D. Laser and E-beam Joining Unusual Fe-base, Ni-base and Refractory Alloys*

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Introduction

Over the past few years our welding group has been asked to join some out-of-the-ordinary metal alloys, usually in dissimilar combinations and on parts of a very small size scale. Our approach has been to use high energy density beam (laser and electron) processes, both pulsed and continuous. We summarize here a few of the more interesting cases, including: small parts (LIGA technology) of electroplated materials (Ni, Ni-Co, Ni-Mn, Fe-Ni); mm-thick sheets of Nb to Ta with extremely large density difference; Ferralium to Nitinol (Shape Memory alloy) where Ni-Ti chemistry differences yield brittle intermetallics in the fusion zone; and Hiperco 50 (Fe-49 Co-2 V) to PH 13-8Mo stainless steel, where HAZ brittleness and minimal distortion are concerns.

Technical Approach

Laser spot and seam welding of Ferralium to Nitinol, plated LIGA materials, Nb to Ta and Hiperco 50 to PH13-8Mo SS employed pulsed Nd:YAG welders. Process parameters of focus (spot size), pulse energy (2 to 7 J/pulse) , pulse length (4, 7 and 9.9 ms), and frequency were studied in air, UHP Argon, and UHP forming gas ($5H_2$/95Argon) shielding. Fit-up and beam angle-to-sample orientations were also studied. Direct welding of Ferralium to Nitinol was unsuccessful, so, both laser and electron beam brazing were attempted, using several filler metals including: Cu-Sil, Sil-Fos, and Ni. Laser process parameters and filler metal dimensions were adjusted to account for high reflectivity of the latter. Electron-beam brazing used a Leybold-Heraeus hi-vacuum hi-voltage e-beam 15 KW (150kV at 100 mAmps) machine. LIGA welds were produced with laser spot sizes as low as 40 μm. A significant process study was necessary to weld without excessive spatter.

Results and Discussion

We were unable to weld Ferralium to Nitinol without significant cracking. The base metals by themselves welded nicely, giving smooth, shiny welds, but all dilutions showed cracking. Poor fit up exacerbated this; however, even when good, the welds still cracked due to the metallurgical incompatibility (brittle Fe-Ti/Ni-Ti intermetallic formation) of the base metal pair. High reflectivity of braze materials attempted made it difficult to effectively laser heat the braze metal without melting the base materials, giving similar cracking as when welding the dissimilar metals directly; laser power sufficient to melt the braze materials generally melted the base materials also. Direct welding using the cw e-beam produced cracking as with the laser. E-beam brazing with CuSil filler gave the best results. Great care in process control, joint fit up and filler metal geometry were necessary to make the process work. Hiperco 50 rotors were successfully laser spot-welded to PH 13-8Mo shafts despite concerns of Hiperco's HAZ brittleness. Six stitch welds (three pulses/set, ~50% overlap) were made symmetrically around the joint circumference. The units were mechanically tested, exceeding design and modeled failure criteria by 50 % with acceptable distortion. LIGA (electroplated) materials were successfully welded using small spot sizes. The process requires extensive testing to ensure non-violation of the welding-drilling transition common in such a “small” regime. An Fe-Ni alloy exhibited poor weldability because of S-containing bath additions. Nb to Ta pulsed laser seam welds of 1mm sheet were also successful. Large differences in material density played a role in choosing the proper welding schedule. Interestingly, the plume generated evidenced directionality in that it tilted towards the greater density material while pool ripple marks showed directionality in the opposite sense.

Conclusions

Joining problematic materials is often necessary to enable new technology or improve existing ones; however, this requires expenditures in developing the joining process. Specific scenarios reported upon included: laser spot welding Ferralium to Nitinol gave cracked welds due to brittle intermetallics, even though either material was weldable by itself. Laser brazing was difficult because of braze material reflectivity, so electron beam brazing was required with appropriate filler material and fixturing; Hiperco 50 disks were pulsed laser welded to PH 13-8Mo shafts, exceeding design criteria; tiny LIGA parts were successfully welded (though some alloys tested had poor weldability) using ~40 μm laser spot sizes while avoiding drilling. Successful Nb to Ta seam welds' large density difference gave pool ripples evidencing flow directionality from the high to low-density material.