METALLOGRAPHIC QUALITY CONTROL OF WELDING AND BRAZING*

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Introduction

Metallography serves as an invaluable quality control technique in many welding and brazing operations in the energy field. It often supplements nondestructive testing processes such as dye-penetrant and radiography. Additionally, it can provide information ordinarily not obtainable by conventional inspection procedures. This paper describes a number of case histories illustrating the value of metallography in assuring integrity in the fabrication of metals and components in energy systems.

Measurement of Ferrite in Stainless Steel Welds

To minimize the possibility of hot cracking during welding of the austenitic stainless steels, it is common practice to produce welding filler metals of such composition that the weld deposit contains a small amount (on the order of five percent) of delta ferrite. Both crack susceptibility and mechanical behavior are related to the amount and morphology of ferrite in the weld metal. It thus often becomes important to measure the amount and distribution of ferrite in representative weld deposits.¹ Metallography provides additional information to that obtained from other ferrite-measuring techniques.

Figure 1 (Y-130280) illustrates the extent of cracking which can occur when inadequate ferrite control is maintained. Figure 2 (Y-95374) allows a comparison of ferrite distribution in welds produced by different processes.

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It appears that the "coarseness" of the ferrite distribution depends primarily upon the substructure size, that is, essentially upon the relative weld energy input utilized. The ferrite morphology is thus quite process dependent.

Brazing of Thermocouples to Test Components

Metallographic examination provides an excellent means for assessing the reliability of brazed joints including those which secure thermocouples to test components. A photomicrograph of a satisfactory braze of a stainless steel-clad thermocouple to the inside of a fuel rod sheath is shown in Fig. 3 (Y-45571). A joint with insufficient brazing filler metal is shown in Fig. 4 (Y-45573). The dry-hydrogen furnace brazing procedures were modified sufficiently to produce consistently reliable brazed joints of this type.

Cracking and Porosity in Refractory Metal Welds

The high melting points and high strengths of refractory metal alloys at elevated temperatures make them extremely attractive as structural materials for certain energy systems.^{2,3,4} On the other hand, these alloys have low tolerance for impurities during fabrication and welding. Impurity contamination can result in increased brittleness of the weldment and cracking and porosity. The large grain size usually associated with refractory metal weld deposits also is an important factor in raising their ductile-to-brittle transition temperatures (increased brittleness). Metallography serves as an essential tool for evaluation of these various factors in weld reliability.

Microcracks which developed upon welding of highly contaminated (4200 ppm oxygen) Nb-1 wt % Zr alloy are shown in Fig. 5 (Y-49166). Tungsten is particularly subject to cracking during welding, even if extreme precautions

are taken to avoid impurity pickup and excessive restraint of the joint. A sound gas tungsten-arc weld is shown in Fig. 6 (Y-98419); severe cracking in a similar weld is shown in Fig. 7 (Y-98417).

Beryllium

The welding of end caps in beryllium tubes is a difficult technical problem.⁵ Residual volatile constituents in the base metal lead to weld metal porosity. There is also a general tendency of beryllium to crack during welding. It has been found that the general weldability of beryllium is greatly dependent upon the degree of purification of the base metal obtained during the fabrication process. Metallography serves as the best means for evaluating the weld metal soundness associated with each product.

Figure 8 (Y-42830) is a gas tungsten-arc weld exhibiting extensive porosity, while root cracking is in evidence in Fig. 9 (Y-42848).

Tube-to-Tubesheet Joints

Tube-to-tubesheet joints for heat exchangers are notably difficult to inspect by conventional nondestructive techniques. Thus, metallography serves as a very useful means for developing optimized fabrication procedures. An Inconel weld with severe cracking in the weld resulting from improper welding technique is shown in Fig. 10 (Y-15120). Figure 11 (Y-16601), illustrates a large pore which is virtually undetectable by conventional nondestructive procedures.

Tube-to-Fin Brazing

Metallography serves as an essential means for evaluating many aspects of brazed joints. One application of brazing, that is, the attachment of stainless steel-clad-copper high-conductivity fins to stainless steel tubes, is particularly dependent upon metallography.⁶ During high-temperature service, uncovered copper edges permit extensive oxidation of the copper (Fig. 12 Y-48303). Acceptable bonding but poor edge coverage is shown by metallographic sectioning (Fig. 13 Y-48294). By use of an optimized amount of brazing filler metal, the excellent bonding and edge covering shown in Fig. 14 (Y-15043) can be obtained.

Dissimilar Metal Welds

A problem of great current interest in the production of electric power from fossil-fired plants involves the failures of dissimilar metal welds in superheater and reheater sections.^{7,8} Most superheaters and many reheaters delivering steam at temperatures of 1000°F(538°C) or more contain austenitic stainless steel tubing, whereas the tubing in the lower temperature regions is made of ferritic steels. An increasing number of failures in the transition joints connecting these two materials has occurred in recent years.

Figure 15 (Y-138700) illustrates a crack in the heat-affected zone of the 2 1/4 Cr-1 Mo ferritic steel. A higher magnification view showing the nature of the crack tip is presented in Fig. 16 (Y-130494). The Steam Power Panel of the Joint Committee on the Effect of Temperature on the Properties of Metals (Joint Committee of ASTM, ASME, and MPC) has formed a Task Group to assess the impact of these failures and to formulate a plan to alleviate the problem.

Summary

From the above-mentioned case histories, it is evident that metallography plans an integral role in the quality control of welded and brazed joints. As additional advances are made, it should become an even more important tool.

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Fig. 1. Cracking in Stainless Steel Weld Metal Resulting from an Inadequate Amount of Delta-Ferrite.

COMPARISON OF FERRITE DISTRIBUTION IN WELDS PRODUCED BY DIFFERENT PROCESSES

Fig. 2. Ferrite Distribution in Stainless Steel Weld Metal Deposited by Different Welding Processes.

Fig. 3. Stainless Steel-Sheathed Thermocouple Brazed to the Inside of a Stainless Steel Fuel Rod Sheath. Good filleting and wetting is observed.

Fig. 4. Thermocouple-to-Sheath Braze with an Inadequate Amount of Brazing Filler Metal.

Fig. 5. Microcracks Which may Develop Upon Welding Highly Contaminated Nb-1 wt % Zr Alloy.

Fig. 6. Gas Tungsten-Arc Weld in Tungsten Sheet. No defects are evident.

Fig. 7. Tungsten Weld with Intergranular Cracking.

Fig. 8. End-Closure Weld in Beryllium Tubing Exhibiting Extreme Porosity.

Fig. 9. End-Closure Weld in Beryllium Tubing
Exhibiting Root Cracking.

Fig. 10. Severe Cracking in an Inconel Tube-to-Tubesheet Weld Resulting From Improper Welding Techniques.

Fig. 11. Large Pore in Inconel Tube-to-Tubesheet
Weld.

Fig. 12. Severe High-Temperature Oxidation of Copper in Stainless Steel-Clad-Copper High-Conductivity Fin Resulting From Unprotected Edge.

Fig. 13. High-Conductivity Fin Brazed to Stainless Steel Tube. Excellent adherence is evident but the copper edge is not protected.

Fig. 14. Brazed High-Conductivity Fin Showing Edge
Protection of Copper.

Fig. 15. Crack in Heat-Affected Zone of Ferritic Steel
Immediately Adjacent to Inconel Weld Metal.

TRANSITION JOINT FAILURE IN 2 1/4 Cr-1.0 Mo STEEL
NEXT TO FUSION LINE WITH INCONEL 132 WELDMENT

Fig. 16. View of Crack Tip in Failed
Dissimilar Metal Weld Transition Joint.