*Kovove Mater. 50 2012 229–233*
*DOI: 10.4149/km_2012_4_229*



# Microstructure and fracture characteristics in vacuum brazed joint of super-Ni/NiCr laminated composite

N. Wu, Y. Li*, J. Wang

*Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials (Ministry of Education), Shandong University, Jinan 250061, P. R. China*

Received 7 July 2010, received in revised form 12 January 2011, accepted 13 January 2011

**Abstract**

The objective of this study is to investigate the brazeability of a new laminated composite with Ni-Cr-P filler metal in vacuum. Microstructure, microhardness and shear strength of the brazed joint were investigated by means of scanning electron microscopy, energy-dispersive spectroscopy, microsclerometer and electromechanical universal testing machine. Excellent joint of super-Ni/NiCr laminated composite to Cr18-Ni8 steel was obtained at 1040 °C for 20 min through vacuum brazing with Ni-Cr-P filler metal. $Ni_2Cr$ particles precipitated in NiCr base layer under the influence of thermal cycle. The brazed region consisted of $\gamma$-Ni(Cr) solid solution and eutectic of $\gamma$-Ni(P) and $Ni_3P$. Microhardness of the eutectic was as high as 630 HV. Shear strength of the brazed joint was 137 MPa and the joint fractured in the eutectic. Steps and cracks formed in the fracture surface under the shear force.

K e y w o r d s: laminate, super-Ni/NiCr, vacuum brazing, Ni-Cr-P, microstructure

## 1. Introduction

Super-Ni/NiCr laminated composite is a newly developed material composed of super-Ni cover layer and NiCr base layer. Super-Ni cover layer has special resistance to high-temperature and corrosion. However, the strength of super-Ni cover is low. In contrast, NiCr base layer is featured with lower density, higher strength and lower cost than super-Ni cover layer. Super-Ni/NiCr laminated composite combines the merits of the two layers, which has the potential to reduce weight and improve performance of the structures. Super-Ni/NiCr laminated composite has vast application prospect in aerospace, energy and power industries.

For some special applications, it is necessary to join super-Ni/NiCr laminate to one similar or dissimilar material as integrated components [1–3]. Therefore, weldability of super-Ni/NiCr laminate must be well established.

The welding of super-Ni/NiCr laminated composite is complex due to its unique structure and composition. Both super-Ni cover layer and NiCr base layer should have good bonding with weld metal. Super-Ni cover layer is so thin (about 0.3 mm) that it is easy to burn through in traditional welding process (Fig. 1). Therefore, it is difficult to keep the structure integrity of super-Ni/NiCr laminate after welding. Moreover,

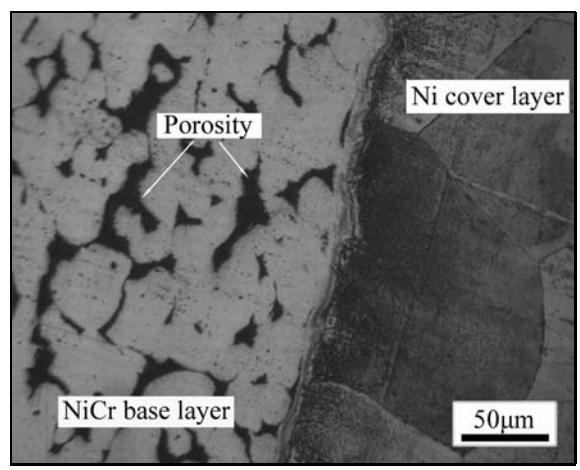


Fig. 1. Microstructure of super-Ni/NiCr laminated composite.

*Corresponding author: tel./fax: +86 531 88392924; e-mail address: yajli@sdu.edu.cn

internal porosities makes NiCr base layer uniquely different in terms of brazing characteristics [4–6].

High-temperature brazing, especially using Ni-based filler metals, produces a joint with oxidation and corrosion-resistant at high temperature [7], which is favorable to make full use of super-Ni/NiCr laminate. Vacuum brazing with Ni-Cr-P filler metal was used for joining super-Ni/NiCr laminated composite to Cr18-Ni8 steel. This study attempts to investigate microstructure, chemical composition and shear strength of the brazed joint.

## 2. Experimental details

A sandwich plate composed of vacuum pressed super-Ni cover layers (0.3 mm) and NiCr base layer (2 mm) was used in this study. NiCr base layer was nichrome-based powder alloy (Ni80Cr20). Relative density of Ni80Cr20 base layer was 6.77 g $cm^{-3}$ and porosity ratio was about 35.4 % [8]. Grain sizes in super-Ni cover layer were about 100 μm. NiCr base layer consisted of bone-shaped γ-Ni(Cr) solid solution in white and internal porosities in black. Stainless steel used in this study was Cr18-Ni8 steel with the thickness of 2.6 mm.

Ni-Cr-P filler metal was used in this study and its chemical composition in weight percent is (75.0–78.0) Ni, (13.0–15.0) Cr, (9.7–10.5) P, 0.1 Si, 0.02 B, 0.05 Ti, 0.10 Co, 0.06 C. The liquidus is about 890 °C. The size of the specimens was 30 mm × 10 mm × 2.6 mm. The brazing specimens were arranged in butt joint. The specimens were brazed at 1040 °C for 20 min under a vacuum of $10^{-4}$ Pa.

Transverse sections of the brazed joints were grinded, polished and etched with a solution consisting of HCl, HF and $HNO_3$. Microstructure and chemical composition were investigated using FEI-QUANTA2000 scanning electron microscopy (SEM) installed with OXFORD energy-dispersive spectroscopy (EDS). Vickers microhardness was measured by DHV-1000 microsclerometer, with a constant load of 50 g for 10 s. Shear strength testing was carried out by setting the joint in a special clamping fixture (Fig. 2) with CMT-5105 electromechanical universal testing machine. The fracture surfaces were observed by SEM and EDS.

## 3. Results and discussion

### 3.1. Microstructure

Microstructure of the brazed joint is shown in Fig. 3. Ni-Cr-P filler metal exhibits good wettability to both the cover layer and base layer, providing structural continuity through the whole joint.

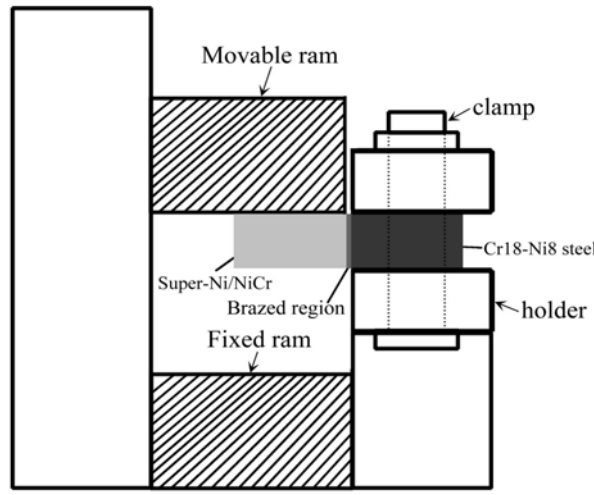


Fig. 2. Clamping fixture used for shear strength testing.

Table 1. Chemical composition of the points in the brazed joint

| Points | Elemental composition (at.%) | | | | Phases |
|---|---|---|---|---|---|
| | Ni | Cr | P | Fe | |
| 1 | 80.5 | 11.0 | 8.5 | – | γ-Ni(P) |
| 2 | 70.0 | 7.6 | 22.3 | 0.7 | $Ni_3P$ |
| 3 | 78.3 | 16.7 | 2.1 | 2.4 | γ-Ni(Cr) |
| 4 | 78.4 | 16.7 | – | 4.9 | γ-Ni(Cr, Fe) |
| 5 | 66.9 | 34.1 | – | – | $Ni_2Cr$ |

Internal porosities make brazing characteristics of NiCr base layer unique. The porosities generate great capillary force pulling molten filler metal into the porosities and there are three cases. An excessive amount of filler metal will infiltrate into the porosities when the capillary force is too great. As a result, an insufficient amount of filler metal remained in the joint gap leading the formation of voids [4]. Porosities have the potential to diminish the contact area when there is no infiltration into porosities [5]. Infiltration to short distance is advantageous in creating a strong bond by increasing the contact area [6]. A sufficient amount of filler metal remained in the joint gap and a good bonding without voids and flaws was obtained between super-Ni/NiCr laminated composite and Cr18-Ni8 steel.

Chemical composition of the points in the brazed joint was identified by EDS and the result is shown in Table 1.

There was noticeable reticular agglomerate along the centerline of the brazed region. According to the Ni-P phase diagram [9], the phase (point 1) was iden-

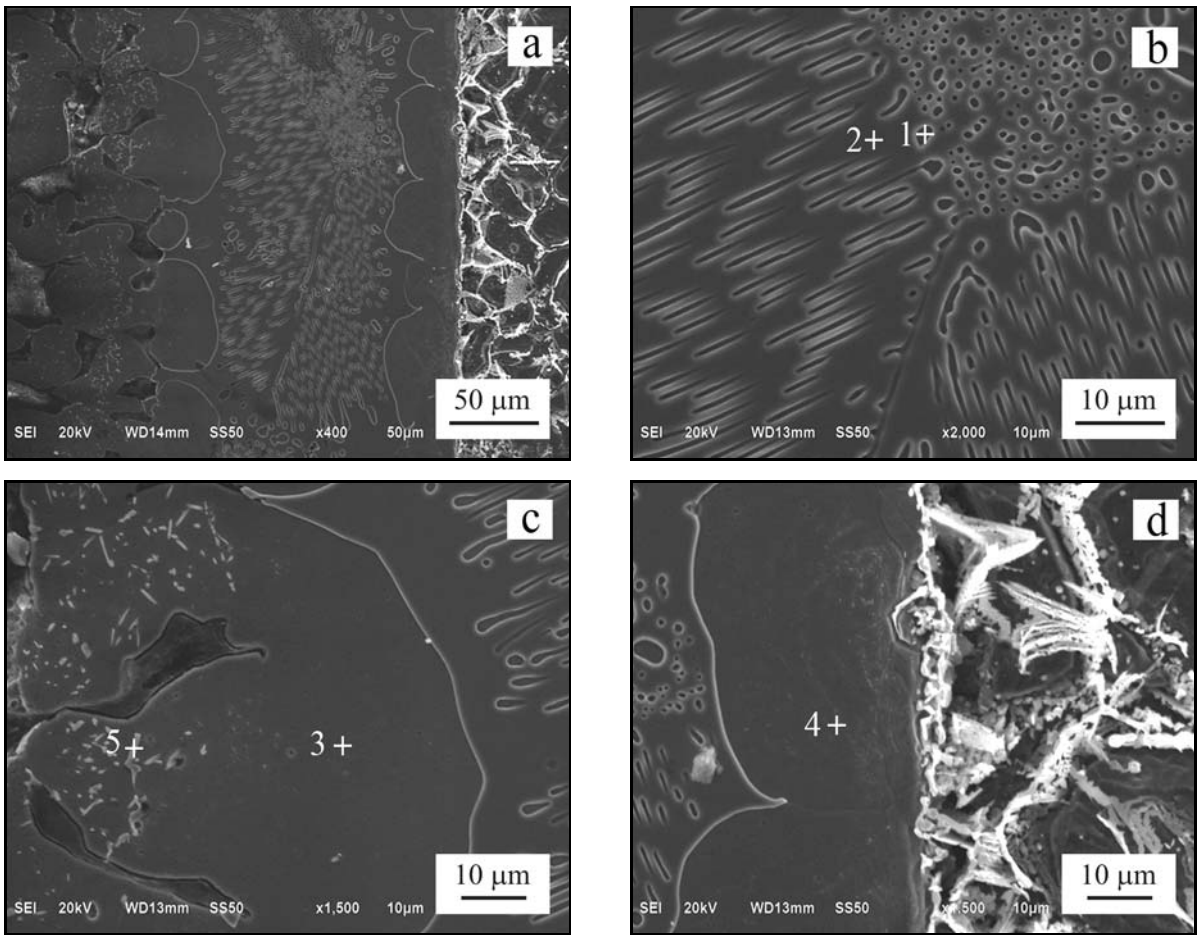


Fig. 3. Microstructure of brazed joint: (a) brazed region, (b) eutectic zone, (c) interface between the brazed region and NiCr base layer, (d) interface between the brazed region and Cr18-Ni8 steel.

tified as $\gamma$-Ni(P) solution and the phase (point 2) was speculated to be $Ni_3P$, which were just the binary eutectic of $\gamma$-Ni(P) solid solution and $Ni_3P$. The light gray phases near to super-Ni/NiCr laminate and Cr18--Ni8 steel (point 3 and point 4) were $\gamma$-Ni solid solution. There were mainly dissolution and diffusion due to the same matrix of super-Ni/NiCr laminate and the filler metal. So the interfacial region between them was not clearly observed. There was only a dividing line instead of continuous reaction layer between the brazed region and Cr18-Ni8 steel, which may be the weakness of the joint. A large amount of white particles precipitated in NiCr base layer. The chemical composition analysis (point 5) indicated the particles to be $Ni_2Cr$.

The brazed region can be divided into solid solution zone (SSZ) and eutectic zone (EZ). The solidification process can be summarized as following: solidification of $\gamma$-Ni(Cr) solid solution occurred firstly with the formation of nodules along the surface and grew from the faying surface to the melt. And then the remaining melt rich in P solidified into an eutectic structure of $\gamma$-Ni(P) and $Ni_3P$.

### *3.2. Microhardness*

Microhardness of the brazed joint was measured by DHV-100 microsclerometer with a constant load 50 g for 10 s. According to Fig. 4, microhardness of super-Ni cover layer was 100 HV and that of NiCr base layer was 200 HV. Microhardness of $\gamma$-Ni solid solution was 220 HV. However, microhardness of the Ni-P eutectic increased to 630 HV due to the existence of brittle $Ni_3P$. Microhardness of Cr18-Ni8 steel was 220 HV. Therefore, microhardness of Ni-P eutectic was the highest in the brazed joint.

### *3.3. Fracture morphology*

The shear strength test was carried out at room temperature to evaluate the joining properties. It reached the highest value (137 MPa) when the joint was brazed at 1040 ℃ for 20 min. The morphology and EDS result of the fracture surface are shown in Fig. 5. EDS analysis of the fracture surface presented strong

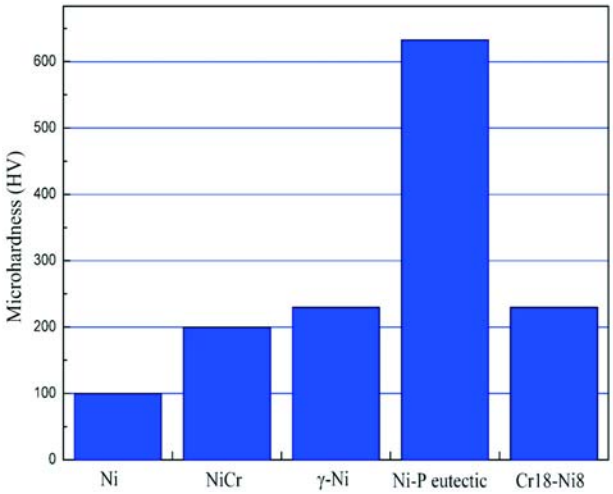


Fig. 4. Microhardness histogram of the brazed joint.

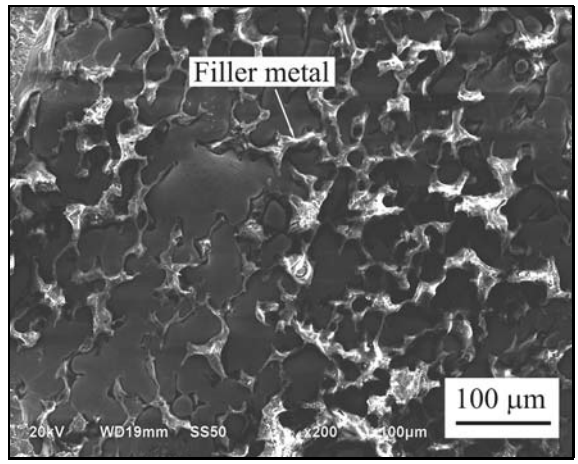


Fig. 6. Infiltration into porosities of NiCr base layer.

peaks of Ni (68 %), Cr (8.2 %) and P (23.8 %), indicating that the failure occurred in the eutectic zone of the brazed region. Therefore, the interface between the brazed region and Cr18-Ni8 steel was not the weakness in the joint.

Fracture morphology of the brazed joint displayed

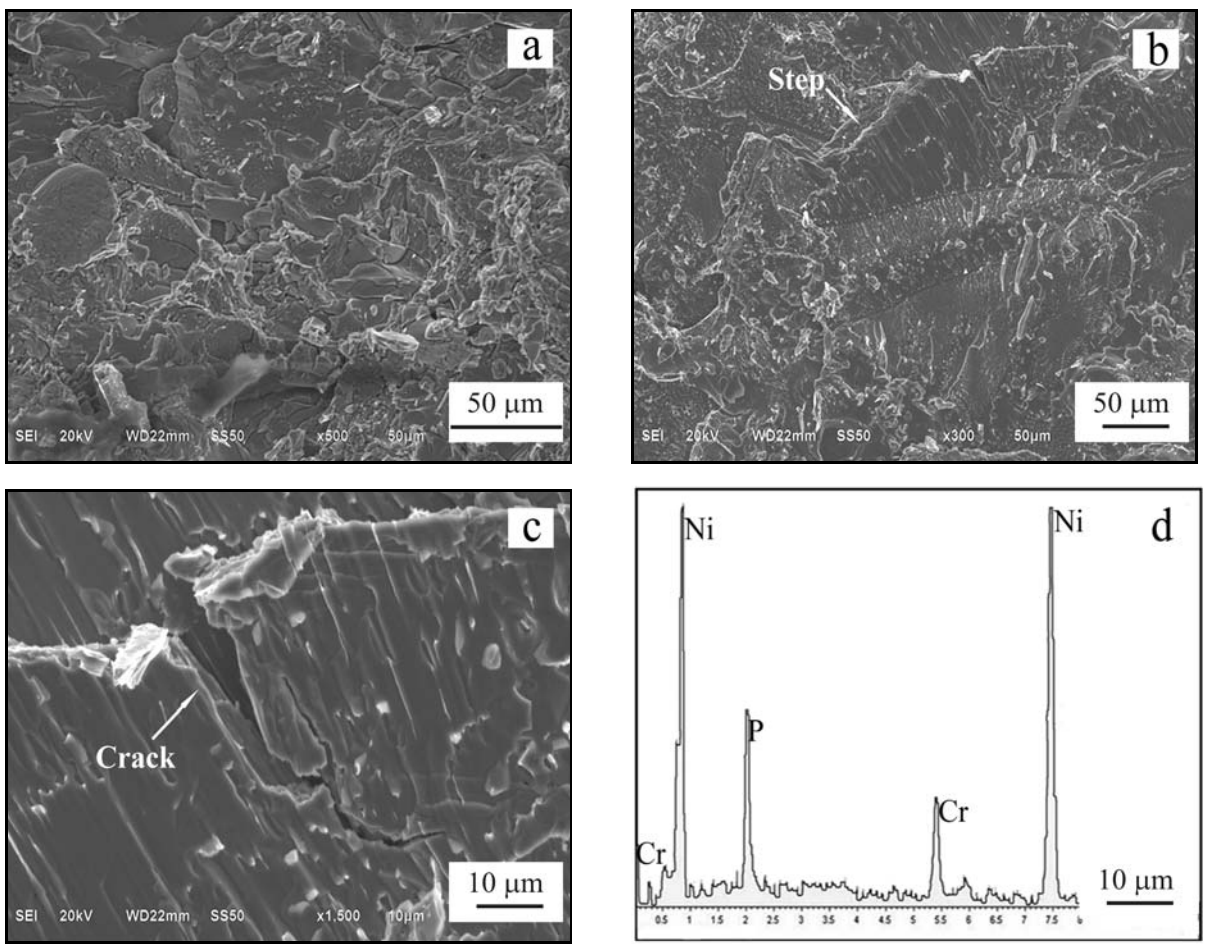


Fig. 5. Fracture morphology of brazed specimens: (a) Ni cover layer and (b) NiCr base layer at 1040 °C, (c) crack propagation, (d) EDS analysis of fracture surface.

brittle features. It was difficult for the brittle eutectic to deform plastically under the shear force. A step was formed in the fracture surface and cracks formed here (Fig. 5b). The cracks propagated under the shear force (Fig. 5c).

The brittle eutectic was the key factor to the shear strength of the brazed joints. Consequently, the mechanical property can be improved by increasing the brazing temperature, extending the holding time or decreasing the joint gap, which will reduce the amount of the eutectic.

The fracture surface where there was void in the brazed region before fractured is shown in Fig. 6. The fracture morphology illustrates that Ni-Cr-P filler metal infiltrated into porosities of NiCr base layer.

## 4. Conclusions

1. Vacuum brazing was suitable for joining super-Ni/NiCr laminated composite to Cr18-Ni8 steel with Ni-Cr-P filler metal. $Ni_2Cr$ particles precipitated in NiCr base layer under the influence of thermal cycle.

2. The brazed region was composed of $\gamma$-Ni(Cr) solid solution and eutectic of $\gamma$-Ni(P) and $Ni_3P$. Microhardness of $\gamma$-Ni(Cr) solid solution was 220 HV and microhardness of the eutectic was as high as 630 HV.

3. Shear strength of the brazed joint reached 137 MPa when brazed at 1040 ℃ for 20 min and the failure occurred in the eutectic zone. Steps and cracks formed in the fracture surface under the shear force.

## Acknowledgements

This project was supported by the National Natural Science Foundation of China (50874069) and Doctoral Fund of Ministry of Education of China (200804220020).

## References

[1] Correa, E. O., Costa, S. C., Santos, J. N.: J. Mater. Process. Tech., *209*, 2009, p. 3937. doi:10.1016/j.jmatprotec.2008.09.008

[2] Rao, S. S., Jayabharat, K., Ashfaq, M., Krishna, B. V.: Sci. Technol. Weld. Join., *11*, 2006, p. 183. doi:10.1179/174329306X84382

[3] Kim, J. K., Yu, T. Y.: J. Mater. Process. Tech., *63*, 1997, p. 33. doi:10.1016/S0924-0136(96)02596-4

[4] Hamill, J.: Metal Powder Report, *62*, 2007, p. 22. doi:10.1016/S0026-0657(07)70106-6

[5] Gao, H. Y., He, Y. H., Shen, P. Z., Jiang, Y., Huang, B. Y., Xu, N. P.: Transactions of the China Welding Institution, *19*, 2009, p. 90.

[6] Sokolowski, P. K., Murphy, T. F., Lindsley, B. A.: In: Powder Metal World Congress and Exhibition. Hollywood, Florida, USA 2010.

[7] Sakamoto, A., Fujiwara, C., Hattori, T., Sakai, S.: Weld. J., *68*, 1989, p. 63.

[8] Xia, C. Z., Li, Y. J., Wang, J., Puchkov, U. A., Jiang, Y. N.: Kovove Mater., *48*, 2010, p. 257.

[9] Lugsheider, E., Zhuang, H. S.: High Temperature Brazing. Beijing, National Defence Industry Press 1989.