Bull. Mater. Sci., Vol. 28, No. 1, February 2005, pp. 63–67. © Indian Academy of Sciences.

Effect of Cr and Ni on diffusion bonding of Fe_3Al with steel

WANG JUAN[†] LI YAJIANG*[†] and MA HAIJUN[†]

*Key Lab of Liquid Structure and Heredity of Materials, Ministry of Education, Shandong University, Jinan 250061, China

[†]National Key Lab of Advanced Bonding Production Technology, Harbin Institute of Technology, Harbin 150001, China

MS received 17 August 2004

Abstract. **Microstructure at the diffusion bonding interface between Fe_3Al and steel including Q235 low carbon steel and Cr18–Ni8 stainless steel was analysed and compared by means of scanning electron microscopy and transmission electron microscopy. The effect of Cr and Ni on microstructure at the Fe_3Al/steel diffusion bonding interface was discussed. The experimental results indicate that it is favourable for the diffusion of Cr and Ni at the interface to accelerate combination of Fe_3Al and steel during bonding. Therefore, the width of Fe_3Al/Cr18–Ni8 interface transition zone is more than that of Fe_3Al/Q235. And Fe_3Al dislocation couples with different distances, even dislocation net occurs at the Fe_3Al/Cr18–Ni8 interface because of the dispersive distribution of Cr and Ni in Fe_3Al phase.**

Keywords. **Cr; Ni; Fe_3Al/steel interface; diffusion bonding.**

1. Introduction

Fe_3Al intermetallic is a candidate material for structural application in many industrial fields such as aviation, automobile and energy transition system because of its excellent strength at elevated temperature, resistance to oxidation and low cost (Mckamey *et al* 1991; Sun *et al* 2001). The weldability of Fe_3Al intermetallic has also drawn wide attention of the research community. The welding processes used are gas tungsten arc welding, electron beam welding and vacuum diffusion bonding (David and Zacharia 1993; Gao *et al* 2000; Li and Wang 2003). The results indicate that only by choosing weld wire with the same chemical composition as the base metal and strictly controlling welding heat input, can weld crack be avoided when using gas tungsten arc welding. While using electron beam welding and vacuum diffusion bonding processes, weld crack can be effectively avoided because of the vacuum atmosphere in welding. In addition, the vacuum diffusion bonding of Fe_3Al intermetallic with dissimilar materials has been studied (Wang *et al* 2001, 2003). But reports on the effect of alloying elements on diffusion bonding of Fe_3Al with steel are few.

In this paper, microstructure at the diffusion bonding interface between Fe_3Al and steel including Q235 low carbon steel and Cr18–Ni8 stainless steel was analysed and compared by means of SEM and TEM. The effect of Cr and Ni on microstructure at the Fe_3Al/steel interface was discussed. The results indicate that it is possible to promote favourable microstructure at the Fe_3Al/steel diffusion bonding interface.

*Author for correspondence (yajli@sdu.edu.cn)

2. Experimental

The base metals in the test are Fe_3Al intermetallic, Q235 low carbon steel and Cr18–Ni8 stainless steel. The chemical composition of Q235 steel is (wt%) C 0·14%, Si 0·10%, Mn 0·5%, S 0·035%, P 0·035% and Fe balance. The chemical composition and thermo-physical properties of Fe_3Al and Cr18–Ni8 steel are listed in table 1.

Samples for diffusion bonding were prepared by grinding on sand paper, acetone cleaning, alcohol cleaning, water rinsing and drying. Diffusion bonding was conducted in vacuum chamber of Workhorse II equipment immediately after the above treatments. The diffusion bonding was carried out at 1333 K for 60 min with a pressure of 15 MPa in a vacuum of $4·5 \times 10^{-5}$ Pa. In the heating process, several holding temperature stages were included to promote uniformity of heat in the samples. The temperature of chamber is brought down to 373 K by water circulation and then it was cooled to room temperature within the furnace.

The samples of Fe_3Al/steel joint were cut and etched with a solution of 75% hydrochloric acid and 25% nitric acid for metallographic observation. Microstructural characteristics and fine structures at the Fe_3Al/Q235 and Fe_3Al/Cr18–Ni8 interface were analysed by means of JXA-840 scanning electron microscope (SEM) and transmission electron microscope (TEM) with PV9900-H-8010 energy spectrum analysis system.

3. Results and discussion

3.1 *Effect on microstructure*

Microstructure at the Fe_3Al/steel diffusion bonding interface obtained under 1333 K for 60 min with a pressure of 15 MPa is shown in figure 1. It can be seen that there is obvious mutual diffusion and an interface transition zone is formed between Fe_3Al and steel. Microstructure in the interface transition zone and on two sides of Fe_3Al and steel is interlaced. The width of Fe_3Al/Cr18–Ni8 interface transition zone is 35 μm, which is more than that of Fe_3Al/Q235 interface transition zone (29 μm) under the same bonding parameters (1333 K × 60 min, 15 MPa). This is because the diffusion of Cr and Ni from Cr18–Ni8 to Fe_3Al can affect the dynamic balance at the Fe_3Al/ Cr18–Ni8 interface and accelerate the diffusion of Al towards the side of Cr18–Ni8 to improve the bonding between Fe_3Al and Cr18–Ni8.

In addition, there are second phases with irregular shape distributed dispersively in the interface transition zone between Fe_3Al and steel. The chemical composition of second phases was analysed by means of electron probe microanalysis (EPMA) and the results are listed in table 2.

C and Cr contents in the second phase of the Fe_3Al/ Q235 interface transition zone are more than that in the matrix and Fe and Al contents are less, while in the Fe_3Al/ Cr18–Ni8 interface transition zone, Cr and Ni contents are more than that in the matrix and Fe and Al contents are also less. This is because of the insufficient time for C and Cr to diffuse fully in the Fe_3Al/Q235 interface transition zone during diffusion bonding. The second phase rich in Cr and Ni in the Fe_3Al/Cr18–Ni8 interface transition zone can restrain effectively C precipitation to avoid the formation of carbide.

3.2 *Effect on fine structure*

TEM morphology and electron diffraction pattern of Fe_3Al in the Fe_3Al/Q235 interface transition zone are shown in figures 2a–c. The results from electron diffraction pattern and index schematic diagram indicate that Fe_3Al formed in Fe_3Al/Q235 interface transition zone exhibits a superlattice. It can be seen from [110] orientation that fine structure of Fe_3Al consists of dislocation walls which include several small regions. The production of Fe_3Al dislocation walls is closely related to the

Table 1. Chemical composition and thermo-physical properties of Fe_3Al and Cr18–Ni8 steel.

	Chemical compositions (wt%)									
Material	Al	Cr	Nb	Ni	Zr	B	Ce	S	P	Fe
Fe_3Al	16·0 ~ 17·0	2·40 ~ 2·55	0·95 ~ 0·98	–	0·05 ~ 0·15	0·01 ~ 0·05	0·05 ~ 0·15	–	–	Bal.
Cr18–Ni8	–	18·21	–	9·43	–	–	–	0·03	0·03	Bal.

					Thermo-physical properties				
Material	Structure	Order critical temperature (K)	Young's modulus (GPa)	Melting point (K)	Coefficient of thermal expansion (10^{-6}·K^{-1})	Density (g·cm^{-3})	Tensile strength (MPa)	Elongation (%)	Hardness
Fe_3Al	DO_3	813	140	1813	11·5	6·72	455	3	≥ 29 HRC
Cr18–Ni8	–	–	–	–	16·7	8·03	520	40	70 HRB

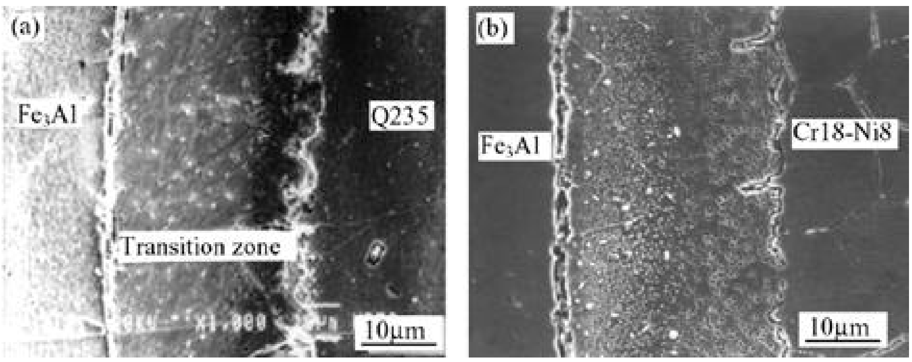

Figure 1. Microstructure at the Fe_3Al/steel diffusion bonding interface: (**a**) Fe_3Al/Q235 and (**b**) Fe_3Al/Cr18–Ni8.

motion of dislocations. The dislocation walls can affect dislocation glide and even microstructure at the Fe_3Al/Q235 diffusion bonding interface.

TEM morphology, electron diffraction pattern and index schematic diagram of Fe_3Al in the Fe_3Al/Cr18–Ni8 interface transition zone are shown in figures 3a–c. Dislocations with [001] orientation are distributed in couples and the spacing is small between the dislocation couples. This is because Cr and Ni diffused at the Fe_3Al/Cr18–Ni8 interface can hamper the superlattice dislocation motion in Fe_3Al. The external applied stress can make dislocations decompose into unit dislocations and they slide alternatively. In addition, Cr and Ni can decrease the antiphase boundary energy during the deformation of Fe_3Al (Mckamey *et al* 1990; Yin *et al* 1996). This will cause an increase in the spacing between dislocation couples.

Fe_3Al dislocations with $[1\bar{2}2]$ orientation are mostly unpaired and they are tangled in some regions (figures 4a–c). This has resulted from the diffusion of Cr and Ni at the Fe_3Al/Cr18–Ni8 diffusion bonding interface. The diffused Cr and Ni can be precipitated in the second phase and distributed dispersively in Fe_3Al. When the individual dislocation moves to the second phase, continued glide is hampered and they form a dislocation net.

When the dislocation pairs with small spacing and dislocations in a network at the Fe_3Al/Cr18–Ni8 diffusion bonding interface move during the diffusion bonding, they restrict the smooth glide of each other. Fe_3Al has these various dislocation features at the Fe_3Al/Cr18–Ni8 diffusion bonding interface because of Cr and Ni diffusion which are favourable for improving the strength of the diffusion bonding interface.

Table 2. EPMA analysis on second phase in the transition zone between Fe_3Al and steel (%).

Position	No.	Fe	Al	C	Cr	Nb	Zr	Ni
Fe_3Al matrix	1	82·60	16·62	0·14	0·52	0·05	0·07	–
	2	82·80	16·40	0·13	0·49	0·03	0·05	–
	3	81·91	17·10	0·13	0·51	0·03	0·02	–
	4	82·21	16·90	0·13	0·54	0·01	0·01	–
Fe_3Al/Q235	1	81·69	16·35	0·55	1·18	0·01	0·02	–
	2	81·94	15·90	0·51	1·28	0·03	0·04	–
	3	82·54	15·47	0·40	1·32	0·04	0·03	–
	4	81·89	16·23	0·22	1·26	0·04	0·06	–
Fe_3Al/Cr18–Ni8	1	71·8	12·5	–	8·9	–	–	4·4
	2	72·3	9·5	–	13·2	–	–	4·5
	3	73·9	2·5	–	17·2	–	–	8·0
	4	71·8	8·3	–	14·3	–	–	5·6

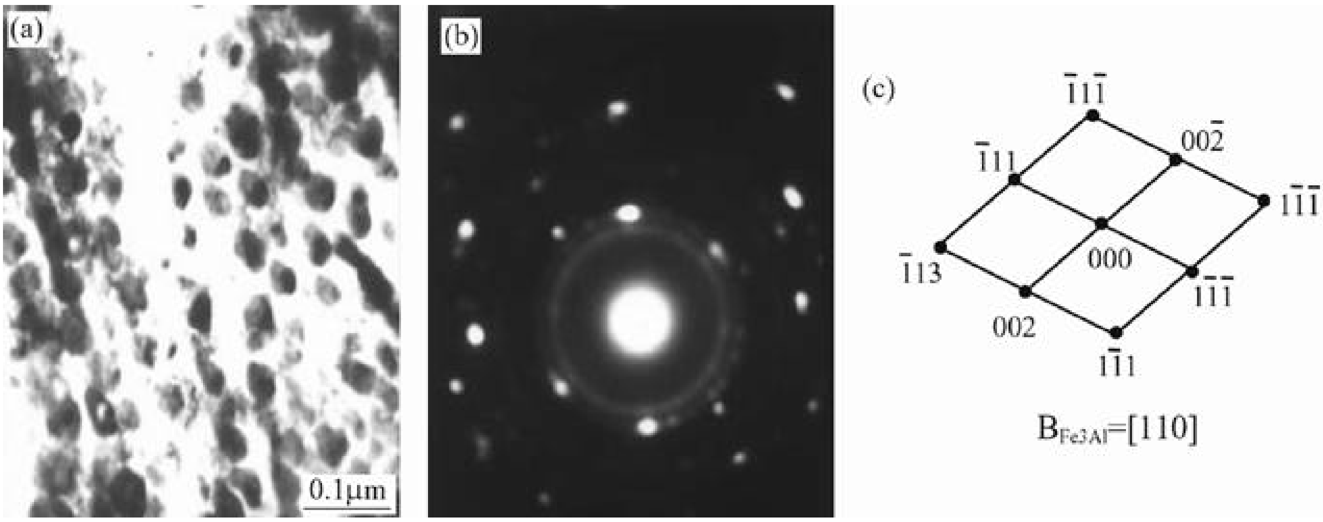

Figure 2. Fine structure of Fe_3Al in the Fe_3Al/Q235 diffusion bonding interface: (**a**) TEM morphology, (**b**) electron diffraction pattern and (**c**) index schematic diagram.

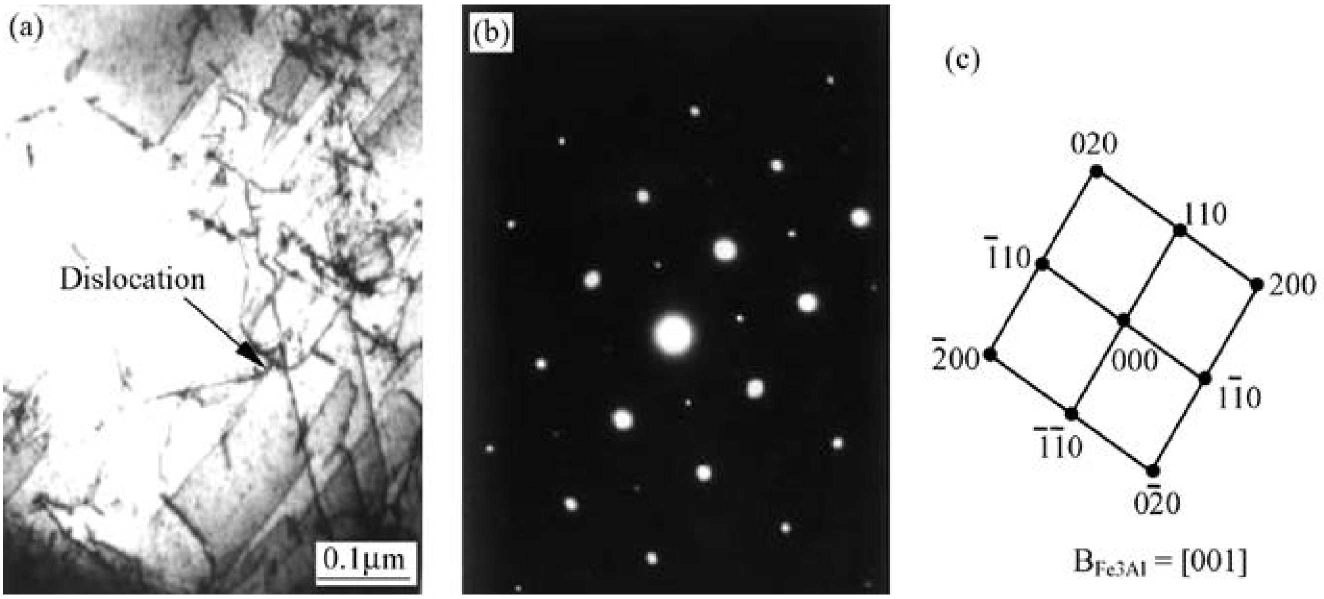

Figure 3. Fine structure of Fe_3Al from [001] orientation in the Fe_3Al/Cr18–Ni8 diffusion bonding interface: (**a**) TEM morphology, (**b**) electron diffraction pattern and (**c**) index schematic diagram.

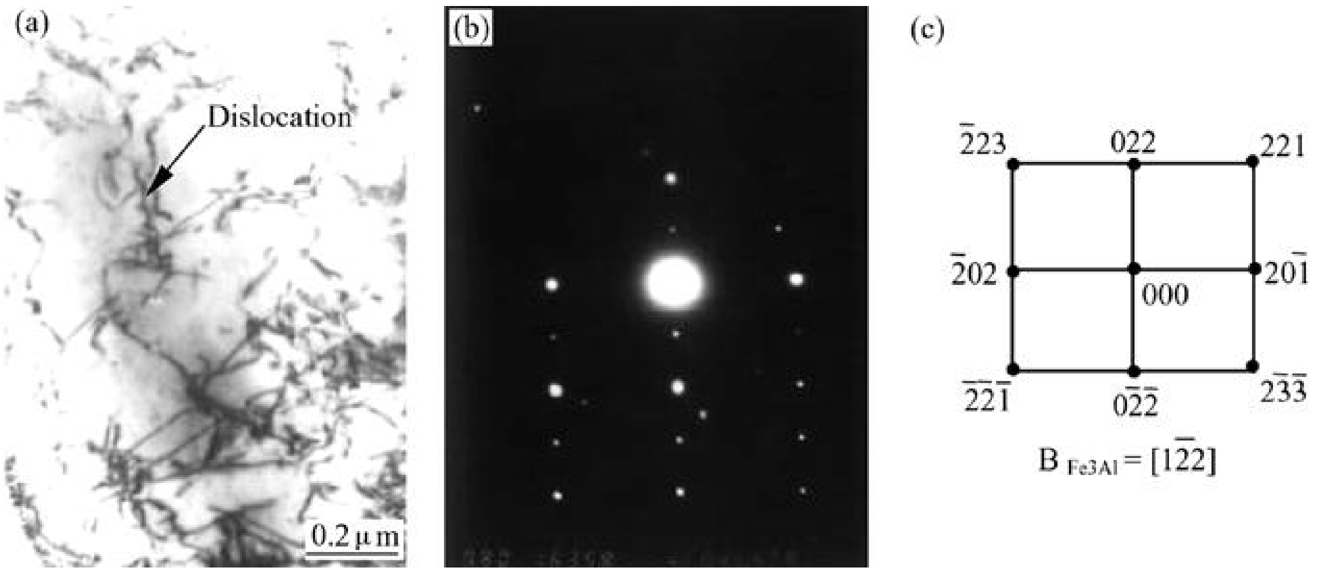

Figure 4. Dislocations in Fe_3Al from $[1\bar{2}2]$ orientation in the Fe_3Al/Cr18–Ni8 diffusion bonding interface: (**a**) TEM morphology, (**b**) electron diffraction pattern and (**c**) index schematic diagram.

4. Conclusions

The diffusion of Cr and Ni at the interface is favourable to improve the strength of the interface between Fe_3Al and steel. The width of Fe_3Al/Cr18–Ni8 interface transition zone is 35 μm. It is larger than that of Fe_3Al/Q235 interface transition zone (29 μm) under the condition of 1333 K × 60 min and a pressure of 15 MPa. The second phase rich in Cr and Ni distributes dispersively in Fe_3Al formed at the Fe_3Al/Cr18–Ni8 interface to cause dislocation couples with different spacing and even dislocation network. This is favourable to improve the joint strength at the Fe_3Al/Cr18–Ni8 interface.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 50375088) and the Natural Science Foundation of Shandong Province (Grant No. Y2003F05). The authors express their heartfelt thanks for this support.

References

David S A and Zacharia T 1993 *Weld J*. **72** 201

Gao D C, Yang W Y, Dong M, Huang J H and Sun Z Q 2000 *Acta Metall*. *Sinica* **36** 87

Li Y J and Wang J 2003 *J*. *Mater*. *Sci*. *& Technol*. **19** 81

Mckamey C G, Horton J A and Liu C T 1990 *J*. *Mater*. *Res*. **4** 1156

Mckamey C G, Devan J H and Tortorelli P E 1991 *J*. *Mater*. *Res*. **6** 1779

Sun Z Q, Gao D C and Yang W Y 2001 *Trans*. *J*. *Mater*. *Res*. **15** 69

Wang J, Li Y J and Wu H Q 2001 *Bull*. *Mater*. *Sci*. **24** 639

Wang J, Li Y J and Liu P 2003 *Int*. *J*. *Joining Mater*. *Sci*. **15** 25

Yin Y S, Fan R H and Xie Y S 1996 *Mater*. *Chem*. *Phys*. **44** 190