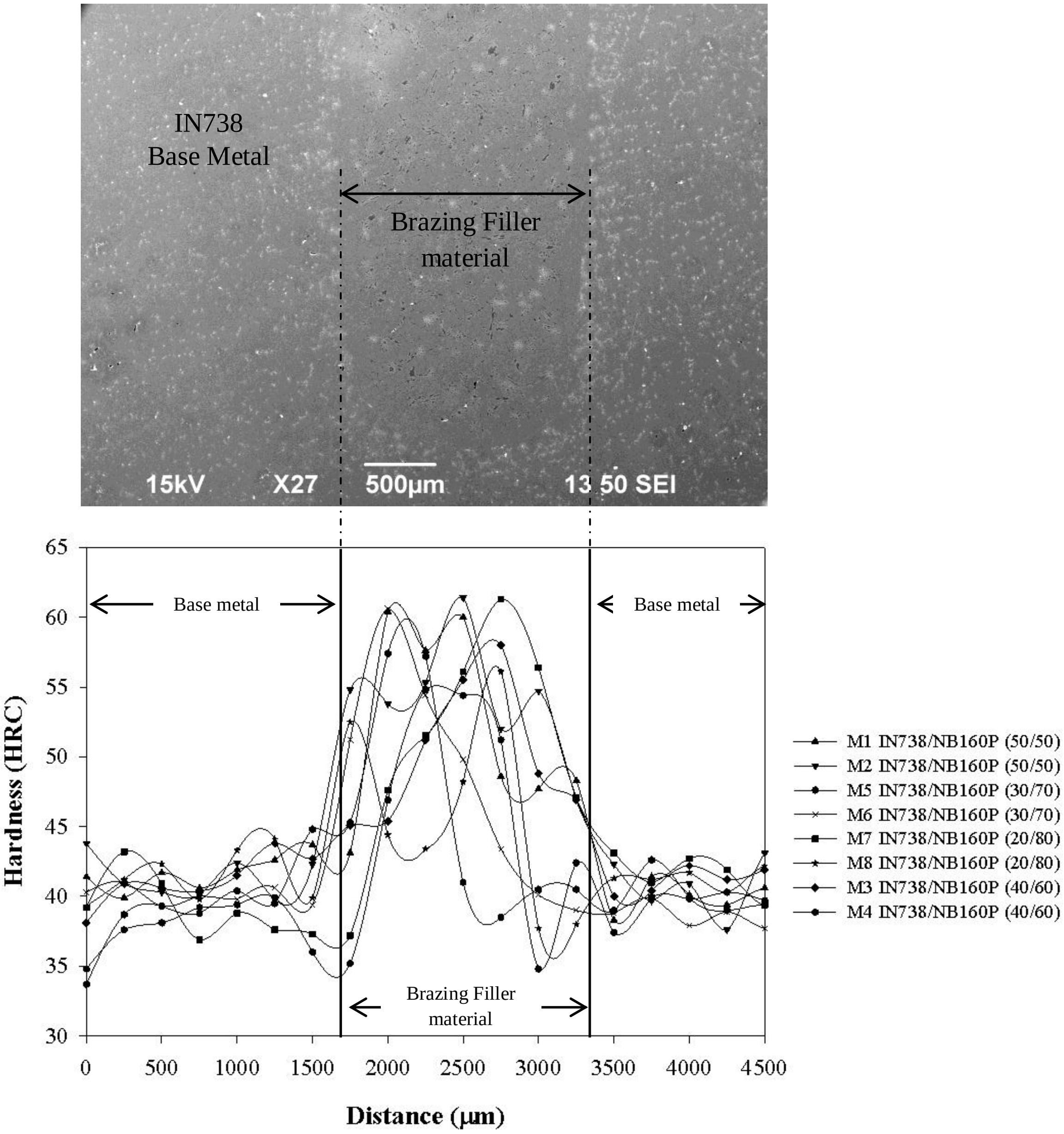

Figure 8. Microstructure and hardness profile of wide gap repair IN738 base metal with IN738/NB160 paste filler material.

Conclusions

In this paper we investigated four different filler materials for brazing process of IN738 superalloys. In all cases, the main phases in solidified microstructure were identified. The IN738/NB160 paste filler material yielded the best results in terms of interface formation with the base metal, minimal porosity, size and distribution of intermetallic compounds in the brazing microstructure and diffusion into the metal base. It was also found that 20/80 Wt% mixture of IN738/ NB160 paste featured extremely good adhesion properties, homogeneity and hardness, indicating that this filler can be very perspective as an alternative material for repairing of the defects and wide cracks in Ni-base IN738 superalloys, in particularly in the components used in gas turbines.

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