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SOLID STATE BONDING
of CuCrZr to 316L Stainless Steel for ITER Applications

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Introduction

Dissimilar metal bonds between CuCrZr and 316L stainless steel were prepared using two different solid state joining techniques. In the first instance, hot isostatic pressing, a high temperature diffusion bonding process was used to join the copper alloy to the stainless steel substrate at temperatures near 1000°C. In the second instance, explosion bonding at ambient temperature was employed. These two techniques both yielded mechanically robust joints, where the strength of the interface exceeded that of the copper alloy, the weaker of the two substrates. However, the two bonding techniques produced near-joint microstructures that were very different. The microstructure and mechanical performance of CuCrZr/316L stainless steel joints prepared via both techniques are compared. Microstructural analysis of the joints included scanning electron microscopy, electron microprobe analysis and Auger spectroscopy techniques. The bulk mechanical properties of the substrate alloys were very different as well and are described. Particular emphasis is placed on the residual mechanical properties of the CuCrZr after thermal processing that simulate beryllium tile bonding since once the Be tiles are in place, the copper alloy cannot be solutionized and age-hardened to return it to full strength.

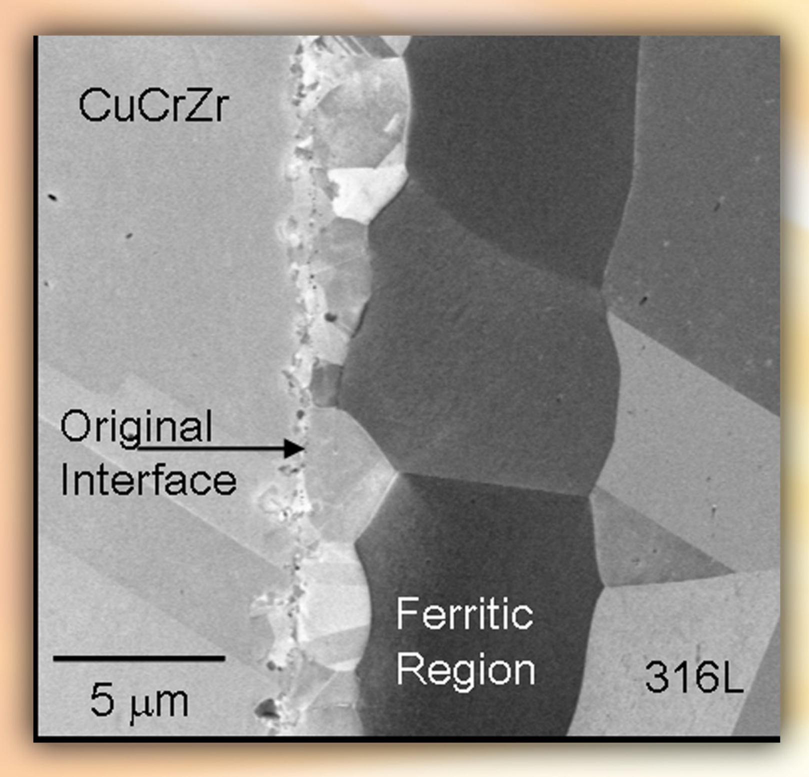

Figure 1. Metallographically prepared cross-section of HIP processed copper alloy/stainless steel joint. Because of the high bonding temperature, interdiffusion rates of the constituent elements of the copper alloy and stainless steel are rapid and the resulting microstructure of the CuCrZr/316L SS bond is complex. The figure shows the CuCrZr to the left and the 316L stainless steel to the right. A central zone is indicated as having a ferritic structure. The composition of the near interface region was characterized via electron microprobe analysis (EMP).

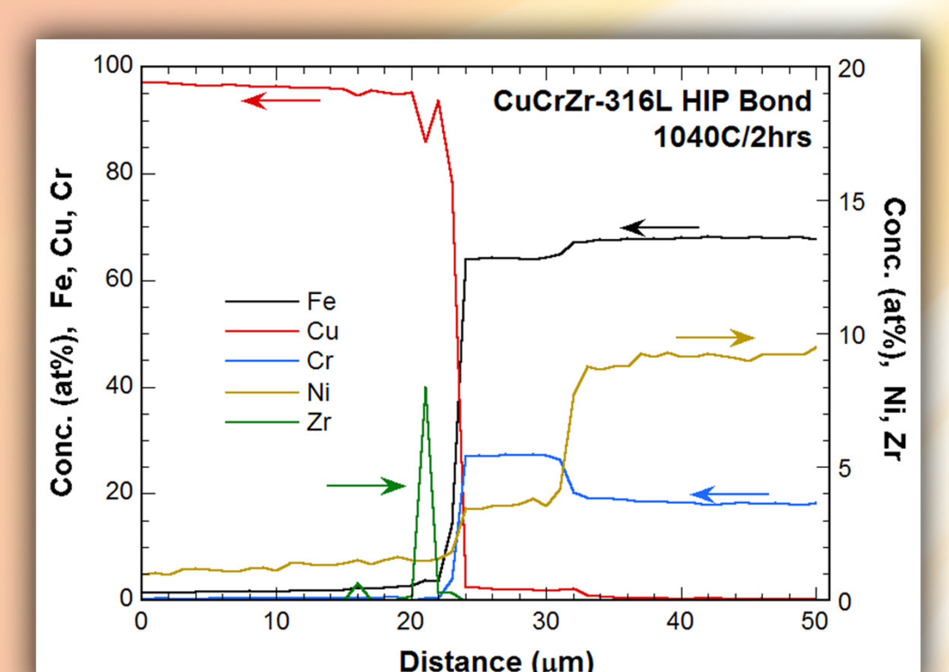

Figure 2. Distribution of the principal alloying elements of both the copper and stainless steel across the HIP bondline. Nickel depletion in the stainless steel is sufficient to destabilize the FCC austentic structure yielded a fully ferritic zone with a high magnetic permeability.

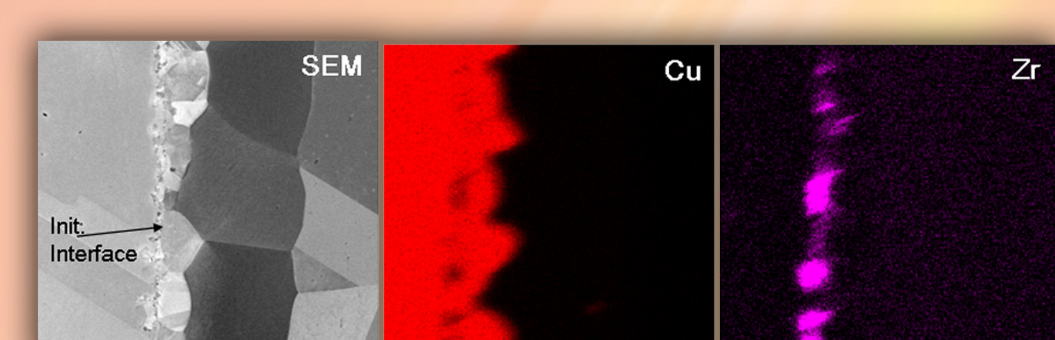

Figure 3. Elemental maps for copper and zirconium derived from energy dispersive spectroscopy (EDS). The map for zirconium shows discreet features exhibiting very high concentrations of Zr. Immediately to the right of the original interface and abutting the steel is a region of nearly pure copper.

Diffusion Bonding Results

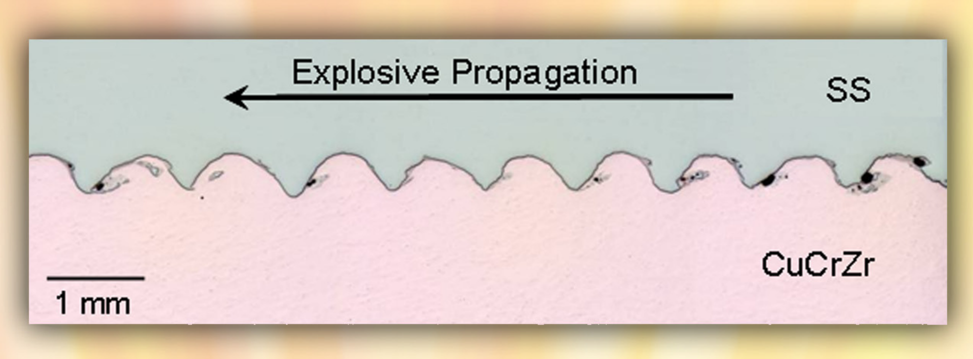

Figure 4. Optical micrograph of interface between CuCrZr and 316L SS explosion bonded at 2300 m/sec with a 1 cm standoff gap between the substrates.

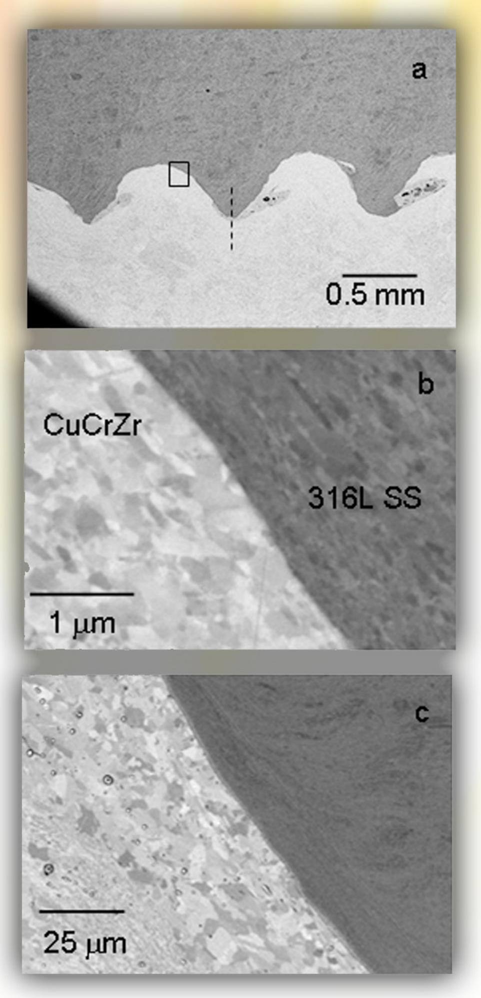

Figure 4a. Rippled interface is characteristic of explosion bonding. **Figure 4b** reveals that a nanocrystalline grain structure has been developed in both the CuCrZr and in the stainless steel as a consequence of the extreme local deformation induced by the bonding process. Because explosion bonding is essentially athermal, there is little or no diffusion-driven mass transport across the interface and therefore there are no changes in local composition and crystallographic structure that is characteristic of the HIP bond. Indeed **Figure 4c** shows that there is a sharp interface between the copper heat sink alloy and the stainless steel.

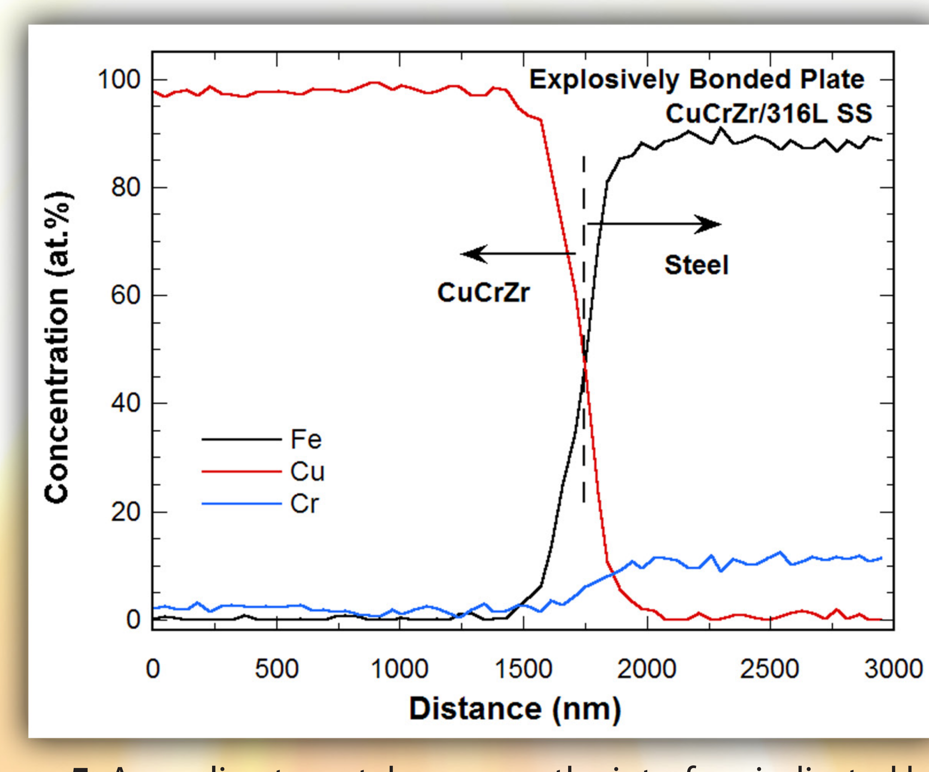

Figure 5. Auger line trace taken across the interface indicated by the broken line in Figure 4a illustrates the sharp interface between the copper alloy and the stainless steel. The width of the interface, as measured by Fe, Cr and Cu redistribution across the interface is less than 500 nm.

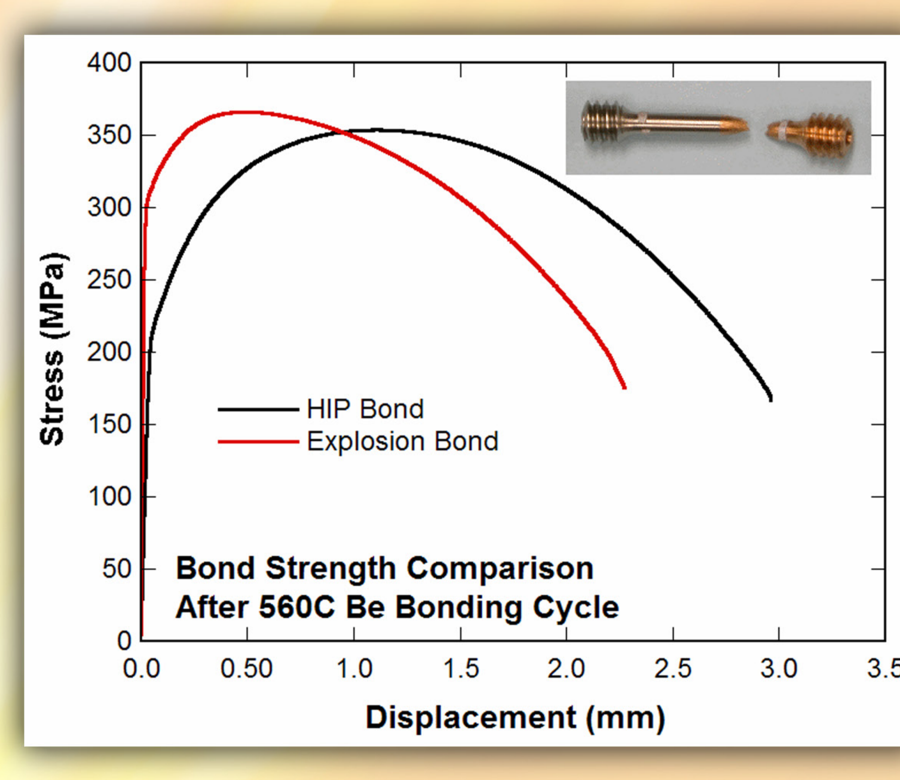

Figure 6. Representative tensile curve (black) for a specimen extracted from across bondline of HIP'ed joint after the final heat treatment at 560°C compared to that for an explosion bonded specim en (red) extracted from across the bondline also after the final heat treatment at 560°C. Although it is difficult to identify a "yield strength" from these bi-metallic specimens, it is clear that there is a substantial strength margin for the explosion bonded specimen.

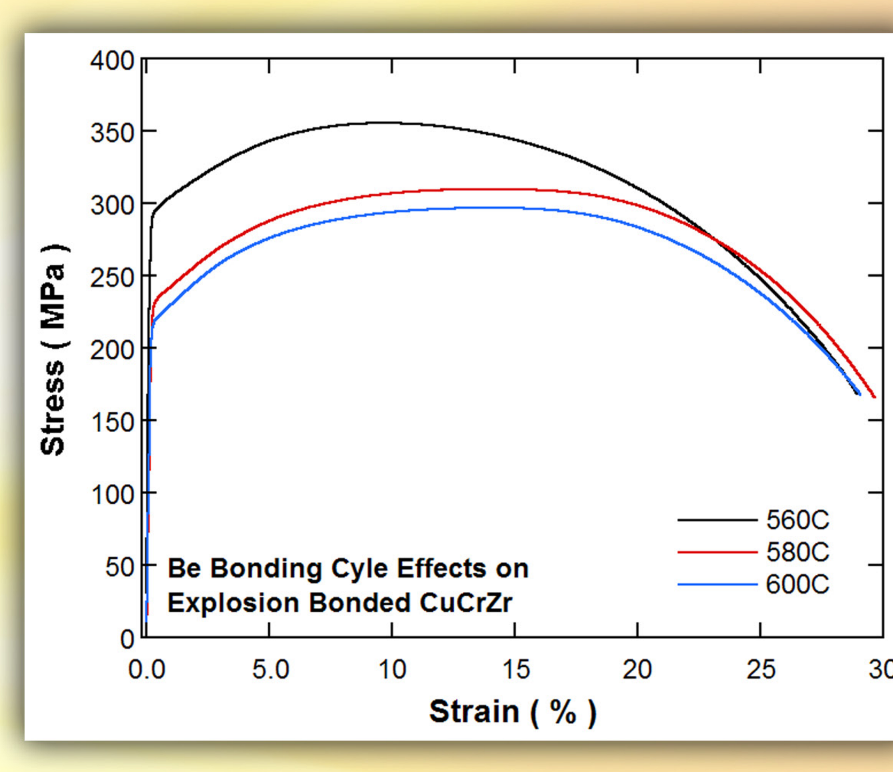

Figure 7. Companion specimens extracted from entirely within the copper reveal a yield strength of 225 MPa for the HIP bonded specimen. This yield strength is well above the minimum required specification of 175 MPa. However, work has shown that Be HIP bonding cycles at even modestly higher temperatures (580-600°C) degrade the yield strength to values that have insufficient margin or are below 175 MPa requirement. Additional copper specimens were extracted from the explosion bonded structure and heat treated at 580°C and 600°C (simulating higher Be bonding temperatures) in order to characterize the margin on strength. Results shown in this figure reveal that the yield strength of the copper alloy after heat treating was 230 MPa (after 580°C/2 h) and 220 MPa (after 600°C/2 h). Thus the strength of the explosion bonded copper after 600°C processing was essentially equivalent to that of the HIP bonded copper after 560°C processing.

Explosion Bonding Results

Implications for Beryllium Bonding

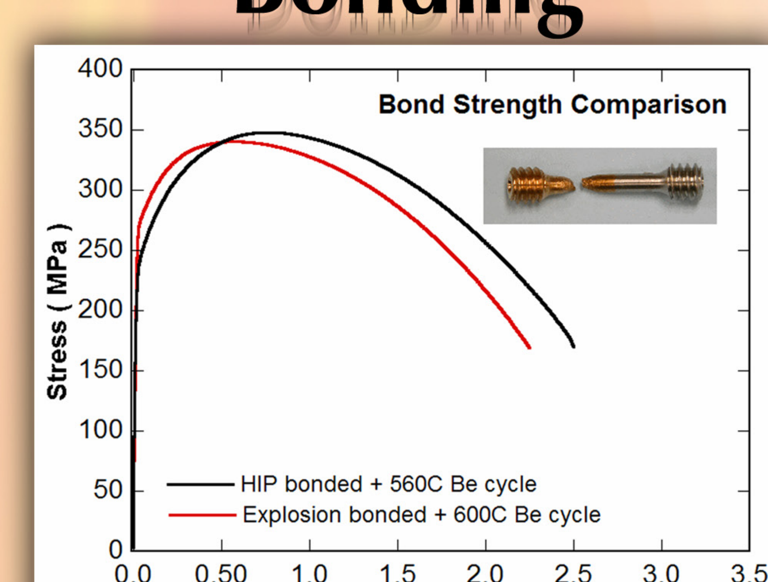

Figure 8. Representative tensile curve (black) for a specimen extracted from across bondline of Hip'ed joint after the final heat treatment at 560°C compared to that for an explosion bonded specimen (red) extracted from across the bondline also after the final heat treatment at 600°C. The strength of the these two specimens are nearly identical, indicating that explosion bonding allows for increased Be tile bonding temperatures while still satisfying minimum strength requirements.

Conclusions

CuCrZr and 316L stainless steel can be successfully joined using either HIP bonding or explosion bonding. However HIP'ing produces diffusion-driven changes in local composition of both the copper alloy and stainless steel that can be problematic. The cold work and fine grain size of the explosion bonded copper renders the alloy less susceptible to anneal softening during follow-on Be tile bonding. The increased residual strength of the CuCrZr permits the Be tiles to be bonded to the copper alloy/316L structure at a substantially higher temperature (600°C vs. 560°C) rendering that critical bond more reliable.

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