B. Development of an Explosive Bonding Process for Joining Commercially Pure Niobium to 6061 T6 Aluminum

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Introduction

Explosive welding (EXW) is a unique solid-state bonding process in which an explosive charge is used to accelerate two metals together at a sufficient speed to produce a metallic bond. This technique can be used to join materials which present significant difficulties for conventional fusion welding techniques. The bonding of niobium to aluminum is such a case because of the potential formation of brittle Al-Nb intermetallics during the fusion welding process. Improvements in the EXW process have allowed Nb plate to be directly bonded to the Al in the T6 condition, thus avoiding any additional heat treatments.

Technical Approach

A series of explosive bonds are made using 508 mm x 508 mm x 9.5 mm thick commercially pure niobium and 508 mm x 508 mm x 203 mm thick 6061 Al in both the T4 and T6 temper conditions. In these tests, the location of the detonation of the explosive is varied, and the addition of both Nb and annealed Al interlayers is investigated in an attempt to produce an acceptable bond. The resulting bond integrity is analyzed using both ultrasonic testing techniques and optical metallography. Testing of the bond mechanical properties is performed using a series of testing methods specially designed to determine the shear, tensile, and impact properties of the explosive bond.

Results and Discussion

Al-Nb explosive bonds with both good bond integrity and mechanical properties have been produced using a detonator placed in the center of the Al and Nb plates and two thin intermediate layers have been successively bonded to the thick Al plate. The placement of the detonator in the center of the plate, rather than on the side of the plate, allows for more uniform bond integrity in the important middle regions of the Al and Nb plates. This result is confirmed using ultrasonic examination of the bond interface. The use of multiple interlayers, consisting of thin sheets of Al and Nb, allow smaller explosive charges to be used at the Al-Nb interface, thus decreasing the likelihood that melting occurs and intermetallic phases may from. In addition, these interlayers allow the Nb plate to be directly bonded to the 6061 Al plate in the T6/T651 temper condition, with no subsequent heat treatments required.

The mechanical properties of the Al-Nb explosive bonds have also been measured for different EXW process conditions. Whereas the tensile and shear properties remain rather constant with changes in the placement of the detonator and the addition of Al and Nb interlayers, the impact strength of the bond shows significant differences with these changes in the process parameters. In particular, the addition of the thin Al and Nb interlayers significantly increases the impact energy of the bond. Care must be taken in maintaining a suitable detonation velocity in the bonding of the Al interlayer. For example, insufficient detonation velocities are shown to cause a change in the failure mode in the bond, with failure occurring at the Al-Al interface, rather than within the Al interlayer, which is the predominant failure location in the tests.

Conclusions

EXW is used to join commercially pure Nb and 6061-T6 Al. In order to achieve acceptable bond integrity, thin Al and Nb interlayers are used to prepare the surface of the 203 mm thick Al plate for bonding to the 9.5 mm thick Nb plate. The bond integrity is verified using ultrasonic testing, and specialized mechanical tests are used to measure the properties of the joint. These tests show a bond tensile strength greater than 250 MPa, a shear strength greater than 124 MPa, and an impact strength measured in a 161 mm^2 sample of greater than 16 J.

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