MASTERTECHNIQUES FOR NONDESTRUCTIVE EVALUATION OF
RADIOACTIVE WASTE CAPSULE END CAP WELDS

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ABSTRACT

Solid radioactive waste storage requires a high degree of container integrity. This paper describes the techniques developed at Battelle-Northwest to nondestructively inspect end cap welds for cesium and strontium waste containers. Ultrasonic methods have been defined for locating weld anomalies and acoustic emission techniques are currently being evaluated as an additional method to monitor weld quality. Initial ultrasonic and acoustic emission data taken with prototype equipment have exhibited good correlation with destructive analysis of sample capsule welds.

The ultrasonic inspection system is designed to incorporate a novel data presentation technique. The ultrasonic scanning and data readout system produce a very readable, easy-to-interpret record of the weld inspection. The scanning technique can be adapted to X-Y recorder printout or high speed CRT mapping methods. Future development areas are suggested which could extend the recording method to present depth-of-flaw or signal amplitude information in other ultrasonic inspection applications.

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TECHNIQUES FOR NONDESTRUCTIVE EVALUATION OF RADIOACTIVE WASTE CAPSULE END CAP WELDS

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SUMMARY

A program has been formulated at Battelle-Northwest Laboratories to apply state-of-the-art nondestructive evaluation techniques to solid radioactive waste containers. Included in the evaluation program are procedures designed to determine upper and lower end cap weld quality.

Weld quality is established through the use of acoustic emission weld monitoring and ultrasonic inspection techniques. Unique ultrasonic scanning methods have been developed for inspection of the end cap welds. The ultrasonic data presentation methods included in the inspection system produce readable, easy-to-interpret records of the weld inspection. Several sample end cap welds have been monitored and inspected. Metallographic sectioning has confirmed the accuracy of the ultrasonic inspection system. The ultrasonic and acoustic emission data compare very favorably for the initial samples.

Future development of the testing technique developed during this program appear applicable to other test specimens. High speed data presentation devices may allow application of these ultrasonic techniques to production operations.

INTRODUCTION

The problem of safe storage of radioactive waste materials has led to the implementation of programs designed to encapsulate these wastes in high integrity containers. A specific example is a program currently

underway to doubly encapsulate solidified strontium fluoride and cesium chloride. The nondestructive evaluation program associated with this encapsulation project includes techniques for determining the quality of the waste container upper and lower end cap welds. This paper briefly describes the nondestructive evaluation procedures currently being developed to assure end cap weld integrity. Ultrasonic and acoustic emission test results for sample end cap welds are presented and areas for future development of these inspection techniques are outlined.

CONCLUSIONS

- The application of ultrasonic inspection procedures to the waste capsule end cap welds has been made possible by proper weld design. This points out the importance of initiating a nondestructive evaluation program early in the design stages of similar projects, where weld quality is critical.
- Data presentation techniques, such as the spiral trace recording method, which produce accurate and reliable data displays are very important for fast and accurate determination of end cap weld quality. These displays aid metallographic sectioning procedures and are valuable in determining the detection capabilities of the ultrasonic system.
- Acoustic emission weld monitoring techniques have shown promising results when applied to end cap welds; however, additional work must be performed in order to determine the full capabilities of this technique.
- Future development of the ultrasonic scanning and data presentation techniques should produce data displays capable of recording several parameters of the ultrasonic data. Production applications of ultrasonic scanning methods may require high speed recording methods similar to the CRT display used in the end cap weld inspection system.

NONDESTRUCTIVE EVALUATION PROGRAM

The Nondestructive Testing Section of Battelle-Northwest has the responsibility of developing a comprehensive nondestructive evaluation (NDE) program to assure the integrity of these storage capsules. An extensive testing program has been formulated to provide NDE throughout the encapsulation process. This program is outlined below:

- Raw Material Inspection

Ultrasonic and fluorescent penetrant inspection are to be performed on the tubing used for the waste capsule walls. Waste capsule end caps will also undergo ultrasonic and fluorescent penetrant inspections.

- Lower End Cap Weld Inspection

The bottom end cap weld for both inner and outer capsules will be inspected by fluorescent penetrant and ultrasonic inspection.

- Final Closure Weld

The top end cap weld of both inner capsules will be tested by helium leak detection to insure weld integrity. The top end of both outer capsules will be ultrasonically inspected. Acoustic emission weld monitoring techniques are currently being studied for application to these welds.

- Surveillance

Methods are currently being considered to provide long term surveillance of the integrity of the stored capsules. A periodic ultrasonic scan of the outer capsule wall appears to be the most promising method at the present time.

The ultrasonic end cap weld inspection is of particular interest since the final closure weld (upper end cap weld) will necessarily be made inside a radioactive containment ("hot") cell. This requires a remotely operated test system for inspection of the final closure weld of the outer capsule. The lower end cap welds will be inspected outside of the "hot" cell. Ultrasonic inspection of the end cap welds will provide information on the weld penetration depth and other anomalies in the weldment area. Those welds which exhibit insufficient weld penetration or contain other anomalies which may be detrimental to the overall safety of the capsule storage program will be rejected as unsafe.

END CAP WELD EVALUATION

END CAP WELD DESIGN

The solidified waste containers are shown in Figure 1. Basically the containers consist of a section of tubing to which a lower end cap is welded. The solidified wastes are then placed inside the container and a final closure weld is made on the upper end cap. This container is placed into a second container and the welding process is repeated on the outer capsule.

Battelle-Northwest participated in the nondestructive evaluation program early in the encapsulation project, thus close cooperation was maintained between weld design personnel and nondestructive evaluation personnel. This close cooperation led to the development of a weld design which maintains satisfactory welding characteristics and also permits accurate ultrasonic inspection. The weld joint design is shown in Figure 2. Advantages of this weld design for ultrasonic inspection are:

- The maintenance of a weld joint parallel to the end cap surface.
- Square outer corner of the end cap.

- Extension of the end cap well below the weld area.
- The relatively small distance from the end cap surface to the weld area.

The parallel weld joint and end cap surface allow inspection of the weld area by a focused ultrasonic beam entering perpendicular to the end cap as shown in Figure 2. The square corner of the end cap maintains a surface perpendicular to the ultrasonic beam for proper focusing at the weld joint. The unwelded length of the weld joint reflects a portion of the incident ultrasonic energy. Weld anomalies such as cracks, porosity, or inclusions can be located in the same manner. Extension of the end cap well below the weld area disallows interference of the ultrasonic beam reflections from this surface with the reflection from the weld joint. Maintenance of a relatively thin end cap reduces the amount of signal attenuation and permits good signal-to-noise ratios to be maintained.

ULTRASONIC INSPECTION SYSTEM

A versatile ultrasonic test system has been designed to perform the ultrasonic inspections previously mentioned, including the end cap weld inspection. The system consists of a "remote" test tank located inside the "hot" cell, a local test tank, and a control console common to both the local and remote test tanks. A basic outline of the ultrasonic inspection system is given in Figure 3.

The test tanks perform the required capsule positioning and rotation, transducer manipulations, and other mechanical functions. Pulse generation and signal preamplification circuitry are the portion of the electronics located at the test tanks. The control console contains the signal processing electronics and data readout mechanisms. A high degree of versatility has been maintained throughout the system design, especially in the data readout and presentation portions. An X-Y recorder, a strip chart recorder, and an oscilloscope are available for use in presentation of the inspection results.

ACOUSTIC EMISSION MONITORING SYSTEM

Acoustic emission techniques have also been used as an additional weld quality monitor. The monitoring system used is shown in Figure 4. Acoustic emissions generated during or shortly after the welding process are detected via a sensor located near the weld. These signals are processed and recorded on a strip chart recorder. Welds exhibiting above average acoustic emission activity are suspected of containing cracks, inclusions, or some other form of weld anomaly. During the non-destructive evaluation program, welds which generate a large number of acoustic emissions are subjected to metallographic examination to relate acoustic emission output with weld quality. Correlation of the acoustic emission data with ultrasonic inspection results provides additional information on weld quality.

ULTRASONIC INSPECTION TECHNIQUE

The technique used to ultrasonically inspect the end cap weld requires rotation of the waste capsule. Precise location and rotation of the capsule allow the transducer focal point to scan the weld area as the capsule is rotated. During rotation of the capsule, the transducer is translated inward toward the center of the capsule producing an inward spiral path traced out by the focal point. Figure 5 illustrates the scanning technique and transducer location. A precise location of the initial starting point of the scan is attained by locating a reference point on the end cap prior to starting the scan. A small indentation in the end cap has been used effectively as a reference mark and has allowed precise locations of weld flaws. This location accuracy is essential for successful metallographic sectioning.

A test standard end cap (shown in Figure 6) has been used during the initial phases of the testing program to properly evaluate the inspection technique. The test standard consists of an end cap containing various diameter flat bottomed holes drilled to a depth equal to the weld joint lip. This test standard has provided valuable information in formulating the inspection procedure and in determination of the system sensitivity and resolution.

ULTRASONIC DATA PRESENTATION

Presentation of the ultrasonic data is a very important part of the ultrasonic inspection technique. Proper data presentation is essential for accurate data interpretation and for providing permanent test records of the inspection results. The methods which have been selected for presentation of ultrasonic data on the end cap weld inspection are:

- Deflection of strip chart recorder pen,
- Pen lift of an X-Y recorder and
- Intensity modulation of a cathode ray tube (CRT) display.

An example of the strip chart recording method is shown in Figure 6. The Pen of the recorder is deflected an amount corresponding to the reflected signal from each drill hole in the test standard. This method records signal amplitude information which can be correlated with the size of the anomaly encountered. The primary disadvantage of this technique is the amount of data interpretation which must be performed to correlate position of pen deflection along the recorder chart to actual anomaly location around the end cap weld. For high speed testing applications, data interpretation such as this should be kept at a minimum.

The spiral scan of the ultrasonic beam along the end cap weld has permitted the development of a spiral recording technique applicable to both X-Y recording and CRT display. A spiral scan of the recording pen (or oscilloscope beam) is produced by properly monitoring the rotational and transverse positions of the transducer in relation to the end cap weld. Anomaly detection is presented along the normal scan path by lifting the pen of the X-Y recorder or intensity modulation of the CRT beam. Examples of the X-Y recorder and CRT scans of the test standard end cap are shown in Figure 7.

The X-Y recorder map produces a true magnification of the scanned area and the anomaly shape as seen by the focal point of the transducer. Thus, the round drill holes in the test standard end cap are accurately reproduced on the recorder scan. The true magnification of weld anomalies make the X-Y recording technique very attractive from the standpoint of data interpretation.

The small size of the CRT face relative to the X-Y recorder trace requires that only the magnified portion of the weld be shown on the CRT. The subsequent reduction in scan diameter results in a scan which is magnified in the radial direction but not in the circumferential direction. This creates a distortion in anomaly shape as can be seen in the CRT scan of the test standard holes (Figure 7). Large diameter CRT displays could be used to eliminate the distortion and produce accurate representations of weld anomalies; however, a large diameter CRT was not available when these scans were made. The high speed, accuracy, and reliability of CRT displays make them the desired method of data display for high speed ultrasonic inspections. Standard plotters or scope cameras can be used to produce permanent records of the displays.

ACOUSTIC EMISSION MONITORING TECHNIQUES

The acoustic emission activity generated during the end cap welding process is detected by a sensor located near the weld area. The monitoring period is started at the beginning of the welding process and continues for approximately one minute after the welding arc is broken. The sensor output is amplified and processed by an acoustic emission monitoring instrument. A strip chart recorder is used to record the monitor output signal. Comparison of acoustic emission monitoring records for "normal" and intentionally defected welds indicates the acoustic emission activity anticipated for naturally occurring weld defects.

WELD INSPECTION RESULTS

The spiral scan recording technique has been used on several 304L stainless steel end cap welds which were inspected with a prototype of the ultrasonic test system. Sample capsules containing insufficient weld penetration and intentional weld defects were inspected to determine the detection capabilities of the test system. Figure 8 is the X-Y recorder scan for a capsule lacking full weld penetration. The outer circumference of the scan corresponds to the outer edge of the end cap. Comparison of this scan with the test standard scan indicates a 50 to 60% weld penetration. 100% weld penetration is defined as complete fusing of the weld joint to a depth equaling capsule wall thickness. Note the variations in penetration depth around the circumference of the weld. Areas containing unexplained variations in penetration are prime candidates for metallographic sectioning and examination. The photomicrograph (Figure 8) of a section of this weld confirms the ultrasonic scan indication of 50% weld penetration at that point.

A similar scan of an intentionally defected weld sample is shown in Figure 9. The weld was defected by introducing a foreign metal into the weld at the points marked on the scan. The metallographic section photomicrograph indicates the foreign metal introduced into the weld resulted in an unfused weld joint. The unfused portion of the weld joint was detected by the ultrasonic scan and recorded on the scan record.

A comparison of the acoustic emission output for normal and intentionally defected welds is made in Figure 10. The acoustic emission output for the defective weld is substantially higher than the output from a normal weld. These results indicate acoustic emission monitoring techniques can be valuable in determining end cap weld quality.

The current development program at Battelle-Northwest is expected to include ultrasonic inspection of additional capsule materials such as 316 SS and Hastalloy C-276. Normal welds and intentionally defected welds of the materials will be inspected. Correlation of acoustic emission, ultrasonic, and metallographic data from this program will provide the background data required for the end cap weld quality assurance program.

FUTURE DEVELOPMENT AREAS

CRT recording techniques have several advantages over other data display methods for high speed, production type applications. The development of the CRT recording method for application to end cap welds can be further refined to present additional ultrasonic data. One technique currently being considered for displaying signal amplitude information would use a color display console. The location of a weld anomaly would position it on the CRT face. Variations in signal amplitude could be presented as color changes on the screen. This method could also be used to display depth-of-flaw information by controlling the color combinations with signals corresponding to the timing of reflected ultrasonic indications in the test specimen.

Permanent records of CRT scanning displays are possible by two methods. The more obvious method is standard CRT photography using a camera mounted on the face of the CRT. In addition, the display information could be recorded on video tape. Either of these methods would provide permanent records of the inspection results which can be easily stored for future reference.

The spiral ultrasonic scanning technique is not limited to the inspection of end cap welds. Large areas can be scanned using this method, such as the entire waste capsule end cap. Further development of this scanning technique could permit its application to the ultrasonic inspection and data readout for other shapes and sizes of specimens.

FIGURE 1
STRONTIUM FLUORIDE AND CESIUM CHLORIDE CAPSULE DESCRIPTION

FIGURE 2
WELD JOINT DESIGN AND ULTRASONIC TEST MECHANICS

E_I - INCIDENT ULTRASONIC ENERGY

E_J - REFLECTION FROM UNFUSED JOINT

Figure 3

Basic Outline of Ultrasonic Inspection System

FIGURE 4
ACOUSTIC EMISSION WELD MONITORING EQUIPMENT

Figure 5

Ultrasonic Scanning Technique and Transducer Positioning

Figure 6

Ultrasonic Test Standard and Strip Chart Test Record

STANDARD REFERENCE
END CAP

Figure 7
X-Y Recorder & CRT Scan Records
For Test Standard

X-Y Recorder Scan Record

CRT Scan Record

Figure 8

Ultrasonic Scan Record For Sample End Cap Weld

X-Y Record Scan of Sample
End Cap Weld

Photomicrograph of Section A-A

Figure 9

Ultrasonic Scan Record For Intentionally
Defected Weld Samples

X-Y Record Scan of Intentionally
Defected Weld

Photomicrograph of Section A-A

FIGURE 10
COMPARISON OF ACOUSTIC EMISSION FROM NORMAL
AND SALTED WELD SAMPLES