EFFECT OF TRANSITION METAL Ni ON WELDING PROPERTIES OF TITANIUM ALLOY STAINLESS STEEL①

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ABSTRACT With increase of Ti alloys use in industry, weld of Ti alloys to steel becomes more and more impotant. Microstructures and properties of diffusion welded joint of TC_4 to 1Cr18Ni9Ti adding the transition metal Ni have been observed with microscopy, SEM, EPMA and tested by tensile tests, respectively. The results show that atom diffusion and migration between Ti and Fe or C are effectively prevented by adding pure Ni as transition metal and a film joint is obtained. The properties of welded joint depend on weld rate of Ti to stainless steel and the thickness of Ni-Ti metallic compounds. The optimum weld parameters are as follows: weld temperature is 850 ℃, weld time is 5 min, weld specific stress is 10 MPa.

Key words Ti alloy stainless steel transition metal Ni diffusion welding

1 INTRODUCTION

Ti and its alloys have high Specific Strength and good erosion resistance, thus they have been widely used in aerospace and chemical industry. With increase of use of Ti alloys, the welding of Ti alloys to steel becomes more and more important.

When the Ti alloys are directly welded to stainless steel, amount of TiFe and $TiFe_2$ metallic compounds are formed in the weld joint because the solubility of Ti and Fe is very small and TiC is also formed because Ti is carbide strong formation element. On one hand, the formation of TiFe, $TiFe_2$ and TiC results in embrittlement of weld joint; on the other hand, large internal stress is formed because of much difference of linear expansion and heat transmission coefficient between Ti and steel, which leads to weld crack[1]. Now, the indirect weld is mostly realized by adding transition metal elements. The ultimate tensile strength of friction weld joint using interlayer aluminum is up to 150 MPa and fracture occurs at the aluminum layer[2]. The diffusion weld joint using (Ni-Cu) interlayer is very brittle and the strength is only 146 MPa[3]. A good joint of Ti to steel can be obtained by means of the diffusion welding using V-Cu or V-Cu-Ni intermediate layer and its strength is 1~ 2 times more than that of copper. However, the erosion resistance of this kind of joint cannot meet the demands of engineering.

Ni has good erosion resistance and can form unlimited solid solution and Ni-Ti metallic compound has a certain plasticity. Therefore, in this paper, the diffusion welding of TC_4 to 1Cr18Ni9Ti was conducted adding Ni as transition metal and the properties of the weld joint were also investigated.

2 EXPERIMENTAL

Master alloys: TC_4 Ti alloy (Ti-6Al-4V) and stainless steel (1Cr18Ni9Ti). Transition

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metal: pure Ni, which is foil with thickness of 40 μm. Master alloys were cut to cylinder specimens with *d* 10 mm × 20 mm. Welded surface was ground flat to be by 500# grinding paper and the oxide film was removed by pickle. Diffusion welding experitments were conducted on Gleeble-15000 thermal/stress analogue machine with a 1.33 × 10^{-3} Pa vacuum. The welding temperatures were measured with Ni-Cr and Ni-Al thermocouples fixed to stainless steel 1 mm from the side of weldface. The weld parameters are given as follows:

θ/ ℃	750	800	850	900
Specific stress *p* / MPa	2	5	10	20
t / min	2	5	10	20

Tensile tests and fracture analysis of weld joint were conducted after welding. The dispersion of elements in diffusion layer and the thickness of metallic compounds were measured by EPMA.

3 RESULTS AND DISCUSSION

3.1 Effect of weld temperature on the strength of weld joint

Weld temperature influences yield stress and atomic diffusivity, thereby it influences deposition rate, homogeneity of composition and microstructure of weld joint. Fig. 1 shows the effect of weld temperature on strength of weld joint and the thickness of Ni-Ti metalic compounds. It can be seen that when the weld temperature θ is 750 ℃, the strength of weld joint varies parabolically with θ and is very low (only 258 MPa), this is bacause the yield stress of welded material is still high, contact of welded surface is poorer and thermal excitation is not enough when the weld temperature is lower. With θ increasing, the yield stress of master alloy decreases and the atomic diffusivity increases, then the deposition rate and strength of weld joint increases. When θ is 850 ℃, the strength of weld joint is up to maximum (352 MPa). With further increase of weld temperature, the thickness of Ni-Ti metallic compounds increases quickly, then the strength of weld joint decreases. From Fig. 1 it can be also seen that when weld temperature is below 850 ℃, the thickness of Ni-Ti metallic compounds increases slowly and is smaller than 4 μm. When the weld temperature reaches 900 ℃, the thickness of Ni-Ti metallic compounds increases rapidly up to 7~ 8 μm.

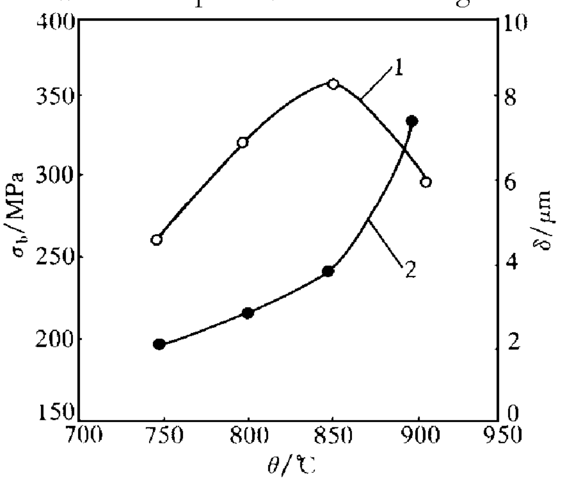

Fig. 1 Effect of weld temperature on strength and thickness of Ni-Ti metallic compounds of weld joint (*p* = 5 MPa, *t* = 10 min)
1 —strength; 2 —thickness

3.2 Effect of weld specific stress on strength of weld joint

Fig. 2 shows the effect of weld specific stress *p* on strength of weld joint (σ_b) and the thickness of Ni-Ti metallic compounds. It can be seen that when *p* is 1~ 5 MPa, with increase of *p*, the strength of weld joint increases rapidly, However when *p* is more than 5 MPa the influence of *p* on σ_b becomes small.

The above phenomenon can be explained as following: when *p* is small (such as *p* is 1 MPa), contact is only in the micro-protuberance of the welded surface, not in the pit, so the deposition rate and the strength of weld joint are lower. when *p* is larger than 5 MPa, with increase of *p*, the deposition rate changes little, so the properties of weld joint mainly depend on the thickness of Ni-Ti metallic compounds. From curve 2 of Fig. 2, it is seen that the thickness of Ni-Ti metallic compounds increases little with *p* increasing. The above analysis indicates that weld specific stress plays a very important role in

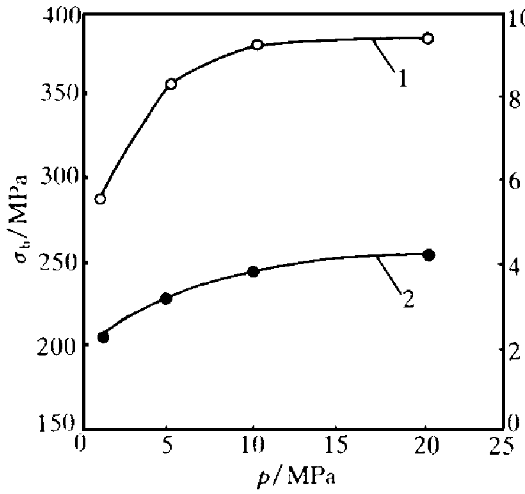

Fig. 2 Effect of weld specific stress on strength and thickness of Ni-Ti metallic compounds of weld joint (θ = 850 ℃, *t* = 10 min)

1 —strength; 2 —thickness

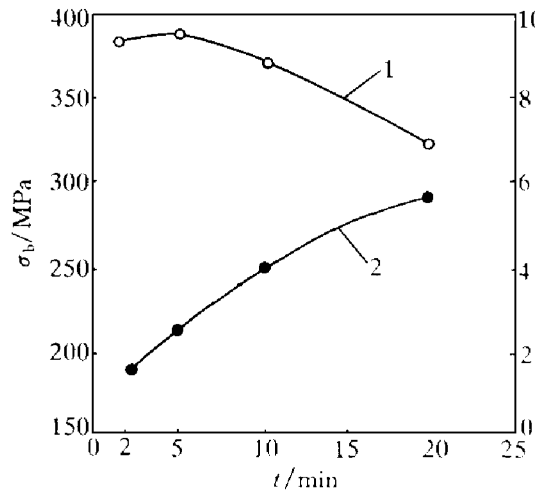

Fig. 3 Effect of weld time on strength and thickness of Ni-Ti metallic compounds of weld joint (θ = 850 ℃, *p* = 10 MPa)

the formation of practical contact and the process of atomic bonding, neither does it in the atomic diffusion . However , weld temperature plays an important role in the whole process of diffusion welding.

3.3 Effect of weld time on strength of weld joint

Weld time t has an effect on the creep of micro-protuberance and the quantity of atomic diffusion. The selection of weld time relies on the value of θ and p. Under optimum weld parameter(θ is 850 ℃ and p = 10 MPa), which is concluded from above experiment, the effect of welding time on the strength of weld joint was investigated, the results are shown in Fig. 3. From Fig. 3 it can be seen that when t is 2～10 min, σ_b changes little with increase of t. Howevere, When t is more than 10 min, the thickness of Ni-Ti metallic compounds increases remarkablely and the strength of weld joint decreases.

3.4 Dispersion of element and microstructure in diffusion layer

Fig. 4 is EPMA micro-area line analysis element dispersion curve of weld joint. Fig. 5 is optical microstrcture of weld joint. From Fe, Cr, Ni and Ti dispersion curves in Fig. 4 it is seen that a certain amount of diffusion occurs between transition metal Ni and master alloy and the mutual diffusion layer in which the composition changes gradually is formed near the interface.

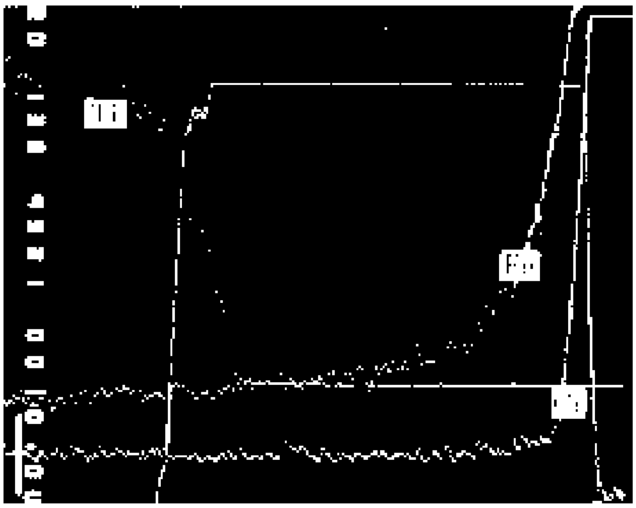

Fig. 4 Micro-area element dispersion curve of weld joint (θ = 850 ℃, *p* = 5 MPa, *t* = 10 min)

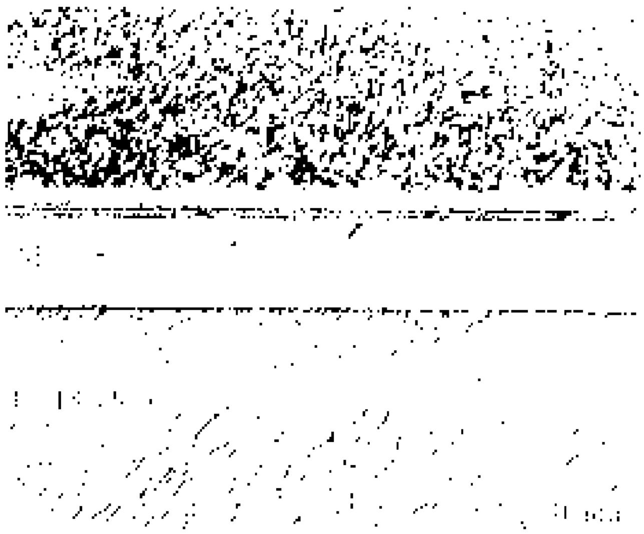

Fig. 5 Optical microstructure of weld joint (θ = 850 ℃, *p* = 10 MPa, *t* = 10 min, Ti side)

The diffusion distance from Ni to stainless steel is short and the slope of element dispersion curve is very sharp. The diffusion distance from Ni to Ti alloy is long and there exists an undular plateau in the element dispersion curve indicating that the metallic compound film is formed in diffusion layer. In this paper, the plateau size is defined as the thickness of metallic compounds.

Besides, from Fig. 4 it is also seen that Fe and Ti element did not permeate through the Ni intermidiate layer, so the addition of this layer relieved the hard and brittle metallic compounds of TiFe and $TiFe_2$ optical microscopy observations (Fig. 5) show that no obvious transition layer was found on the interface between transition metal Ni and stainless steel, but a wider transition layer and a bright strip were observed between Ni and Ti alloy. According to Fig. 3 the bright strip was determined to be Ni-Ti metallic compound film. Further observations also show that the width of bright strip increases with weld temperature increasing and weld time prolonging.

3.5 Fracture analysis of weld joint

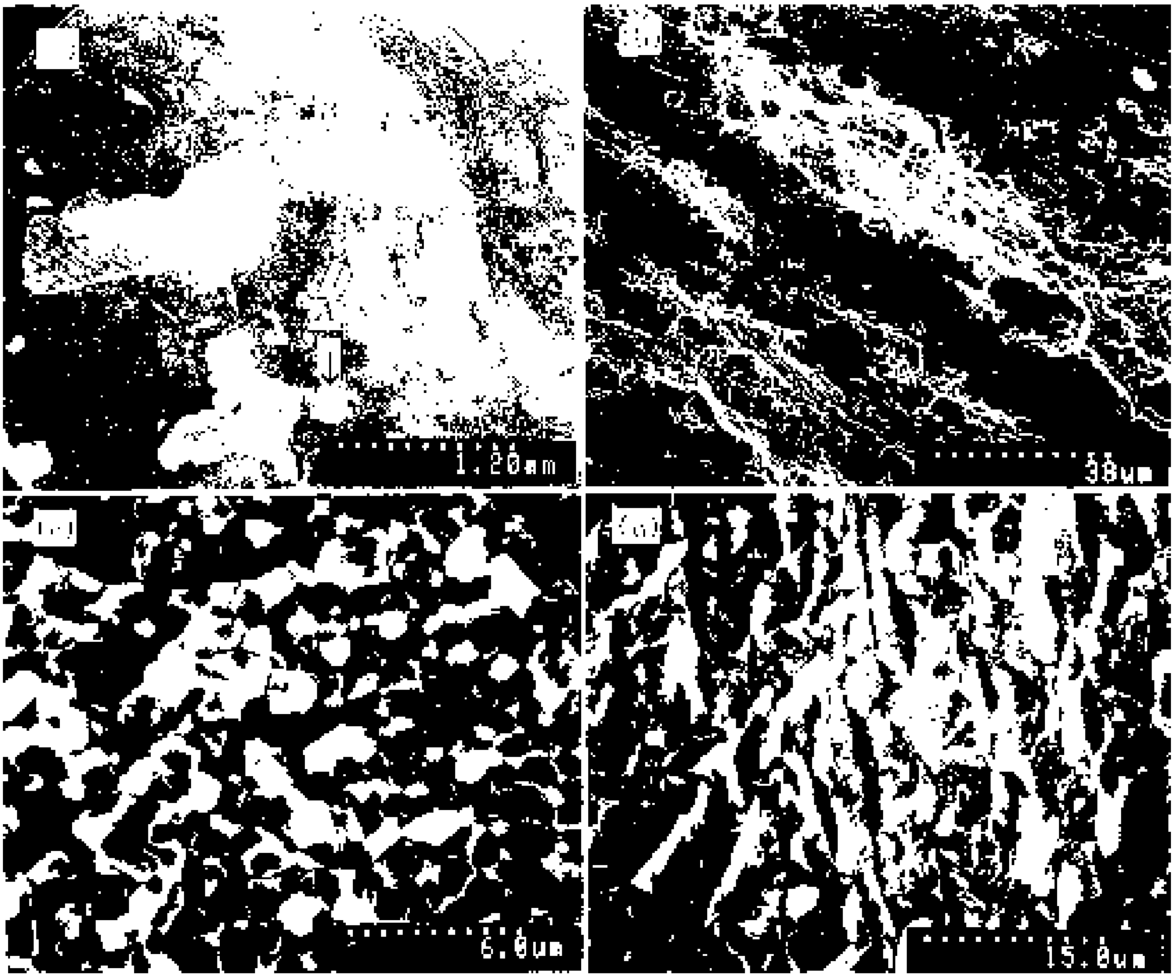

Fig. 6 Fracture SEM image of weld joint
(θ= 850 ℃, p= 10 MPa, t= 10 min, Ti side)
(a) —whole fracture configuration of weld joint; (b) —fracture configuration of Ni-stainless steel; (c) —fracture configuration of Ni-Ti in area *A* ; (d) —fracture configuration of Ni-Ti in area *B*

Being tensiled, most specimen fractures occur on the interface of Ni-Ti alloy or Ni-stainless steel. According to the variations of weld process, the proportion of fracture occuring at the interface of Ni-Ti and Ni-stainless steel is different when weld temperature is lower (θ is 750 ℃) or weld time is shorter (t is 2 min), the fractures mostly occur at Ni-stainless steel interface. With θ increasing and t prolonging, the proportion of fracture occuring at Ni-stainless steel interface decreases and increases at Ni-Ti interface increases. When θ is 900 ℃, the all fractures occur at Ni-Ti interface. Fig. 6 shows the SEM fracture configuration for the specimens welded under 850 ℃, 10 MPa and 10 min. It can be seen that the majority of fractures occurs at Ni-Ti interface and minority at Ni-stainless steel (Fig. 6(a)). There exists dimple and unwelded area in the fracture of Ni-stanless steel (Fig. 6 (b)). The fracture of Ni-Ti alloy is brittle and can be divided into two areas (A and B) (Fig. 6 (a)). Area A and B display particle and laminal configuration, respectively (Fig. 6(c) and Fig. 6 (d)).

4 CONCLUSIONS

(1) The hard and brittle phases of TiFe, $TiFe_2$ and TiC can be relieved using transition metal Ni and the firm joint.

(2) The good joint between the tansition metal Ni and stainless steel has been obtained, but the tansition layer is formed between Ni and Ti alloy. There exists a Ni-Ti metallic compound film in the transition layer which leads to the brittle fracture of weld joint.

(3) When the weld temperature is lower (or the weld time is shorter) the strength of Ti alloy-Ni-stainless steel mainly depends on the deposition rate of Ni and stainless steel. When the weld temperature is higher (or weld time is longer) the strength of the weld joint relies on the thickness of Ni-Ti metallic compounds. Under the experimental condition, the optimum weld parameters are as following: weld temperature $\theta = 850$ ℃, weld time $t = 5$ min, weld specific stress $p = 10$ MPa.

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