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Container Integrity Assurance

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Ultrasonic Test Support for Container Integrity Assurance*

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ABSTRACT

Ultrasonic nondestructive testing techniques, when properly integrated into the capsule development program, can be used to establish the container integrity of fueled isotope capsules. The ability of ultrasound to detect close fitting cracks, and to obtain complete inspection of the container volume, was found to advantageously supplement the information normally acquired through radiographic, dye penetrant, and metallographic analysis.

Ultrasonic test support during an isotope capsule development and fabrication program may be classified into four phases with each phase having specific quality control and ultrasonic test development objectives. The first phase concerns the ultrasonic inspection of the raw material quality and establishment of basic ultrasonic techniques to be used during the following test development phases.

Close cooperation between the weld development and nondestructive test personnel during the closure weld development phase is necessary

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to provide adequate weld parameter characterization and the subsequent assurance of weld testability on the fueled capsule. Radiographic and metallographic analysis is used extensively during the ultrasonic test development phase to verify the ultrasonic test results. Thus, thorough characterization of the weld parameters is obtained.

The ultrasonic test techniques developed must be standardized and calibrated. A test standard jointly designed by both the fabrication and test personnel is most effective in establishing reject criteria for welds on fueled capsules.

The remote ultrasonic verification of the integrity of fueled SNAP-21 capsules illustrates the effectiveness of applying a cooperative approach between capsule fabrication and NDT personnel to assure capsule certification.

INTRODUCTION

Ultrasonic nondestructive testing (NDT) advantageously supplements the quality control tools of radiography and metallography and enhances the ability to establish the integrity of the isotope container components and closure welds. The use of ultrasound to detect close fitting cracks and to obtain complete maps of container material parameters has been particularly useful in the support of closure weld development and integrity certification.

Integration of ultrasonic testing into the design and development phases of capsule fabrication provides two main functions. First, complete ultrasonic scanning of weld volumes for weld parameter variations facilitates selective use of radiography and metallography in possible problem areas. Thus, the probability of detecting and defining undesirable weld characteristics during the development phase is enhanced, and optimum welding and testing techniques can be developed. Secondly, the correlation obtained between nondestructive and destructive data on developmental capsules is necessary to develop confidence in the ability to nondestructively establish the integrity of a fueled capsule.

General methods and philosophies of ultrasonic test development and verification have evolved which provide economical and high confidence use of ultrasound as a capsule fabrication quality control tool. The ultrasonic support is conveniently split into the four following phases:

Phase 1: Preassembled Component Inspection

Phase 2: Developmental Closure Weld Inspection

Phase 3: Ultrasonic Test Standardization and Calibration

Phase 4: Establishment of Fueled Capsule Container Integrity

Each phase provides quality control and design feedback information to the capsule fabrication organization in addition to the ultrasonic test development considerations. The following discussion, through examples of our recent activities in this area, illustrates the ultrasonic test support sequence and test verification techniques.

DISCUSSION

PHASE 1 - PREASSEMBLED COMPONENT INSPECTION

Efficient inspection of the components is obtained when ultrasonic, radiographic, dye penetrant, and metallographic analyses are used in a complementary manner. Specific objectives of the ultrasonic inspection in this phase are to supplement the radiographic and dye penetrant test by the detection of intersurface defects and tightly closed surface cracks.

The supplementary use of ultrasonics and radiography is illustrated through the results obtained during the inspection of vendor fabricated seam welds in the rhenium cylinders procured as containers for the Goddard Microthruster capsules. Two types of inner-surface weld defects, insufficient penetration, and cracks, which are ultrasonically detected in the seam welds, are shown in Figure 1. Radiographic analysis of the seam weld detected weld porosity, and, thus, consideration of both the ultrasonic and radiographic data was necessary for selecting best cylinders.

Of particular note were the severe laminar defects shown in Figure 2 detected in a 16 ft. long, Hastelloy-X tube initially procured for the outer clad of the SNAP-23 development capsules. Removal of the sample from the pipe caused the separation of the laminations. The high incidence of the laminations in this pipe necessitated replacement of the pipe by the vendor.

Lack of penetration and/or inner-surface cracks were ultrasonically indicated in the seam weld of a 10 ft. long section of Hastelloy-X tubing procured for the inner clad on developmental SNAP-23 capsules. Subsequent radiographic analysis of the weld verified the ultrasonic indications and, additionally, permitted differentiation between the two defect types.

Severe cracking, some entirely through the wall, was ultrasonically detected in the Tungsten-25% rhenium cylindrical cans procured for a promethium capsule developmental program. The capsule diagram in Figure 3 shows locations of the cracks. The axial cracks were detected by both ultrasonics and dye penetrant techniques and appeared to radiate from chuck marks. Galling of the surfaces during the machining operation masked the lip and circumferential defects, and they were not detected during the dye penetrant analysis. Fourteen out of 40 capsules contained defects.

The above examples illustrate the supplementary and complementary nature of different NDT methods and this interrelationship is maintained throughout the following development phases.

PHASE 2 - DEVELOPMENTAL CLOSURE WELD INSPECTION

Assurance of fueled capsule closure weld testability is acquired through test development performed on developmental welds. Quality control objectives of the ultrasonic inspection are to provide feedback information to weld development engineers concerning (a) areas where possible cracks or voids exist, (b) variations in, and extent of, weld penetration, and (c) suggestions for weld joint design changes, if necessary, to enhance weld compatibility with ultrasonic testing.

The test development objective in this phase is to develop ultrasonic techniques which can be calibrated, standardized, and then reliably implemented for the inspection of a fueled capsule.

The general compatibility of the capsule design with application of ultrasonic techniques can be theoretically evaluated by the ultrasonic engineer by considering such factors as wall thickness, surface finish, and weld joint configuration. Thus, consideration of weld testability at the initial design stage can decrease the cost of test development.

Ultrasonic indications of variances in weld properties are generally verified by radiographic and/or metallographic analysis. When close communication is maintained between the ultrasonic, radiographic, and metallographic personnel, the weld development personnel are provided with the most economic and thorough definition of the weld characteristics.

The weld closures discussed in the following were selected to illustrate the use of ultrasonics to define weld characteristics during the weld development phase. These examples were obtained during the early weld design stages of the SNAP-21 and AMSA program and they should not be construed as containing any indication whatsoever of ORNL's or PNL's weld design or weld performance capabilities.

Through close interlaboratory cooperation between the 3M Company, ORNL and PNL, the weld parameters of the early design, SNAP-21 development TIG (Tungsten Inert Gas) welds were ultrasonically evaluated and undesirable weld characteristics were found to exist. Figure 4 shows two detrimental weld characteristics--weld root cracks and lack of weld penetration. Through extensive metallographic evaluation of the ultrasonic defect indications, the weld root cracks were found to exist primarily in the inner and outer welds of the three pass weld. Excessive melt down of the outer corner was the prime cause of insufficient penetration. Due to the melt down of the outer corner, highly refined and complicated ultrasonic techniques were required to monitor the weld parameters on these developmental welds. Considering these undesirable weld characteristics and the difficult ultrasonic test procedures required to establish the integrity, the weld joint was modified and the TIG welding techniques were reevaluated.

Two other developmental welds were subsequently evaluated, a second design TIG weld and a first design electron beam (e. b.) weld. Although the redesigned TIG weld showed a significant reduction of weld root cracks, gross variances of weld penetration at the seam

weld in the cylinder wall produced an area of insufficient penetration as shown in Figure 5. The penetration was maximum in the area of the seam weld and minimum on one side of the seam weld. Melt down of the outer corner continued to be a problem in the implementation of the ultrasonic tests. Additionally, variations in the amplitude of the ultrasonic signals from the unwelded joint were encountered. Metallographic analysis in the areas of reduced signal amplitude showed tightly closed joints at the weld root and at intermediate points along the joint. These variances in signal amplitude further complicated the ultrasonic testing and calibration procedure.

The photomicrographs in Figure 6 show the ultrasonically detected, metallographically verified, characteristics of the first e. b. developmental welds. Although the .200 inch to .300 inch penetration far exceeded the .100 inch required, three undesirable characteristics--porosity, laminar voids and misaligned weld volumes were observed. The majority of the porosity and laminar defects were located in the weld root area and thus did not undermine the integrity of the weld. The end-caps of the sample welds were removed to enhance the radiographic analysis of the weld, and porosity was readily detected with the radiographic techniques. Comparison between the radiographic and ultrasonic results showed porosity to account for approximately 30% of the defects. Laminar defects accounted for the remaining 70%.

The laminar defects, porosity and unwelded joints in the e. b. welds, were optimally oriented for detection with an ultrasonic technique which could be reliably performed remotely. Due to their

testability and desirable penetration, the e. b. welds were selected over the TIG welds for the fueled SNAP-21 capsules. Subsequent weld technique development and ultrasonic test optimization resulted in the establishment of high integrity of the closure weld on the fueled SNAP-21 capsules.

AMSA Weld Development Samples

The developmental weld characteristics of the e. b. closure welds in the L-605 material of the AMSA capsule closely resembled the characteristics of the SNAP-21 e. b. welds as shown in Figure 7. Note the presence of porosity, intervolum cracks, and insufficient penetration due to a misaligned weld volume. Although the weld characteristics paralleled those of the SNAP-21 welds, development of ultrasonic inspection techniques were most difficult due to the circumferential location of the weld, and two different ultrasonic tests were required to establish weld integrity.

The results of the SNAP-21 and AMSA test development programs illustrate several pertinent points. As demonstrated in the comparison of ultrasonic signals between the first and second developmental TIG welds in the SNAP-21 program, changes in weld joint design and/or the welding technique can significantly change the character of the ultrasonic signals. Thus, reevaluation of the test method is recommended when weld design parameters are changed. The melt down of the outer corners of the SNAP-21 TIG welds prevented automatic scanning of the weld parameters and the refined, manual test procedures would have been impractical for remotely measuring the penetration on a fueled capsule. The melt down of the outer corner of a peripheral weld generally complicates

the test methods and should be avoided if remote and/or automatic inspection of the weld is desired.

The peripheral location of the SNAP-21 e. b. welds facilitated the development of test methods which could be performed both remotely and automatically. In comparison, the circumferentially located AMSA e. b. welds were not conducive to remote or automatic inspection even though the undesirable characteristics to be detected were the same as the SNAP-21 welds. Thus, the test requirements are a function of the location of the weld on the capsule.

The weld root cracks in the TIG, and laminar type cracks in the e. b. weld, were detectable by radiographic techniques. Ultrasonic results could not differentiate between the porosity and cracks in the e. b. weld. Thus, both ultrasonics and radiography were necessary to completely define the undesirable weld characteristics.

PHASE 3 - ULTRASONIC TEST STANDARDIZATION AND CALIBRATION

Development of realistic weld defect standards for calibration of ultrasonic techniques and equipment are necessary if high confidence is to be obtained in the ultrasonic establishment of the weld integrity on fueled capsules. The standard must be representative of undesirable weld parameters characterized during the development period and must permit interpretation of the ultrasonic data in terms of the weld specifications. Most effective standardization of the ultrasonic test is obtained when the fabrication and nondestructive testing personnel jointly design the standard. The confidence level of the ultrasonic test techniques should be established not only by the consideration of the test performance on the standard, but also by the test performance on actual developmental weld flaws.

The test standard shown in Figure 8 was jointly developed by ORNL, the 3M Company, and PNL to assist in the calibration of the ultrasonic weld evaluation on fueled SNAP-21 capsules. Test standardization was based on the ultrasonic reflections from the bottoms of eight radially orientated drill holes. The standard cylinder was machined to the same tolerances as the actual SNAP-21 capsule clad and out of the same Hastelloy-X bar stock. The holes were machined to the average radial depth of a typical weld volume. The holes ranged in diameter from .015 inches to .070 inches as shown in Figure 9. The ultrasonic indications are shown in the graph. Seven holes, located in a circumferential plane, provided the basic standardization. The eighth hole, 0.015" dia., was located within 0.005 inch of the top and was used to evaluate the ultrasonic test in that area. As is noted in Figure 9, the top drill hole was detectable with a slight modification of the ultrasonic test incident angle. Ultrasonic defect indications were correlated to the standard by noting the number of circumferential passes during which the indication was observed.

The X-Y recordings shown in Figure 9 illustrate a read out technique which was developed to display small, randomly located defect indications such as those observed in the SNAP-21 e. b. welds. Each line spacing represents .006 inch of axial transducer travel, with one line representing a complete circumferential scan. Thus a map of the weld area is obtained.

The X-Y recording shown in Figure 10 facilitates data interpretation when unwelded portions of the weld joint are being monitored.

The line spacing and length represents the axial and circumferential positions, respectively. The recorder pen is actuated only when a signal indicating the presence of the joint is detected.

As can be noted by comparing the above examples, the read out technique depends upon the parameter that is being monitored. When these recordings are calibrated by the use of a standard, they provide a convenient data recording method.

PHASE 4 - INSPECTION OF FUELED CAPSULES

Three factors to be considered before applying the ultrasonic tests developed in Phases 1, 2, and 3 are: (a) radiation protection for test operators, (b) ultrasonic test equipment, and (c) thermal protection of the ultrasonic transducer.

Test facilities which provide the necessary operator radiation protection can vary from the remote, "hot cell" facilities, for inspection of strontium fueled capsules, to the "controlled area" facilities, for promethium and plutonium capsules.

The radiological, thermal, and geometrical characteristics are unique to each individual capsule, and the ultrasonic tests and equipment required to inspect the capsules are unique to that particular capsule. The equipment requirements normally increase as the isolation between the test operator and test tank increases. Thus, the ultrasonic test station developed for the inspection of the strontium fueled capsules was fully automated; whereas, standard laboratory equipment was used for the promethium capsules.

Thermal output of fueled capsules tested to date has ranged from 500 to 1500 watts. In general, the water bath temperature should be maintained below 80°F, and a constant temperature water flow should be directed on the face of the ultrasonic transducer. Precooling of the fueled capsule is recommended to prevent adding extra heat into the ultrasonic test water.

In summary, the successful ultrasonic inspection of fueled capsules is usually the result of an ultrasonic test program performed in support of the capsule development program. Integration of ultrasonic test support into the development program has a dual purpose. First, the preassembled components and development welds are inspected to assure integrity before the capsules are fueled. Secondly, certification of the ultrasonic test techniques during the development period insures the testability of a fueled capsule.

To obtain the best results from sample weld evaluation, ultrasonic, radiographic, and metallographic inspection should be closely coordinated. In particular, ultrasonic and radiographic results often supplement each other and provide a most complete inspection.

FIGURE CAPTIONS

- Figure 1 - Seam Weld Defects in Rhenium Cylinder
- Figure 2 - Laminar Voids in Hastelloy-X Tubing
- Figure 3 - Cracks in Tungsten-25% Rhenium Cylindrical Cans
- Figure 4 - Undesirable Parameters in Phase I SNAP-21 Welds
- Figure 5 - Extreme Closure Weld Penetration Changes in Seam Weld
Area on Phase II SNAP-21 Capsule
- Figure 6 - Undesirable Characteristics in SNAP-21 Development
E. B. Weld
- Figure 7 - Undesirable Weld Characteristics in AMSA E. B. Weld
- Figure 8 - SNAP-21 Ultrasonic Test Standard Flat Bottom Drill
Holes
- Figure 9 - X-Y Calibration Recording of SNAP-21 Standard
- Figure 10 - X-Y Recording of Unwelded Joint in SNAP-23 Developmental
Weld

FIGURE 1. SEAM WELD DEFECTS IN
RHENIUM CYLINDER

FIGURE 2. LAMINAR VOIDS IN HASTELLOY-X TUBING

FIGURE 3. CRACKS IN TUNGSTEN-25% RHENIUM
CYLINDRICAL CANS

4A INSUFFICIENT PENETRATION

WELD
ROOT
CRACK

4B WELD ROOT CRACK

FIGURE 4. UNDESIRABLE PARAMETERS IN PHASE I
SNAP-21 WELDS

FIGURE 5. EXTREME CLOSURE WELD PENETRATION CHANGES IN SEAM WELD AREA ON PHASE II SNAP-21 CAPSULE

POROSITY AND
LAMINAR VOID

← CAPSULE WALL

MISALIGNED WELD

← END CAP

BLOWUP OF MISALIGNED WELD

BLOWUP OF POROSITY AND LAMINAR VOID

FIGURE 6. UNDESIRABLE CHARACTERISTICS IN SNAP-21
DEVELOPMENT E. B. WELD

CRACK

POROSITY

FIGURE 7. UNDESIRABLE WELD CHARACTERISTICS IN
AMSA E. B. WELD

FIGURE 8. SNAP-21 ULTRASONIC TEST STANDARD
FLAT BOTTOM DRILL HOLES

FIGURE 9. X-Y CALIBRATION RECORDING OF
SNAP-21 STANDARD

SNAP-23 PEN LIFT

FIGURE 10. X-Y RECORDING OF UNWELDED JOINT IN
SNAP-23 DEVELOPMENTAL WELD