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AVOIDING DISSIMILAR METAL WELD FAILURES WITH GRADED TRANSITION JOINTS

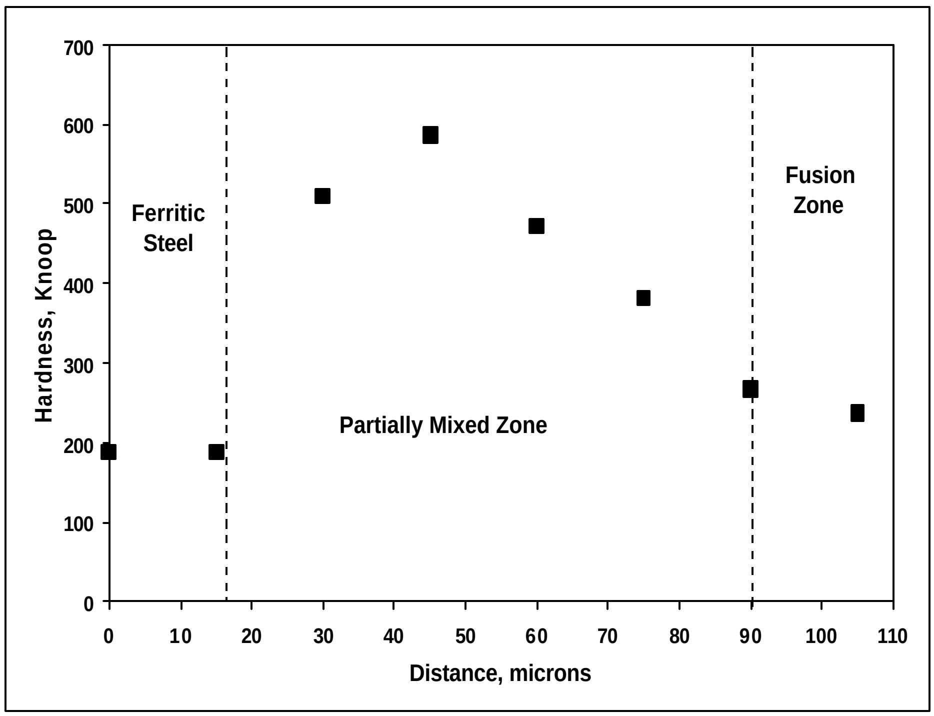

Figure 1: Abrupt hardness gradient in a conventional dissimilar metal weld between a ferritic carbon steel and stainless steel. Using conventional DMW procedures, variations in hardness typically occur over a 100 micron wide region.

Dissimilar metal weld (DMW) failures between carbon steels and stainless steels occur in many industrial applications. These failures are generally attributed to the very sharp changes in composition and corresponding properties which occur along the fusion line of the weld and the formation of locally high stresses associated with a thermal expansion mismatch between the carbon steel and stainless steel. A Lehigh research team has demonstrated the feasibility of using a process referred to as Laser Engineering Net Shaping to prepare a transition joint between carbon steels and stainless steels. This process, which was developed in a research project led by John DuPont of the Department of Materials Science and Engineering and funded by the National Science Foundation, has the potential to solve the failure problems usually seen with dissimilar metal welds.

Coal-fired boilers are typically fabricated from a combination of inexpensive ferritic alloy steels for the lower temperature components and austenitic stainless steels for the superheater and reheater sections which operate at higher temperatures and under more severe corrosion conditions. In this application, dissimilar metal welds must be used in the carbon steel-to-stainless steel transition regions, and these DMW's are often prone to premature failure when exposed to elevated service temperatures.

There are various reasons for these failures. Sharp nickel and chromium composition gradients develop near the fusion line of the DMW due to partial mixing between the two materials that occurs during welding. These composition gradients, combined with the high cooling rate during welding, form a hard and brittle martensitic region in the partially mixed zone of the weld. As shown in Figure 1, this is accompanied by a large, localized increase in hardness in the partially mixed zone, which requires that the weld be post-weld heat treated in order to reduce residual stresses and soften the brittle martensite layer in the partially mixed zone.

Stainless steel alloys typically have lower carbon levels than the alloy steels. This leads to a large carbon concentration gradient across the DMW joint, and this, in turn, results in a significant localized reduction in the creep strength on the carbon steel side of the weld and a modification of the microstructure during heat treatment.

Failure of DMWs in service has been attributed to the sharp changes in hardness and strength described above that occur over very short distances combined with significant differences in thermal expansion between the two materials. For example, the carbon-depleted region, existing on the ferritic side of the weld, has significant localized reductions in creep strength. The region directly adjacent to this is higher in carbon and exhibits significantly higher strength. As a result, strains induced from external service stresses are forced onto the soft, low creep strength ferritic side of the joint. This localized strain is relieved by accelerated creep at the service temperature, which results in eventual failure by link-up of creep voids within the carbon depleted zone.

The life of DMWs can be extended by the use of nickel base filler metals and joint designs with wide included angles. Although these changes help extend the life of DMWs, they do not provide a long-term solution to the problem because failures still occur in joints prepared with these modifications.

DuPont explains, "We have been experimenting with the use of laser formation of graded transition joints as an alternative to the conventional DMW process. The Laser Engineered Net Shaping (LENS™) Process uses a computer-controlled laser system integrated with dual powder feeders. As shown in Figure 2, the LENS™ process utilizes a Nd-YAG laser to produce a melt pool on a substrate attached to an X-Y table. Powder from the dual coaxial powder feeders is injected into the melt pool as the table is moved along a pre-designed two dimensional tool path that is "sliced" from a three dimensional CAD drawing. With this process, a transition joint can be fabricated by depositing successive thin layers of material. The dual powder feeders can be controlled independently so that the composition can be changed in each layer for optimized mechanical and/or corrosion performance.

"The relatively high cooling rates associated with laser processing have been shown to produce refined microstructures with improved mechanical properties. Recent research has also shown this process is well suited for fabrication of functionally graded materials. Thus, this process appears to be well suited for fabricating carbon steel-to-stainless steel transition joints in which the composition is varied in a controlled manner over relatively large distances. We believe that such a transition joint, in which sharp changes in composition, microstructure, and thermal and mechanical properties over short distances are avoided, will eliminate the DMW failure problem described above. With this approach, the transition joint would be inserted between a carbon steel to stainless steel transition to permit the deposition of two similar welds at either end of the joint, replacing the single dissimilar weld that is prone to failure. The objective of our research was to assess the feasibility of fabricating such a transition joint for this application using the LENS process.

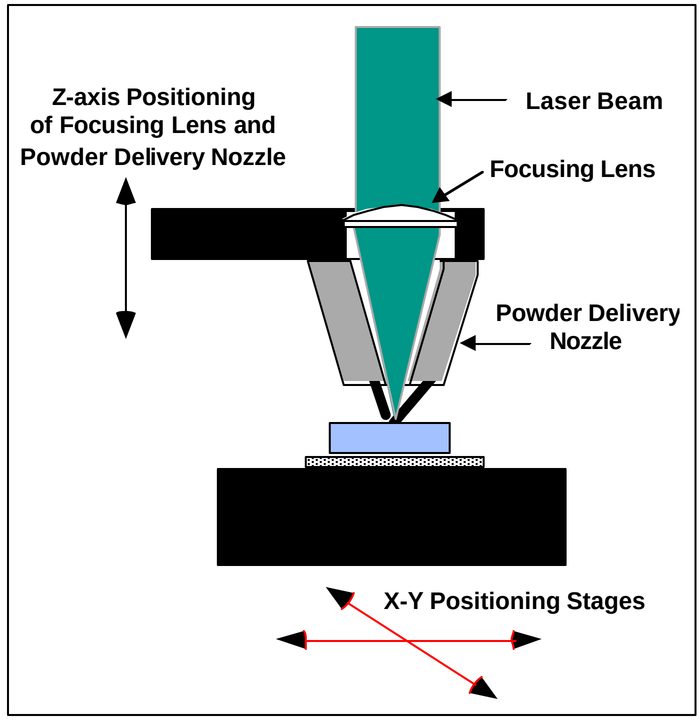

Figure 2: Schematic Illustration of LENSÔ Process.

"We used a direct laser deposition unit in our laboratory to fabricate a 3 inch long transition joint tube with an outer radius of 0.625 inches and wall thickness of 0.25 inches. These dimensions were chosen because they represent typical tube dimensions used by the power industry for waterwall panels in coal fired boilers. The transition joint was fabricated by first depositing 0.5 inches of 316 stainless steel onto a AISI 1020 steel substrate. Next, 2 inches of functionally graded material was deposited in which the composition changed gradually to 1085 steel, and concluded with 0.5 inches of AISI 1085 steel. In practice, a much lower carbon content alloy steel would be used for this application. The 1085 steel powder was chosen here because, at the time of fabrication, it was the only powder commercially available that had the highly spherical morphology and particle size range which are required for LENS processing.

"The initial 0.5 inch length of 316 stainless steel was deposited using 50 layers. The transition region was deposited with 200 layers in which the powder feeders containing each alloy were linearly changed in each layer to gradually vary the composition throughout the graded region. A final 50 layers of 1085 steel were then deposited to complete the transition joint.

"We removed samples from various locations along the transition joint for analysis which included a combination of compositional analysis, hardness testing, light optical microscopy, and scanning electron microscopy. Figure 3 shows the variation in hardness along the laser produced transition joint. Note that, in comparison to Figure 1, the change in hardness now occurs over millimeters instead of microns. In other words, the deleterious gradients are decreased by a factor of one thousand. Analysis of the composition gradients also showed much more gradual variations in composition than occurs in conventional dissimilar metal weld."

DuPont concludes, "The results of this feasibility study show that it is possible to form a graded joint with gradually controlled variations of micro-structure, chemical composition and hardness. We believe that this type of joint would provide extended service life in boiler applications. We are in the process of formulating a joint industry-National Science Foundation proposal for the next stage of this research program, and are currently searching for interested industrial partners. The major objective of this research will be to carry out the detailed investigations needed to optimize the properties of these graded joints and evaluate the performance of optimized joints under actual boiler conditions." ■

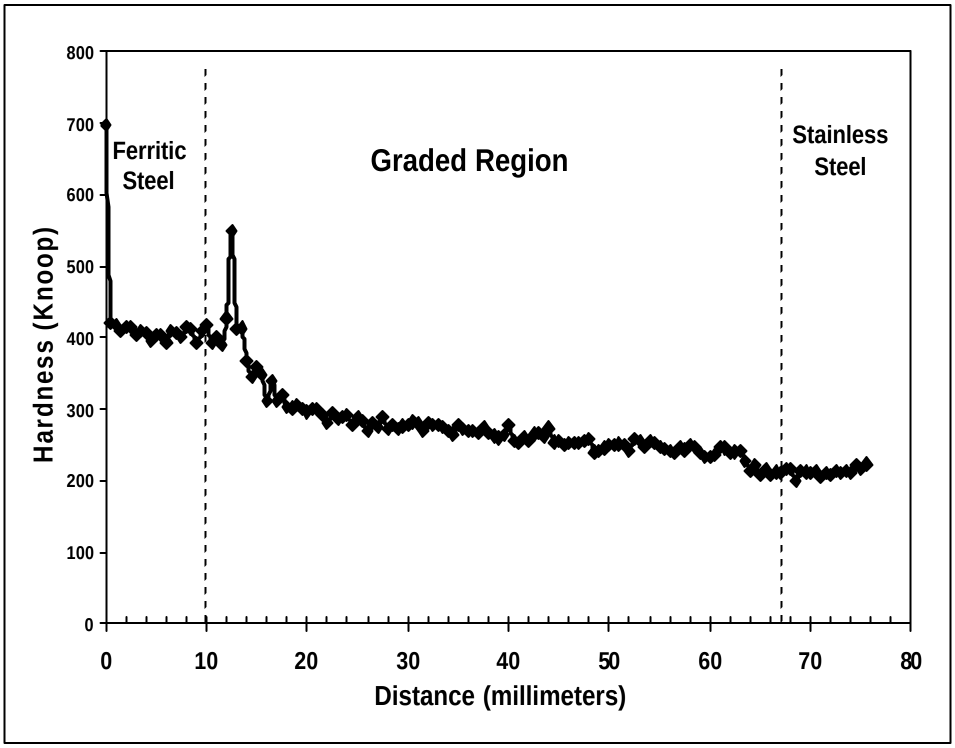

Figure 3: Hardness gradient in a transition joint between a ferritic carbon steel and stainless steel. The graded region, fabricated using the LENS process, was 67 millimeters in width, thus providing a gradual transition region between the carbon steel and stainless steel. This should provide extended service life compared to conventional dissimilar metal welds.