HEAVY WATER ORGANIC COOLED REACTOR

DEVELOPMENT OF SAP-STEEL PRESSURE TUBE TRANSITION JOINTS FOR THE HWOCR

ADDENDUM

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ATOMICS INTERNATIONAL-COMBUSTION ENGINEERING
A Joint Venture for Heavy Water Organic Cooled Reactors

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I. INTRODUCTION

In the original issue of AI-CE-46, the information presented pertained only to the development of hot pressed transition joints between SAP and stainless steel. Additional reports were written covering the development of rolled transition joints and the further testing of hot pressed joints. The objectives of this addendum are to discuss briefly the results of these development tasks excluded from AI-CE-46 and to refer the reader to those documents which present the detailed development and test data of these excluded tasks. The tasks excluded and which are discussed in this addendum are (1) rolled joint development, (2) end thickening of SAP tubes, and (3) out-of-pile loop tests.

II. ROLLED JOINTS

A. FABRICATION

Rolled transition joints of SAP to stainless steel have been made for pressure tube applications. The rolled joint is of the sandwich type, where the SAP is rolled between inner and outer stainless steel sleeves. The fabrication techniques have been developed to assure structurally sound joints. The greatest uncertainty is whether or not the joint will remain leak-tight for 30 years of reactor operation. Leaks could be promoted primarily by either stress relaxation of the joint or by the formation of reaction products between the SAP and the stainless steel. There are several materials which could be used as diffusion barriers, should the formation of reaction products prove detrimental to the joint integrity; however, some additional development work would be necessary if something other than an oxide coating were to be used. At the present time, an oxide-nitride coating on the stainless steel appears to be an adequate diffusion barrier. The oxide-nitride coating is formed by using a standard commercially available process, consisting of treatment in a salt bath.

Each end of the SAP pressure tube has to be flared in order to maintain a constant inside diameter in the pressure tube assembly. The SAP tubing can be flared by mechanical mandrels, hydraulic expanders, or by explosive forming.

All three methods are satisfactory; however, a compressive axial load must be applied to the tube during flaring to prevent splitting.

The stainless steel sleeves can be either grooved or smooth. If they are grooved, two grooves are more than adequate. The grooves are circumferential sinusoidal in cross section and need not be more than about 8 mils in depth. Sharp cornered grooves have a tendency to damage diffusion barriers and break the SAP pressure tube wall as a result of the high shear stress in the low-ductility material.

The actual rolling process for making this sandwich-type joint is a relatively standard one. After inserting the flared end of the SAP tube into the slot formed by the concentric stainless steel sleeves, an initial set in the joint is made by driving a mandrel axially through the inside diameter of the inside sleeve. Standard cold rolling procedures are followed after this initial set is achieved.

Helium leak testing is presently used as the means for evaluating the integrity of rolled joints. Joint x-ray techniques and some ultrasonic techniques were considered. However, these alternative NDT techniques do not appear to be capable of indicating the degree of quality required.

B. PERFORMANCE

Tensile test data show that the rolled joint is stronger than the SAP pressure tube, both in the as-bonded condition and after an equivalent stress-relaxation life of better than 30 years. Thermal cycling 1000 times between 400 and 800°F, at a maximum rate of about 30°F/sec, has not shown any deleterious effect on either the strength or the leak-tightness integrity of the joint.

Rolled joints subjected to a series of tests have retained their integrity, as measured by helium leak testing. In this series of tests, joints were thermally soaked at 1000°F for 500 hours. The activation energy for aluminum stainless steel diffusion is about 45,000 cal/mol, and for stress relaxation of stainless steel about 95,000 cal/mol. This soaking period was therefore equivalent to approximately a 12-year lifetime with respect to diffusion and equivalent to a stress relaxation lifetime in excess of 1000 years. Following the thermal soak tests, the joints sustained pressure and temperature cycling, after which

they were stress-rupture tested under a one-to-one hoop-to-axial stress ratio. The results of this series of tests indicate that the joints tested would have been adequate for use on a pressure tube. There still exists, however, the need to fully qualify the fabrication process and scale it up for both shop and field assembly usage.

III. END THICKENING OF SAP TUBES

Metallurgically bonded transition joints have been developed to the extent of demonstrating the feasibility of hot pressing joints between SAP and stainless steel. The wall thickness of the SAP tubes must be increased at the ends where the hot pressed joint is made, because the apparent efficiency of this joint, based on tensile tests, ranges from 75 to 85%. Generally, a well-bonded joint will fail at a stress level somewhere between the yield strength and the ultimate tensile strength of the SAP material.

The ends of the pressure tubes can be thickened in several ways. The flash welding process was pursued more than any other. This process provides for welding sections machined to the thickness desired, to the ends of the pressure tube. It does have the detrimental effect of creating a weak weld area when used on a thin-wall section of SAP tube; however, there are indications that an acceptable flash welded joint could be developed by taking advantage of the anisotropy of SAP and of the rearrangement of the anisotropic characteristics in the region of the flash weld.

The chemical milling and the standard machining processes have been demonstrated as feasible. The potential disadvantage of these processes is that of cost because of the amount of material lost in the processing. Dimensional control has been shown to be excellent for the chemical milling; for the standard machining process, it may present a problem. Of the other methods evaluated for pressure tube end thickening, only the explosive bonding process shows promise.

IV. OUT-OF-PILE LOOP TESTS

Three in-core sections or mid-sections of the SAP pressure tube assembly have been tested in an out-of-pile organic hydraulic loop. These sections are about 20 ft long with transition joints on each end. Rolled joints were used on two of the test sections and hot pressed joints were used on the third.

The feasibility of fabricating SAP pressure tube assemblies by using both rolled and hot pressed joints has been demonstrated. From a fabrication viewpoint, it has been shown that the dimensional tolerances and inspection requirements are realistic and can be met with careful fabrication procedures.

The program for each of the three SAP in-core test sections tested was planned for three 500-hr out-of-pile tests. The two sections with the rolled joints performed as designed. The section with the flash welds and the hot pressed joint failed. The failure occurred in the flash weld following completion of one 500-hr test at 650°F and 14 hr after the startup of the second 500-hr test at 550°F. The calculated axial stress (including pressure stresses, ΔP forces, weight loads, and measured bending deflections) was between 4600 and 7100 psi at the flash weld. This stress level should not have caused failure of the parent material. The failure can be accounted for by adding the effects of an expected flash weld efficiency of 85% and a stress concentration factor at the weld of 2.5 to 3.0. Metallurgical examination indicates that failure could have been caused as a result of poor quality SAP material* (inclusions degraded flash weld quality) and concomitant high temperature stress-rupture effects on the flash weld under combined loading.

*The only SAP material available was used for this flash weld and was some of the original material manufactured and procured prior to the start of the HWOCR program.

V. REFERENCE DOCUMENTS

Those documents from which detail information can be obtained relative to the items discussed in this addendum are listed below.

1. "Fabrication and Inspection of the TS-20-4 Pressure Tube Midsection," TI-010-21-004, dated May 8, 1967
2. "Fabrication, Testing and Post-Operational Examination of the TS-10-4 Pressure Tube Midsection," TI-010-21-005, dated May 1, 1967
3. "Development of SAP-895 Pressure Tubes with Increased Wall Thickness at the Tube Ends," TI-010-21-007, dated June 7, 1967
4. "SAP - Stainless Steel Hot Pressed Transition Joints - Terminal Report," TI-010-21-011, dated June 28, 1967
5. "Development of Sandwich-Type Rolled Joints, SAP-895 to 304 Stainless Steel," TR-010-21-602, dated September 11, 1967