Abstract

The present research work started with an objective to understand the fundamental kinetics of transient liquid phase (TLP) bonding of nickel-base superalloys; Inconel 718 (IN 718) and deliver methodologies for the improvement of bond properties. The role of process parameters in joining IN 718 with the TLP bonding process is explored with an aim to improve the mechanical properties of the bond. From the experimental investigation, it was ascertained that the bonding temperature, time, and interlayer type and size are the most important process parameter of the TLP bonding process. The higher bonding temperature, time, and optimal interlayer thickness improve the mechanical properties of the TLP bonded IN 718 joint. Higher bonding temperature reduces the isothermal solidification (IS) time. Inadequate bonding time leads to the formation of centreline eutectics in the TLP joint due to athermal solidification of the residual liquid remaining in the bond area. The IS time of the TLP bonding process depends upon factors like temperature, the diffusivity of the melting point depressants (MPD), and the width of the interlayer material. To obtain good bond properties, complete isothermal solidification is necessary. In order to determine IS time, the kinetics of TLP bonding should be known to the industries. To study the kinetics of the TLP bonding and to reduce the experimental time and cost, the interrupted differential scanning spectroscopy (DSC) method was used in the current investigation. The DSC method successfully described the kinetics of the TLP bonding. From the enthalpy of solidification of the DSC curve, the IS time of a material was obtained. And the results of the investigations are in good agreement with the experimental results of the other author.

The presence of centerline eutectic and boride precipitates in the microstructure of the TLP bonded IN 718 joint affects the mechanical properties of the joint. The number of eutectics and borides present in the bond zone should be minimized to enhance the mechanical properties of the bond. This can be achieved to a great extent by prolonged isothermal holding. However, it can induce adverse effects by modifying the microstructure of the base material. Therefore, the homogenization stage of the TLP bonding is essential in removing these deleterious phases. The concentration gradient, borides, and the second phase eutectics formed in the isothermal solidified zone can be reduced by the employment of the homogenization stage of the TLP bonding. Homogenization can dissolve the second phase precipitates from the bond zone and achieve a uniform microstructure. Therefore, homogenization of the bond was carried out as per the TTT diagram of the IN 718. Which resulted in improved mechanical properties of the bond and uniform microstructure. Sometimes, complete homogenization requires higher time to dissolve all the phases to improve the mechanical properties of the bond. Therefore, post-bond heat treatment (PBHT) processes can be implemented to improve the mechanical properties without inducing any harmful effect of prolonged heating. With the application of the PBHT process, the room temperature tensile strength, room temperature fatigue life, and elevated temperature tensile strength of the TLP bonded IN 718 joint has improved significantly. The strength of the TLP bond could be compared to that of the heat-treated base material. The formation of γ'' and γ' precipitates in the IN 718 joint during PBHT, enhanced the mechanical properties of the joint.

TLP bonding is a diffusion-controlled process, therefore, complete isothermal solidification requires higher bonding time. In the case of incomplete isothermal solidification, the remnant liquid solidifies athermally and forms an inhomogeneous microstructure. The thermal mismatch between the bond zone and base material and the inhomogeneous microstructure induces residual stress in the TLP bonding. Residual stress plays a significant role in designing and manufacturing commercial aero-engine components made of IN 718 for their excellent fatigue strength. Thus, a quantitative analysis of the residual stresses is an important aspect of TLP bonding. In this study, the evolution of the surface residual stresses in the TLP bonded samples were investigated using a non-destructive X-ray diffraction measurement $\sin^2\psi$ technique. The quantitative analysis of residual liquid showed there is a compressive stress present in the TLP bonded IN 718 sample.

Interlayer plays important role in the TLP bonding. Designing a suitable interlayer material can reduce the isothermal solidification time. The interlayer material must contain the main alloying elements of the base material and at least one MPD element in order to uphold higher strength. Therefore, in this current study, a Ni-Cr-B-Si-Fe base filler alloy powder has been synthesized by mechanical alloying (MA) technique in a high-energy ball mill to join IN 718 by TLP bonding. The MA process produced a nano-crystalline, and a non-equilibrium solid solution of face-centered cubic structured Ni (Cr, Fe, Si, B) interlayer material. IN 718 superalloys were joined by the TLP bonding process using the newly developed interlayer material successfully.

Keywords: Transient liquid phase bonding, Inconel 718, Post-bond heat treatment, Isothermal solidification, High- temperature property, Mechanical alloying, Homogenization stage