New method to diffusion bond superalloys

A. A. Shirzadi and E. R. Wallach

A new method for diffusion bonding nickel base and cobalt base superalloys has been developed, which is based on non-chemical oxide removal before the bonding process. Using this method, diffusion bonds were produced in nickel base and cobalt base superalloys with 'virtually invisible' bond interfaces and compositions very close to the bulk alloys. The bonding time required is about 1 h and the results of severe mechanical tests of the bonded samples, including directionally solidified (DS), single crystal and dissimilar superalloys, are very promising. The new oxide removal method is very rapid, does not require the use of any sophisticated equipment and is not a costly process. The high temperature properties of bonded samples are currently being investigated. European and USA patents have been applied for and the details of this new method are to be published in the future. STWJ/390

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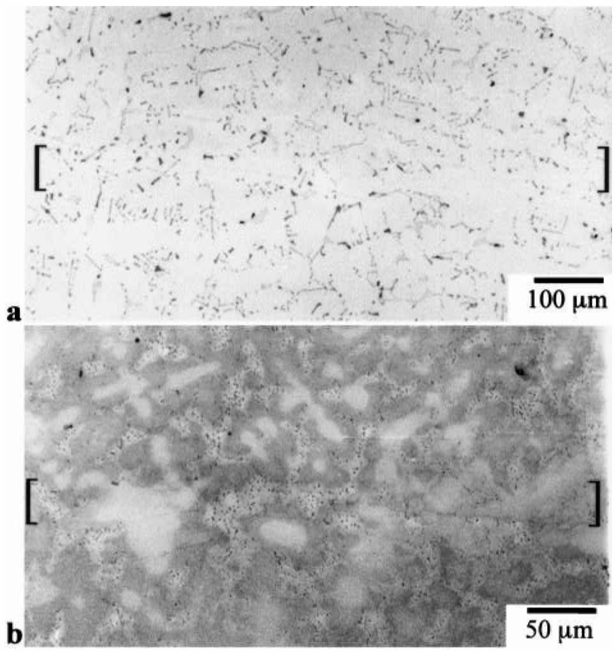
The authors are at the Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, UK (as10043@cam.ac.uk, erw1@cam.ac.uk). *Revised version of a presentation at 'Microstructure and performance of joints in high temperature alloys', organised in London on 20 November 2002 by The Institute of Materials; accepted 6 February 2003.*

BACKGROUND

Nickel base and cobalt base superalloys are especially suitable for the manufacture of components to be used in high temperature applications, e.g. turbine blades and rotary discs used in gas power generation plants and aircraft engines. As a result of the extremely high cost of manufacturing, maintaining and repairing such components, the joining of superalloys has been of major interest to the power plant and aerospace industries, and a considerable amount of research is being carried out in this field. Despite recent developments in the fusion welding of superalloys using laser or TIG welding processes, the formation of cracks remains a major problem.[1,2] Other joining methods, such as brazing and transient liquid phase (TLP) diffusion bonding, normally require long bonding times and/or post-bond heat treatments. Therefore, none of the existing methods for joining superalloys has proved entirely satisfactory and viable for design engineers. Hence, further improvements of the existing joining methods, as well as the development of new joining approaches, are necessary in order to meet some of the more demanding requirements when joining high performance materials.

NEW DIFFUSION BONDING METHOD

Diffusion bonding is a process by which faying surfaces are brought into sufficiently close contact using an applied pressure at elevated temperature to allow bond formation by atomic interdiffusion across the joint interface. There are several hypotheses which have been proposed to suggest how a bond is formed in a diffusion bonding process.[3] One of these hypotheses emphasises the effect of surface oxide layers on the joining process. It was proposed that the observed differences in the weldability of various metals can be attributed to the different properties of their surface films, and hence it is assumed that all metals will bond if thoroughly cleaned surfaces are brought together within the range of interatomic forces.



1 Optical micrographs (etched) of *a* cobalt base superalloy PWA647 and *b* nickel base superalloy C1023, bonded using new diffusion bonding method. Brackets show approximate location of bond line

Table 1 Chemical compositions (wt-%) of alloys used in this work (balance Ni except for cobalt base superalloy PWA647)

Superalloy	Cr	Co	Mo	W	Al	Ti	B	C	Si	Zr	Others
Inconel 718	18·3	0·1	2·85		0·5	0·92	0·003	0·02	0·08	0·01	0·08Mn, 0·0004S
Inconel 738	16	8·5	1·75	2·6	3·4	3·4	0·01	0·17		0·1	1·75Ta, 0·9Nb
C1023	15	10	8·5		4·2	3·6	0·006	0·15			
DSR142	8·3	13	1·5	6	3·4						7Ta, 1·8Hf
PWA647	23	Bal.				0·2		0·6		0·5	10Ni, 7W, 3·5Ta

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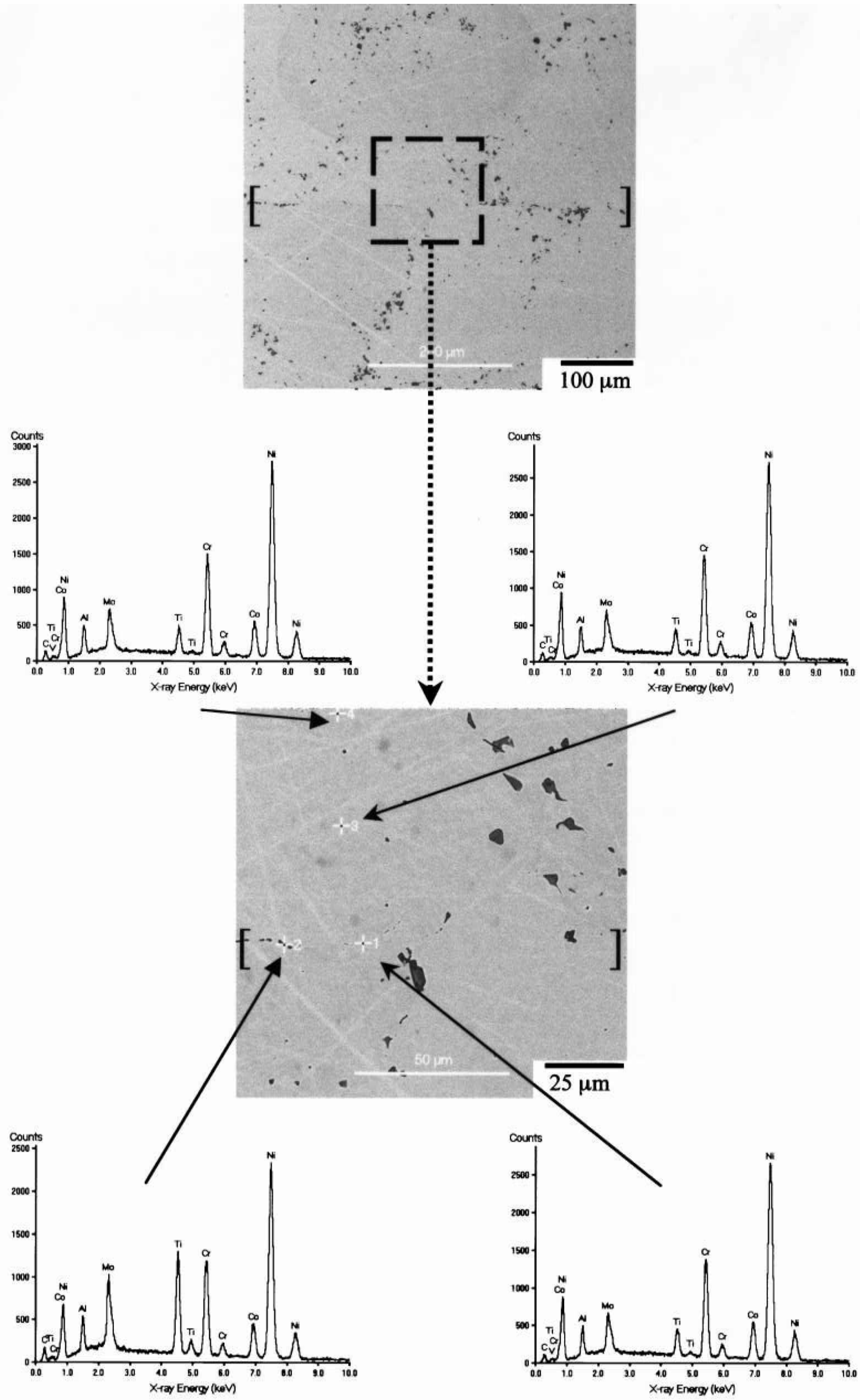
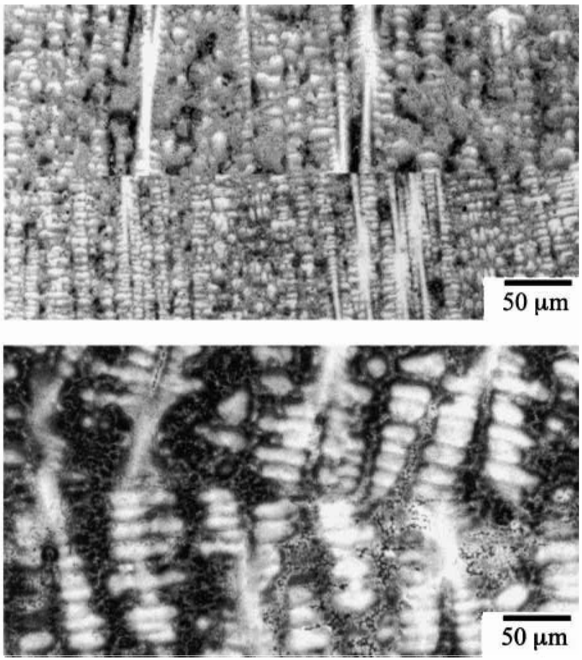


2 SEM micrographs of heat treated bond in C1023 superalloy and results of EDS analysis show microstructure and composition of bond line are very similar to bulk alloy. Brackets show approximate location of bond line

Although surface oxide films can easily be removed by grinding the faying surfaces of an alloy, a new oxide layer forms immediately as a result of the exposure of the ground metallic surface to ambient oxygen. The reformation of the surface oxide is virtually instantaneous for many metallic alloys including most superalloys since they contain elements with a high affinity for oxygen, e.g. Ni, Cr, Al, Co, Ti, W. Therefore, it would be beneficial to develop a method that can remove the surface oxide and then prevent its reformation on the cleaned faying surfaces before bonding.

A new method for diffusion bonding nickel base and cobalt base superalloys has been developed in this work, and is based on non-chemical oxide removal before the bonding process. Using this method, most of the stable



3 Optical micrographs (etched) of nickel base *a* directionally solidified superalloy DSR142 and *b* single crystal SRR 99 bonded using new diffusion bonding method. Bond lines are clearly visible

oxides on the faying surfaces of the superalloy are replaced with a very thin metallic layer. The treated faying surfaces are believed to be either virtually oxide free or contain far less stable and less detrimental surface oxides than the original surface oxide on an untreated surface. The details of this new method are to be published when patent protection has been completed. However, it must be emphasised that the new oxide removal method is very rapid, does not require the use of any sophisticated equipment and is not a costly process.

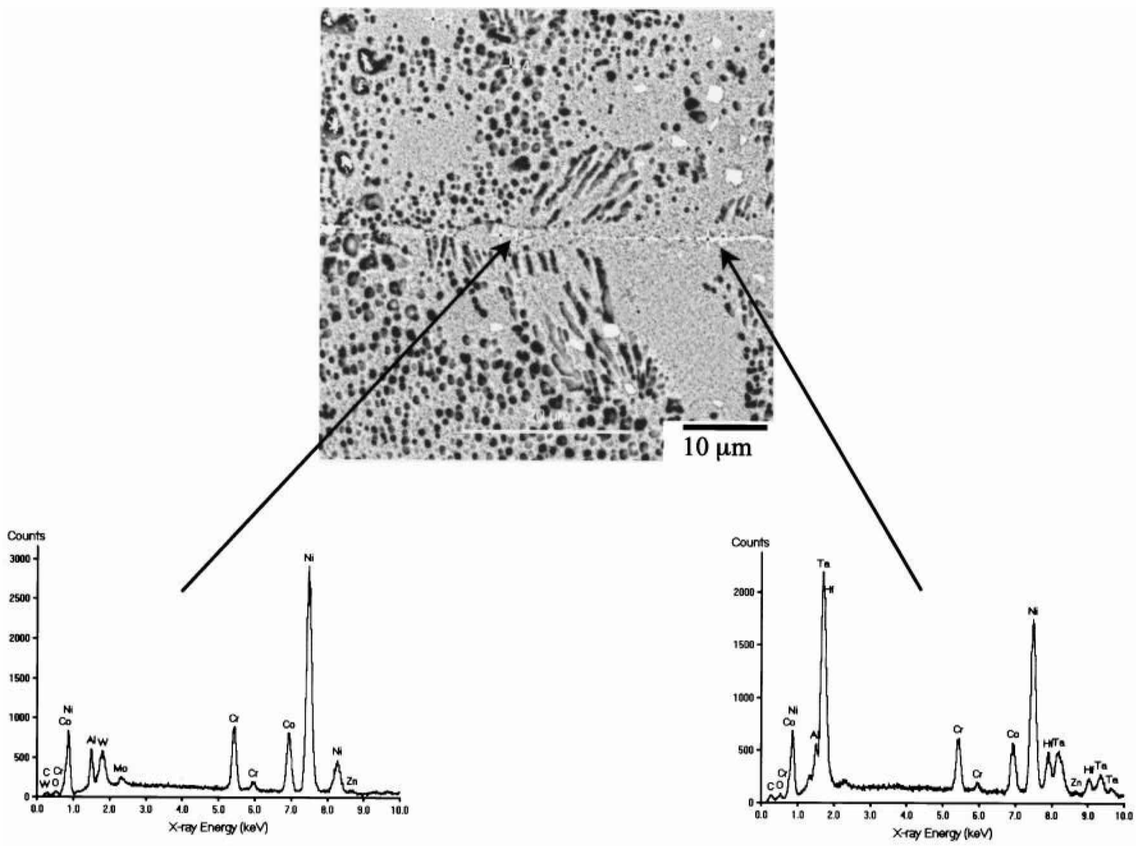
EXPERIMENTAL PROCEDURE

Several nickel base superalloys, including directionally solidified DSR142, single crystal SRR99, and a cobalt base superalloy PWA647, were used in this work. The compositions of the bonded alloys are shown in Table 1.

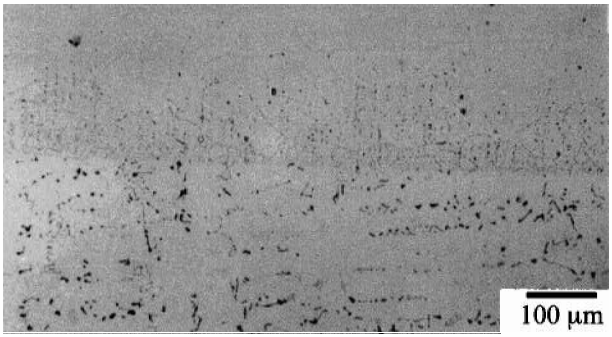
Diffusion bonding of these various superalloys was carried out after treating the faying surfaces using the new oxide removal method. Each sample was bonded in vacuum (10^{-4} mbar) at a temperature between 900 and 1250°C and under a pressure which ranged between 3 and 10 MPa. The precise parameters were dependent on the particular alloy being joined. The bonding time for all samples was 1 h. Some of the samples were post-bond heat treated at 1150°C for 24 h. A few joints between dissimilar alloys were also produced to assess the capability of the new method for producing more complex or multilayer components.

EXAMINATION OF BOND LINE MICROSTRUCTURES

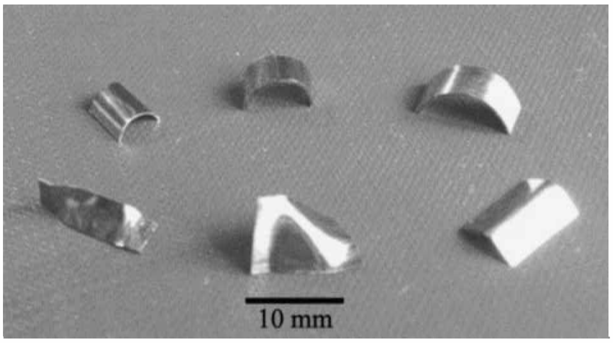
Optical microscopy, scanning electron microscopy (SEM) and X-ray energy dispersive spectroscopy (EDS) were used to study the microstructures and compositions of the bond lines. Figure 1 shows the microstructures of the bonds made in two superalloys (C1023 and PWA647) with equiaxed grains in the as bonded condition. The microstructures of the bond lines are very similar to those of the corresponding bulk alloys, and hence locating the bond lines proved quite difficult. Grains generally crossed the bond line and so left



4 SEM micrograph of DSR142 superalloy and results of EDS analysis show the formation of discontinuous phase (bright) on bond line containing heavy elements such as Ta and Hf



5 Optical micrograph (etched) of dissimilar joint between Inconel 718 (upper part) and cobalt base superalloy PWA647 (lower part) bonded using new diffusion bonding method



6 Bonded samples of various nickel and cobalt base superalloys, including dissimilar and multilayer joints, which have been subjected to severe mechanical deformation of bond lines without showing any failure

only a very small indication of the initial location of the joint interface.

Backscatter electron SEM imaging and EDS were used to investigate any compositional variations in the bond zone compared with that of the bulk alloy, using a diffusion bonded C1023 sample which then had been heat treated at 1150°C for 24 h. Figure 2 shows SEM micrographs of this sample together with the results of EDS analysis on and away from the bond line. It is clear that there is little compositional variation, and any possible difference between the compositions of the bond line and the bulk was below the detection limit of the EDS analyser used (<0·1 wt-%).

In contrast, the joint interfaces in the bonded directionally solidified superalloy DSR142 and the single crystal SRR99 could easily be located as a result of differences in grain alignment or phase distribution in the pieces bonded—see Fig. 3.

Further examination, using SEM and EDS, of the bond in DSR142 revealed that a discontinuous phase was formed on the bond line. There was a high concentration of heavy elements such as Ta and Hf within this discontinuous phase—see Fig. 4 which shows analyses of the bond line with (right-hand side) and without (left-hand side) the discontinuous phase. However, despite the presence of this phase, the bond strength was still excellent, probably owing to the discontinuity of these phases. The effect of post-bond heat treatment on the amount and distribution of this phase will be investigated in future work.

A dissimilar joint between the nickel base superalloy Inconel 718 and the cobalt base superalloy PWA647 was also produced. Figure 5 shows the microstructure of the bond line and it is clear that a substantial amount of interdiffusion across the joint interface has occurred during the 1 h bonding time. No continuous interfacial phase was observed at the bond line.

EVALUATION OF BOND STRENGTH

In order to evaluate the bond strengths of the samples, thin slices with thicknesses between 300 μm and 1 mm were cut and bent across the bond line. Although quantitative mechanical testing was not carried out in this work, the results after severe bending are extremely promising. Most of the sliced samples showed no preferential failure or even lack of ductility at the joint interface. In fact, the slices produced from bonded samples behaved like monolithic pieces of the alloy when tested in a similar manner.

Despite the presence of a distinguishable bond line in the nickel base DS alloy and single crystal, their bond strengths and ductility were also comparable to those of the parent alloys. Similarly, the dissimilar joint between the nickel and cobalt base superalloys, Inconel 718 and PWA647, respectively, had excellent bond strength. Figure 6 shows some bonded samples, including dissimilar joints, which withstood severe mechanical deformation without showing any failure of or preferential fracture on the bond lines.

CONCLUSION

A new diffusion bonding method has been developed, based on removing the surface oxide before bonding. Using this new approach, diffusion bonds in nickel base and cobalt base superalloys were produced with interfacial microstructures and compositions very similar to the bulk alloys. The bonding time required is about 1 h which is substantially lower than values used in previous diffusion bonding approaches, e.g. 10–48 h. The results of severe mechanical tests of the bonded samples, including DS, single crystal and dissimilar superalloys, are very promising. The high temperature properties of bonded samples are currently being investigated.

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