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Interface structure and mechanical properties of Ti(C,N)-based cermet and 17-4PH stainless steel joint brazed with nickel-base filler metal BNi-2

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ABSTRACT

The effects of brazing temperature on microstructure and bonding strength of vacuum brazed joints of Ti(C,N)-based cermet and 17-4 PH stainless steel, using filler metal BNi-2, were investigated. At a lower brazing temperature of 1050 °C, the distribution of melting point depressants (MPD) concentrated on the diffusion affected zone (DAZ) and the brazing seam near the Ti(C,N)-based cermet, the generation of brittle phases in the brazing seam was unavoidable. The uniform distribution of the MPD and full solid solution of γ-nickel occurred in the brazing seam at a higher brazing temperature of 1150 °C. A maximum shear strength of 690 MPa was achieved at a brazing temperature of 1150 °C.

1. Introduction

Cermets are widely used structural materials consisting of metal or alloy matrix and approximately equiaxed hard ceramic particles. Because of the combination of the desirable properties of both metal and ceramic, the cermets exhibit excellent properties, such as high strength, high hardness and wear resistance (Zhang, 1993; Ettmayer et al., 1995). Since the TiC-based cermets were developed in the early 1970s, they have become a kind of important materials in the applications of high speed cutting tools and die materials (Ettmayer and Lengauer, 1989) but the coarsening tendency and instability of the microstructure at higher temperature limited their wide applications. Compared with the TiC-based cermets, the Ti(C,N)-based cermets possess a fine and stable microstructure with higher hot hardness, higher transverse rupture strength and enhanced oxidation resistance (Upadhyaya, 2001). Therefore, more and more TiC-based cermets have been replaced by the Ti(C,N)-based cermets in the commercial cutting applications.

As brittle materials, it is necessary to embed the Ti(C,N)-based cermets in solid backing materials to make full use of their high hardness and wear resistance. High temperature vacuum brazing is one of the most successful methods of joining the cermets and steels as well as other base materials (Ferjutz and Joseph, 1993; Wang, 2007). The copper, silver and nickel-based filler metals were commonly used to braze the nickel alloys and steels. Zhang (2009) brazed the Ti(C,N)-based cermet to steel with a Ag–Cu–Zn filler metal and a maximum shear strength of 95.7 MPa was achieved. Wang (2007) obtained a shear strength of 338 MPa in the joint between Ti(C,N)-based cermet and SUS 410 stainless steel with a copper-based filler metal. Relatively low bonding strength of the cermets and backing materials limited the wide applications of the cermets in industries.

Sufficient interaction between the base metals and filler metals is necessary to obtain the sound and reliable brazed joints. The wettability of nickel-based filler metal BNi-2 on the Ti(C,N)-based cermets and stainless steels is excellent, and also, alloying elements dissolved from the base metals efficiently interact with the nickel filler metal. It was reported that steady TiO_2 oxide film on the surface of Ti(C,N)-based cermet would decrease the wettability of the filler metal with the Ti(C,N)-based cermet, and interdict the interaction between them (Wang, 2007). It was also reported that the oxide film could be removed during high temperature vacuum brazing (Lugscheider and Zhang, 1989). Therefore, the high temperature vacuum brazing of the Ti(C,N)-based cermet and stainless steel with the nickel-based filler metal has the possibility of obtaining a high bonding strength. However, there is no report on the brazing of the T(C,N)-based cermet and stainless steel with the nickel-based filler metals so far.

Precipitation hardened stainless steel 17-4PH (AISI 630) has the ability to develop very high strength without the catastrophic loss of ductility after an aging treatment, and exhibits a superior corrosion resistance to other steels with a similar strength. These superior properties made the 17-4PH stainless steel very attractive to designers and engineers and it has been widely used in medical,

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Table 1
Chemical compositions of 17-4PH steel, BN-2, and Ti(C,N)-based cermet (wt.%).

	C	Cr	Ni	Cu	Nb	Fe
17-4PH	0.04	16.5	4.25	3.6	0.25	Bal.
	Cr	B	Si	Fe	C	Ni
BNi-2	7.0	3.5	4.5	3.0	0.06	Bal.
		TiN	TiC	Mo	Al	Ti	Ni:Cr (4:1)
Ti(C,N)-based cermet		4	40	6	1.2	1.0	Bal.

military, aerospace and nuclear industries (Ye et al., 2008; Mirzadeh and Najaizadeh, 2009).

In this paper, high temperature vacuum brazing of the Ti(C,N)-based cermet and 17-4PH stainless steel with nickel-based filler metal BNi-2 was investigated. The influences of brazing temperature on the morphology, distribution and composition of melting point depressant (MPD) and the relationship with mechanical behaviors were analyzed.

2. Experimental procedure

Wrought precipitation hardened stainless steel 17-4PH (15 mm thick), boron and silicon containing nickel based filler metal BNi-2 and Ti(C,N)-based cermet were employed. Their nominal compositions (wt.%) are given in Table 1. 17-4PH stainless steel and Ti(C,N)-based cermet were machined into cubes of 15 mm × 25 mm × 35 mm, 6 mm × 20 mm × 25 mm, respectively. The faying surfaces of the coupons were ground with 400-grit abrasive paper, degreased with acetone in an ultrasonic bath for 60 min and then stored in acetone prior to brazing.

The high temperature brazing was carried out at different temperatures of 1050, 1100 and 1150 °C for 60 min in a vacuum furnace, operating at a vacuum of approximately 2.0×10^{-3} Pa. The schematic illustration of vacuum brazing and the thermal cycle of high temperature brazing are shown in Fig. 1a and c, respectively.

The brazed samples were prepared for microstructural examinations according to the standard metallographic techniques. Microstructural characterization and analyses were carried out by

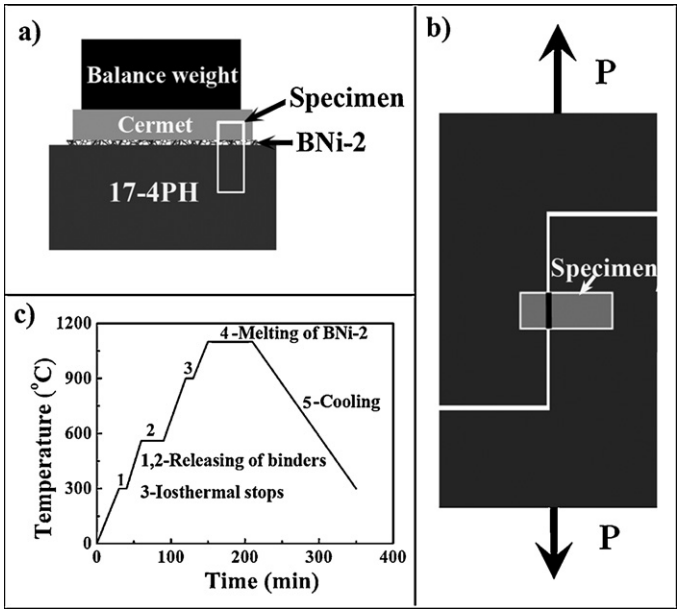

Fig. 1. Schematic illustration of (a) vacuum brazing, (b) fixtures for shear test, and (c) a thermal cycle of vacuum brazing.

Table 2
The EDS results (wt.%) of phases in the joints brazed with BNi-2 for 60 min.

Microarea	Cr	Fe	Ni	Si	B
1	91.26	0.87	1.67	–	6.2
2	15.47	13.67	69.3	1.53	0.3
3	13.52	14.28	68.48	2.01	0.4

electron probe X-ray microanalyzer (EPMA) and scanning electron microscopy (SEM), complemented by energy dispersive spectroscopy (EDS). In this study, the tensile shear tests were performed to evaluate the bonding strength between the Ti(C,N)-based cermet and 17-4PH with BNi-2, and the schematic illustration of the shear test is shown in Fig. 1b. The cylindrical specimens (Ø 6 mm) for shear test were prepared by electrical discharge machine. The specimens were put in the circular orifice with the brazing seam being located between the two parts of the fixtures when tested and at least 5 specimens was tested for each condition.

3. Results and discussion

Boron and/or silicon in the nickel-based filler metals as the MPD have the possibility of forming hard and brittle phases with nickel which are detrimental to the mechanical properties of brazed joints. SEM micrographs of the Ti(C,N)-based cermet/BNi-2/17-4PH joints are shown in Fig. 2. While a few of particles were found in the brazing seam of the joint brazed at 1050 °C (Fig. 2a), a continuous solid solution was observed in the brazing seam of the joint brazed at 1150 °C (Fig. 2b). EDS analyses as shown in Table 2 and the elements distribution of the brazed joint obtained by EMPA (not shown) suggested that the phase marked by 1 was chromium boride and the phases marked by 2 and 3 were nickel-rich solid solution, respectively. These are consistent with the results as reported by Tung (1996).

Figs. 3 and 4 show the distribution of the MPD B and Si in the joints brazed at 1050 °C, 1100 °C and 1150 °C, respectively. As shown in these figures, a zone in the base metal adjacent to the brazing seam which was affected significantly by the MPD elements was denominated the diffusion affected zone (DAZ). At 1050 °C, the boron and silicon concentrated in the DAZ and the zone of the brazing seam close to the Ti(C,N)-cermet (Figs. 3a and 4a). Obviously, the bonding strength would be deteriorated by the brittle phases in the brazed joint which were generated due to the reaction of the MPD elements with the Ti(C,N)-based cermet. With increasing the brazing temperature to 1100 °C, the DAZ expanded visibly and the distribution of boron and silicon in the brazed joint trended to be homogeneous (Figs. 3b and 4b). At 1150 °C, a quite homogeneous distribution of boron and silicon in the entire joint was obtained (Figs. 3c and 4c).

Fig. 5 shows the shear strength of the brazed joints under various brazing temperatures. The joint shear strength increased with increasing the brazing temperatures from 1050 to 1150 °C, and reached a maximum value of 690 MPa at 1150 °C, which was much higher than that obtained using Ag-based filler metal (176 MPa) (Ye et al., 2010). The variation of the joint strength with the brazing temperature was well correlated with the microstructural evolution of the joints, especially the distribution of the MPD and the brittle phases generated in the brazing seam.

Fig. 6 shows the fracture surfaces of the brazed joints after the shear strength test. The fracture surface of the joint brazed at 1050 °C was unique faceted morphology, and the fracture occurred along the brazing seam adjacent to the Ti(C,N)-based cermet (Fig. 6a and b). The unique faceted fracture surface corresponded to the fact that the distribution of boron and silicon mainly concentrated in the interface of brazing seam and Ti(C,N)-based cermet (Figs. 3 and 4), indicating that the interface interactions between

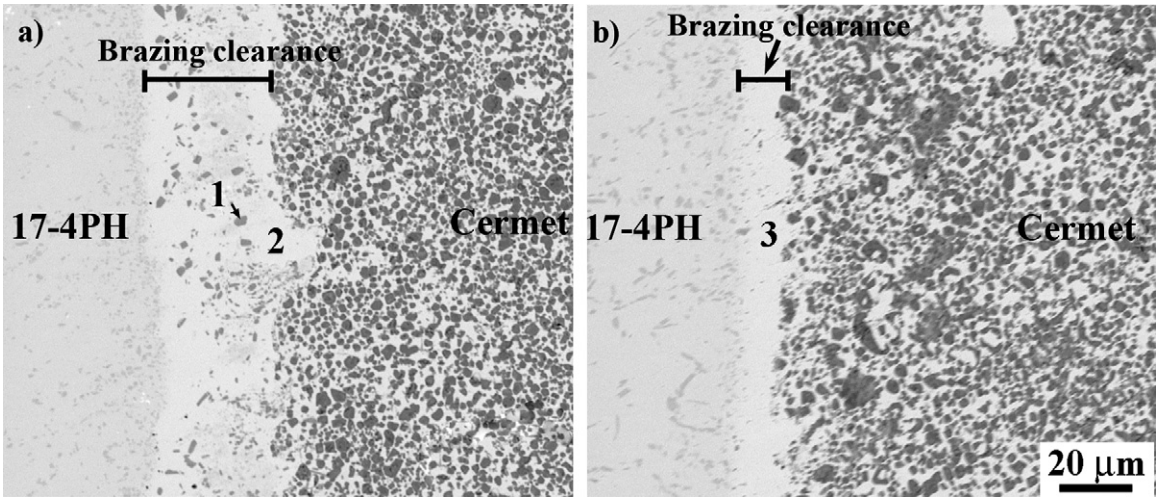

Fig. 2. Back-scattered electron images of joints brazed at (a) 1050 °C and (b) 1150 °C.

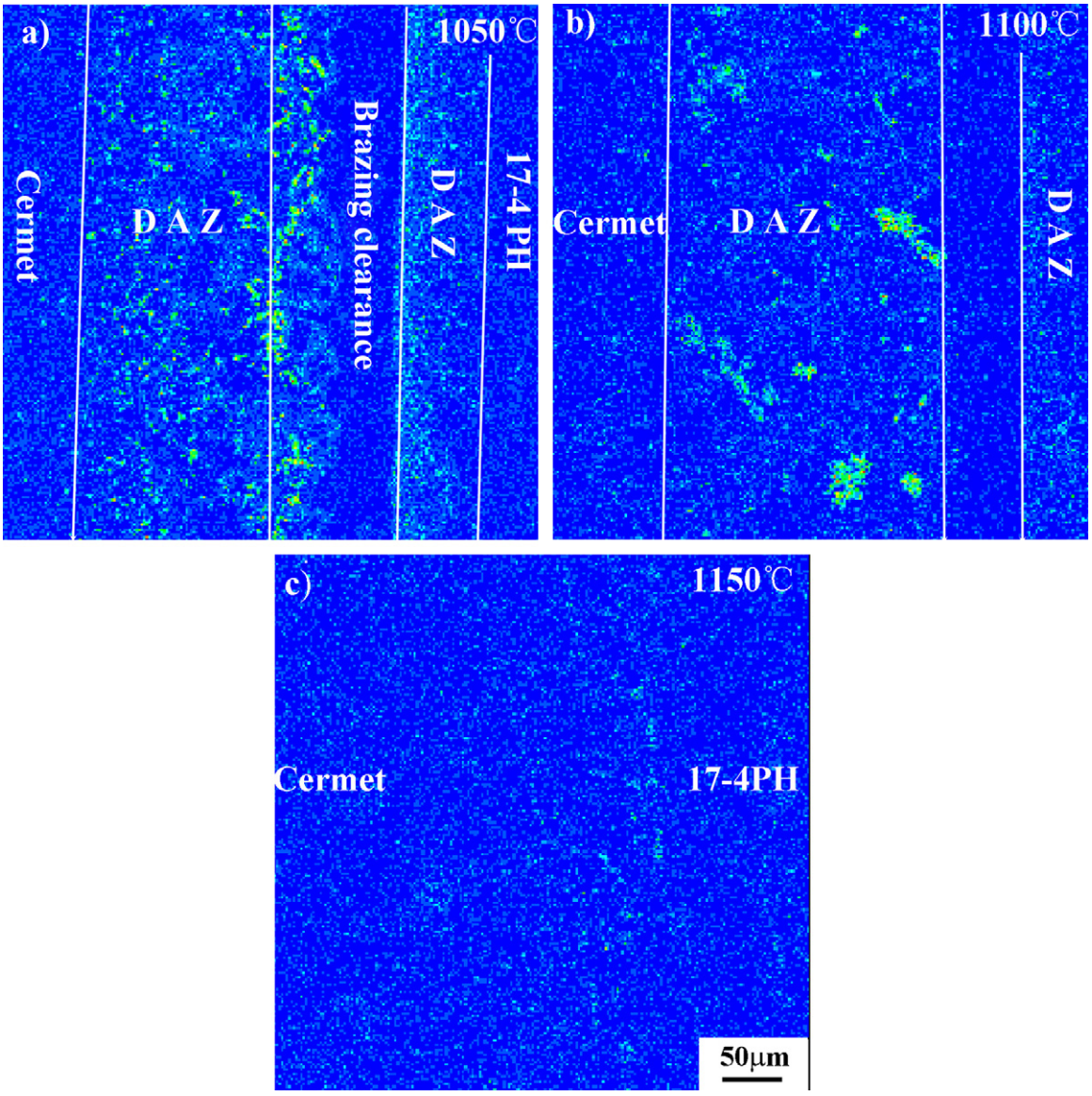

Fig. 3. Surface distribution of B in brazed joints of Ti(C,N)-based cermet and 17-4PH with BNi-2 at different brazing temperatures: (a) 1050 °C, (b) 1100 °C, and (c) 1150 °C.

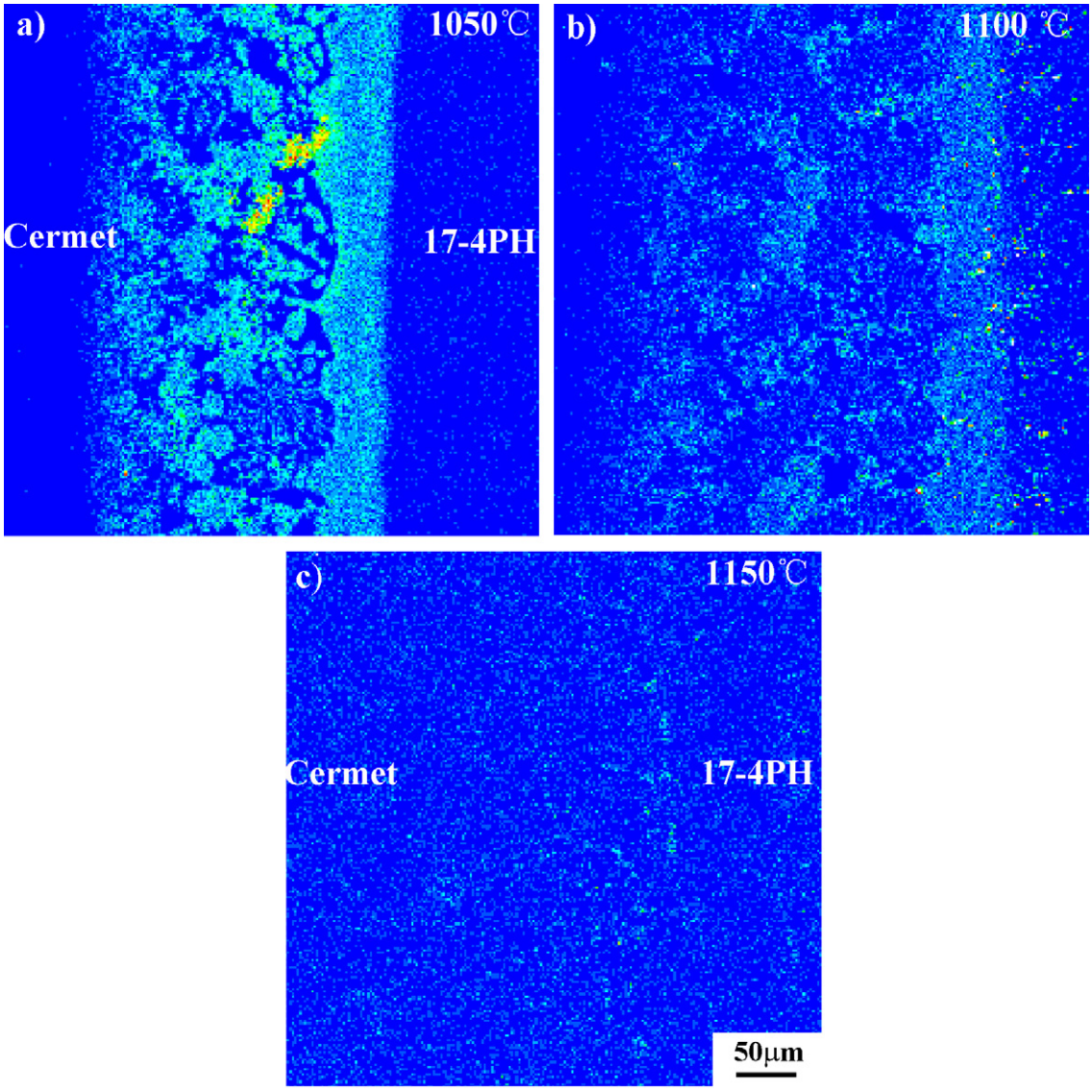

Fig. 4. Surface distribution of Si in brazed joints of Ti(C,N)-based cermet and 17-4PH with BNi-2 at different brazing temperatures: (a) 1050 °C, (b) 1100 °C, and (c) 1150 °C.

the cermet and the filler metal was inadequate. The faceted fracture surface implied a low resistance to crack initiation and propagation, due to a low bonding strength. Fig. 6c and d shows that the fracture surface of the joint brazed at 1100 °C was fluctuating and the fracture occurred partly inside the Ti(C,N)-based cermet, indicating that the reaction between the cermet and the filler metal was enhanced. The fracture surface of the brazed joint at 1150 °C was completely uneven and the crack propagated mainly along the zone of the Ti(C,N)-based cermet affected by the MPD (Fig. 6e and f). As shown in Fig. 6e, the fracture surface had visible plastic deformation which indicated that the crack propagated with high resistance, producing a high bending strength.

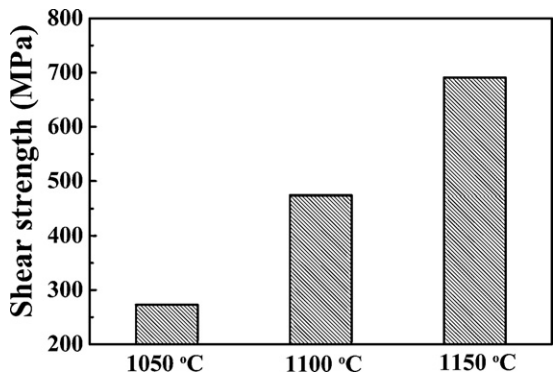

Fig. 5. Shear strength of Ti(C,N)-based cermet and 17-4PH joint vacuum brazed at different brazing temperatures with BNi-2.

There are three stages in the process of the brazing: substrate dissolution, isothermal solidification and solid state homogenization after eutectic melting of the filler metal (Gale and Butts, 2004; Mosallaee et al., 2008). In the first stage, the dissolution of the Ti(C,N)-based cermet into the melting filler metal occurred. The time needed for this process was relatively short because the dissolution did not require a long range diffusion in the solid and the activation energy for dissolution was low. In the second stage, the MPD diffused to the base metals which decreased the concentration of the MPD in the brazing seam and caused the rise of melting point of the filler metal. The so-called "isothermal solidification" happened when the melting point of the filler metal exceeded the brazing temperature. In the third stage, following the completion

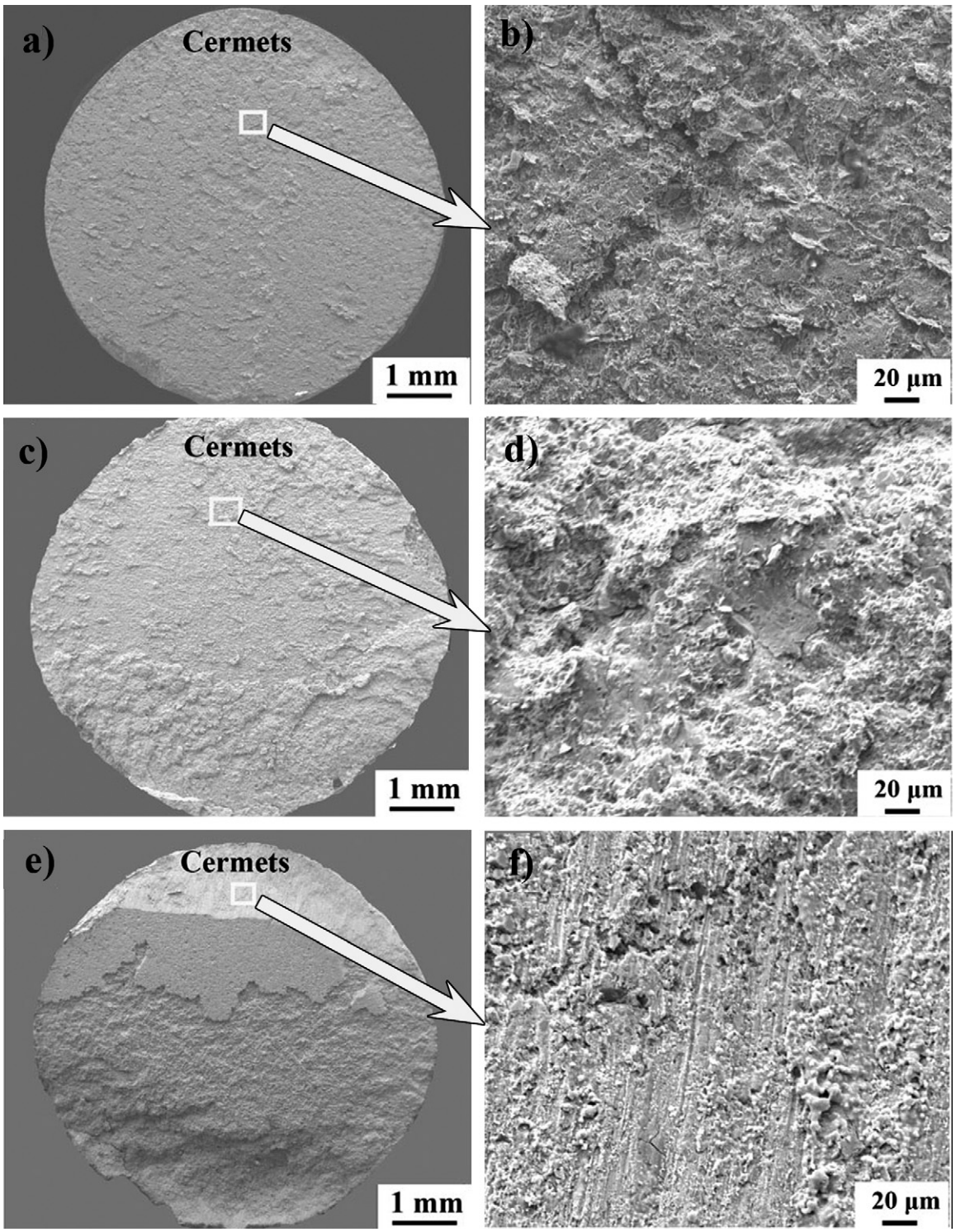

Fig. 6. Fractographs of brazed joints: (a and b) 1050 °C, (c and d) 1100 °C, and (e and f) 1150 °C.

of the isothermal solidification, to avoid the precipitation of brittle and hard second phases when cooled down to the room temperature, the concentration of boron and silicon in the brazing seam had to be reduced to below the solubility of boron and silicon in the cermet at room temperature. This stage requires a long range diffusion of boron and silicon in the brazing seam and base metals.

It has been reported that boron in the filler metal readily diffused into the base metal (Shiue et al., 2002; Arafin et al., 2007) and apparently, if the brazing temperature was low, there would be a certain amount of boron left in the brazing seam, forming the brittle phases at room temperature. The brittle phases formed in the brazing seam at 1050 °C were caused by the following two reasons. First, in the first stage of the brazing, the dissolution of the Ti(C,N)-based cermet in the liquid phase and the interdiffusion between the liquid and solid phases caused the enrichment of the liquid phase with base alloying elements (such as Cr, Mo) which formed the brittle phase (chromium boride) with the MPD (Gale and Wallach, 1992). Second, the residual solubility of the MPD in the liquid phase

was high when the process of isothermal solidification completed and the diffusion of the MPD toward the Ti(C,N)-based cermet were limited with the low brazing temperature.

In summary, the time required for the three stages in the brazing process are different according to different brazing temperatures. The process of the isothermal solidification determined the completeness of diffusion and homogenization of the MPD into the base metals due to the difference in order of magnitude in diffusivity of the MPD in the solid and liquid. The isothermal solidification stage could last longer with higher brazing temperature which means the residual solubility of the MPD in the filler metal could be reduced, limiting the precipitation of undesired phases at room temperature. As a result, the brazing with higher temperature in the brazing temperature range of BNi-2 could achieve sound and reliable brazed joint.

4. Conclusions

The interfacial microstructure and the joint strength of vacuum brazed Ti(C,N)-based cermet to 17-4PH stainless steel with BNi-2 was experimentally assessed. The primary conclusions can be summarized as follows:

(1) The distribution of melting point depressants (MPD) in the brazed joints was varied with the brazing temperature. The number of the brittle phases in the brazing seam decreased gradually with increasing the brazing temperature from 1050 to 1150 °C, and a high distribution uniformity of boron and silicon in the brazed joint could be achieved at 1150 °C.
(2) The bonding strengths increased with increasing the brazing temperature from 1050 to 1150 °C and a maximum shear strength of 690 MPa was obtained at 1150 °C.

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