DISTRIBUTIONS OF RESIDUAL STRESSES IN DIFFUSION BONDING OF DISSIMILAR MATERIALS TIAL TO STEEL 40CR

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Abstract: Distributions of residual stress in diffusion bonding of dissimilar materials intermetallics TiAl to steel 40Cr were simulated by FEM calculation. Results showed that destructive residual stresses presented in the minute area adjacent to bond-line of the base material with smaller coefficient of thermal expansion. Reducing bonding temperature and diminishing bonding time are in favor of the mollification of interface tresses.

Key words: diffusion bonding, FEM calculation, coefficient of thermal expansion

0 Introduction

In diffusion bonding of dissimilar materials, owing to a large difference in physical and chemical property between the base materials or the base materials and interfacial reactors, especially the difference of their heat expansion coefficients, a high stress concentration is induced near the interface and the destructive residual stress is engendered in the joint [1-2]. Though the destructive chemical reactions and the brittle reactors at the interface can be restrained by accession of the interlayer in the definite condition, simultaneously, the interlayer also bring the mechanics asymmetry problem of joint. So, the study of the mechanics behavior and the mollification of interface stress during diffusion bonding with the interlayer and the suitable select of the interlayer in favor of attaining the joint with the excellent performance are provided with academic and actual significance [3-4].

Finite element method developed with the software and hardware technology of the computer as a structure analysis method, it has been largely used to analyze the residual stresses in the bonding of dissimilar materials. Therefore, FEM calculation was used in this paper, and the mechanics behavior of the joint diffusion bonded of intermetallics TiAl to steel 40Cr was analyzed.

1 Foundation of the simulation condition and model of the finite element

In this paper, finite element model was carried out using a two-dimensional elastic-plastic analysis for estimation of the residual stress, software environment of finite element simulation is the non-linear structure analysis program MARC7.2, the logical process program is MENTAT3.2, the process is computed on the PC IBM-P II 400.

Fig.1 is two-dimensional finite element model of simulated TiAl/Ti/V/Cu/40Cr diffusion bonding joint assembly. The corresponding local enlargement at the interface in finite element model with 8 nodes isoparametric elements is shown in Fig.2. Since it is a cylinder of axial symmetric, only half part of the assembly was modeled in this simulation. All the materials were assumed as uniform and isotropy in this work, and the materials properties used in this calculation are listed in Table 1. The von Mises yield criterion was applied to the plastic materials. The effects of temperature change on the materials properties (elastic modulus, thermal expansion coefficient, poisson ratio, work hardening and yielding strength) were taken into accounted. Cool stage is the only outer thermal loading, cooling temperature range is from 1200℃ to 20℃ according to different diffusion bonding parameters. It was also assumed that the temperature distribution was homogeneous in the joint during the cooling because the cooling time is long.

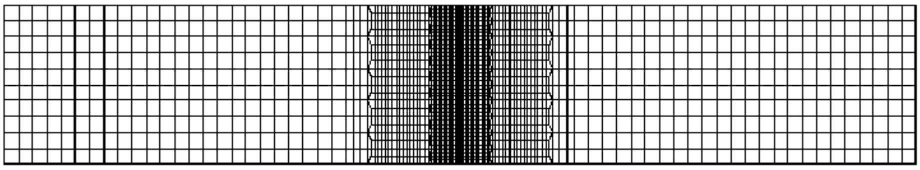

Fig.1 Two-dimensional finite element model of simulated TiAl/Ti/V/Cu/40Cr joint assembly

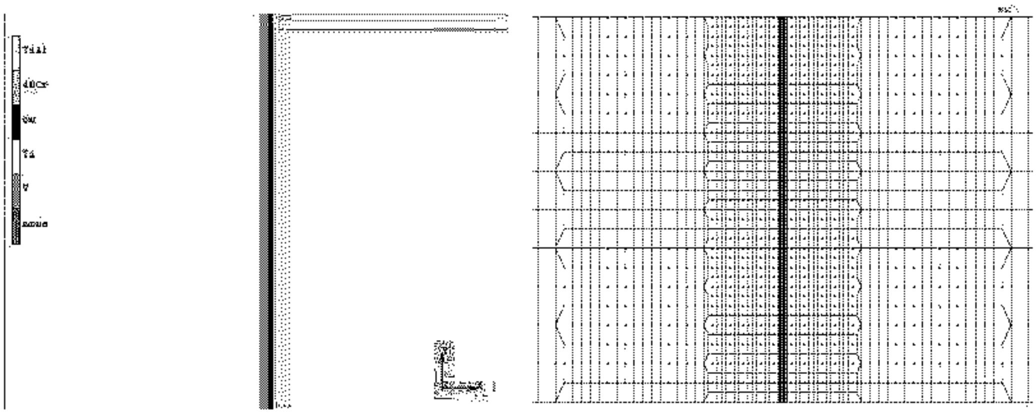

Fig.2 Local enlargement at the interface in finite element model

2 Distributions of residual stresses in diffusion bonding of dissimilar materials

In diffusion bonding of dissimilar materials, the new reacting phase frequently appeared at the interface, and which also bring more serious asymmetrical mechanics problem of, but the former papers ignored its influence when the residual stress of the diffusion bonding was simulated. So, in order to reveal the real distributions of residual stresses, in this paper, when the residual stress in diffusion bonding of TiAl/40Cr was simulated, The change of the brittleness phase TiC and the intermerallics Fe-Al engendered at the interface as the change of diffusion bonding parameters, which affected the distributions of residual stresses, were considered.

Fig.3 shows FEM simulation results of the distributions of residual stresses in diffusion bonding of TiAl/40Cr. From Fig.3a), it shows that the maximum value of destructive axial tensile stress σ_x presents in the narrowness zone close to bonding-line and brittleness phase interface, the zone is small, $\Delta r/r<0.05$, $\Delta h/h<0.1$, and the tensile stress σ_x becomes smaller and smaller as approaching symmetry axial of the cylinder, and it becomes the compress stress in the end. From above results, we deem these narrowness zones are week zones of joint, and cracks are germinated according to crack type I in this zone.

Table 1 Material parameters used in FEM calculation

Material	Temperature (K)	Elastic modulus (GPa)	Poisson ratio	Thermal expansion coefficient (10^{-6}/K)	Yielding stress (MPa)	Work hardening coefficient
TiAl	293	176	0.30	11.6	450	3.4
40Cr	293 473 573 673 773 873	211 202 195 186 177 165	0.28 0.28 0.29 0.29 0.28 0.25	13.0 13.2 13.4 13.9 14.2 14.4	789 706 681 613 390 431	3.3 3.0 2.7 2.0 1.5 1.2
Ti	293 473 573 673 773 873	94 95 83 77 72 63	0.40	8.4 8.6 9.1 9.3 9.4 9.8	450 200 150 100 85 70	1.9
Cu	293 473 573 673 773 873	108	0.35	17.1 17.2 17.8 18.1 20.3	69	1.5 1.4 1.3 1.2 1.1 0.9
V	293	132	0.30	8.3	452	2.8
W	293	410	0.30	4.5	450	3.2
Mo	293	327	0.30	5.2	450	3.5
Nb	293	104	0.30	7.2	410	2.4

The bigger value of shearing stress τ_{rz} (Shown in Fig.3b) appears in the minute area adjacent to bond-line too, and the value become smaller as approaching symmetry axial of the cylinder. So, the type Ⅰ crack presented firstly at the edge of the cylinder, in the interface brittleness phase or the minute area adjacent to TiAl bond-line. Since the crack comes in for the effect of the compress stress σ_x in expanding, the type Ⅰ crack is restrained. Simultaneously, with the impact of shearing stress τ_{rz} in the expanding area of the crack, the germinated crack should extend by the way of type Ⅱ crack, and the value of τ_{rz} determines the extension capability of the crack..

Fig.3c) shows the distribution of radial residual stress σ_r, it shows that the bigger value of radial stress σ_r presents around the center axial of the cylinder adjacent to the bond-line, the stress of TiAl side is the compress stress and the stress of steel 40Cr side is the tensile stress. The value of radial stresses σ_r is smaller in the area adjacent to the edge of the cylinder. The distribution of circumferential stresses σ_θ (Fig.3d) is similar to the radial stress σ_r. The result of FEM simulation shows that, when the diffusion bonding parameters change, the distribution characterization of residual stress in the joint does not change, but the values of the stresses change.

In conclusion, for the diffusion bonding of dissimilar materials, the destructive residual stress presents in the minute area adjacent to bond-line of the base material with smaller coefficient of thermal expansion, and the maximum value of residual stress presents at the edge of the cylinder, in the interface brittleness phase or the minute area adjacent to bond-line. From this we deem that the most important factor affecting performance of joint is the distribution characterization of residual stress in the minute area adjacent to bond-line of the base material with smaller coefficient of thermal expansion and interface brittleness phase, so the distribution of stresses in this area should be concerned on when analyzing the residual stresses of joints.

Fig.4 shows the effect of bond time on the residual stresses of TiAl side adjacent to bond-line, it shows that, when the bond time increases, the distribution characterization of residual stresses in the joint does not change, but values of the residual stresses increase. Microstucture analysis of the interface shows that the brittleness phase thickness at the interface increases as increasing the bond time, and thicker brittleness phase at the interface is, more serious mechanics asymmetry of the joint is, which leads to the increasing of the values of residual stresses in the joint. So, by way of reducing residual stress and improving the joint strength, the bond time should be shorter.

Fig.5 shows the effect of bond time on the residual stresses of TiAl side adjacent to bond-line, it shows that, when the bond temperature increase, the distribution characterization of residual stresses in the joint dose not change, but values of the stresses increase more prominently. Microstucture analysis of the interface shows that not only the brittleness phase thickness at the interface increases intensively as increasing the bond temperature, which leads to more serious mechanics asymmetry of the joint, but also as a result of temperature change range increasing, residual stresses produced by the different thermal expansion coefficients between dissimilar materials and interface brittleness phases increase. So, reducing bond temperature is propitious to optimizing the stress state at the interface. FEM analysis also shows that the effect of the bond press on distribution and value of residual stress at TiAl side adjacent to bond-line is tiny.

3 Conclusion

Distributions of residual stress in diffusion bonding of dissimilar materials were simulated by FEM analysis. Results showed that destructive residual stresses presented in the minute area adjacent to bond-line of the base material with smaller coefficient of expansion. Reducing bonding temperature and diminishing bonding time are in favor of the mollification of interface tresses.

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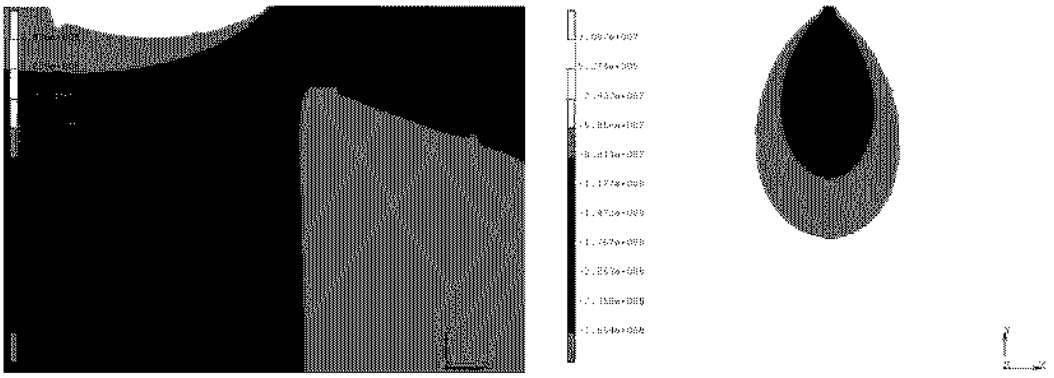
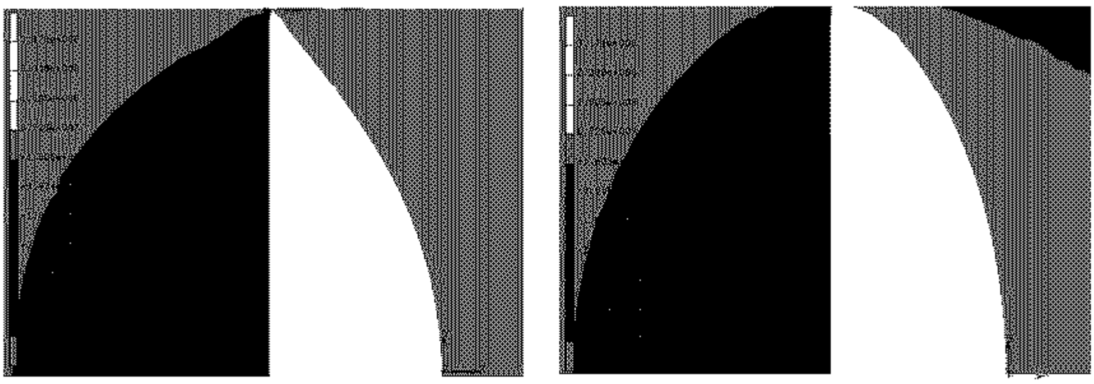
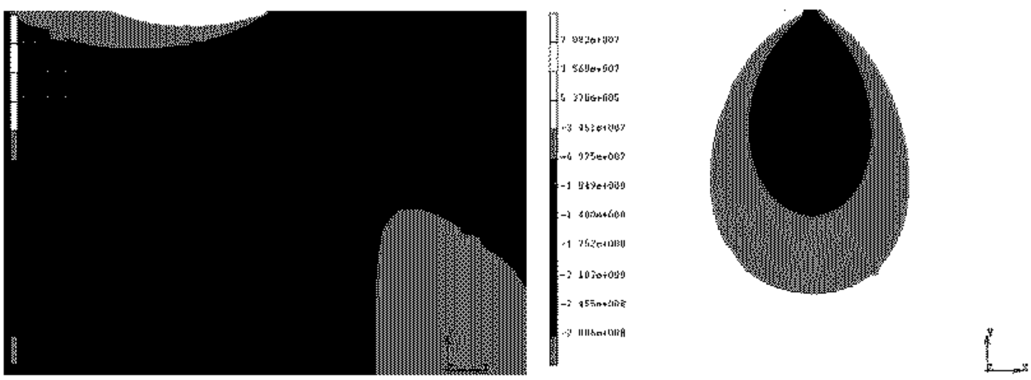


a) σ_x b) τ_{rz}



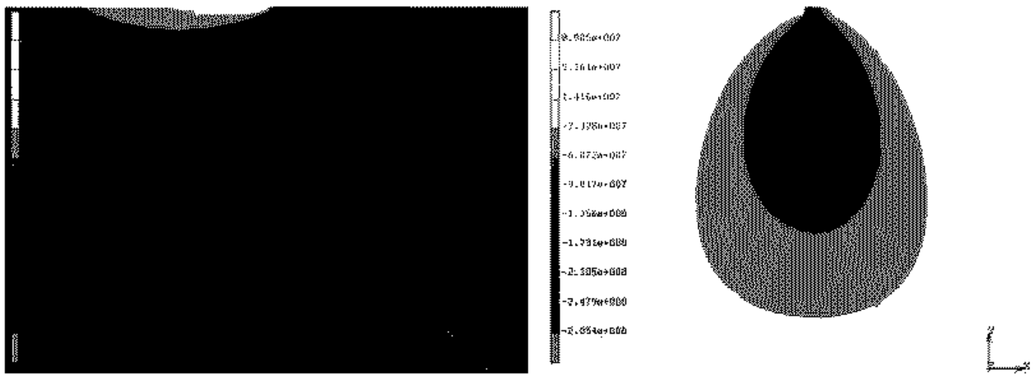
c) σ_r d) σ_θ

Fig.3 Residual stress distribution in the TiAl/40Cr joint



a) σ_x b) τ_{rz}

Fig.4 Effect of bonding time on residual stress distribution in the TiAl/40Cr joint (T=1073K, P=20MPa, t=120min)



a) σ_x b) τ_{rz}

Fig.5 Effect of bonding temperature on residual stress distribution in the TiAl/40Cr joint (T=1273K, P=20MPa, t=30min)