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Application of Flow Forming for Use in Radioactive Material Packaging Designs

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ABSTRACT

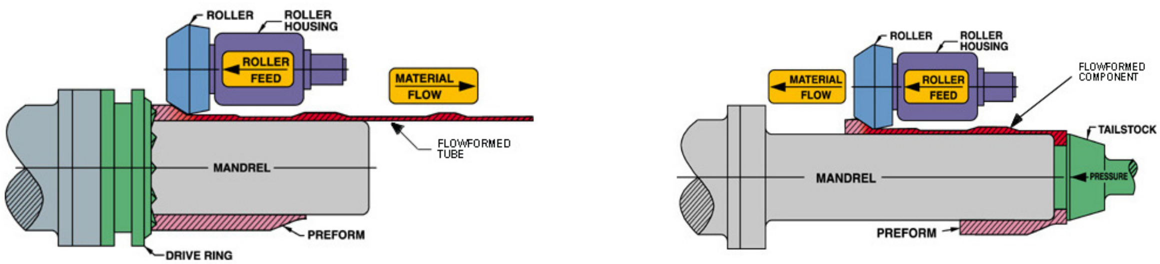
This paper reports on the development and testing performed to demonstrate the use of flow forming as an alternate method of manufacturing containment vessels for use in radioactive material shipping packaging designs. Additionally, ASME Boiler and Pressure Vessel Code, Section III, Subsection NB compliance along with the benefits compared to typical welding of containment vessels will be discussed.

INTRODUCTION

Flow forming is a century-old technique that has been sometimes referred to as Roll-Flo® or flow-turning. The process was initially used in defense, and then later for aerospace applications. It was modernized in the 1950s' in Sweden making it a relatively new method of metalworking. Most recently the process has been adapted for the fabrication of radioactive material shipping package Containment Vessels (CVs). The process reduces or eliminates welding and increases precision of the final product with minimal or no machining required.

Flow forming is a cold working process through which the base metal is stretched plastically to alter its size or shape which reduces the %-elongation of the formed material while substantially increasing its yield and tensile strength compared to the base metal. Returning the material to its base properties requires a cold work solution anneal after the flow forming process. This cold work annealing could be a single operation or a multi-step process integral with the flow forming.

There are two types of flow forming, "forward" and "reverse" (Figure 1). Regardless of which method is used, a piece of material called a "preform" is plastically deformed over a mandrel below the materials recrystallization temperature. For forward flow forming, the part being formed can be closed-ended or partially open-ended and for reverse flow forming the part is open ended. Whereas for forward flow forming the mandrel must match the finished part length, for reverse flow forming the formed part may be many times longer than the mandrel length. The term "cold" in cold worked is a misnomer since the preform is placed under significant structural loading by a series of offset rollers which produce significant heating during radial and axial movement of the material during the forming process. Proprietary coolants are typically used by the manufacturers that produces flow formed parts. The coolants are used to reduce friction, galling and tool drag.



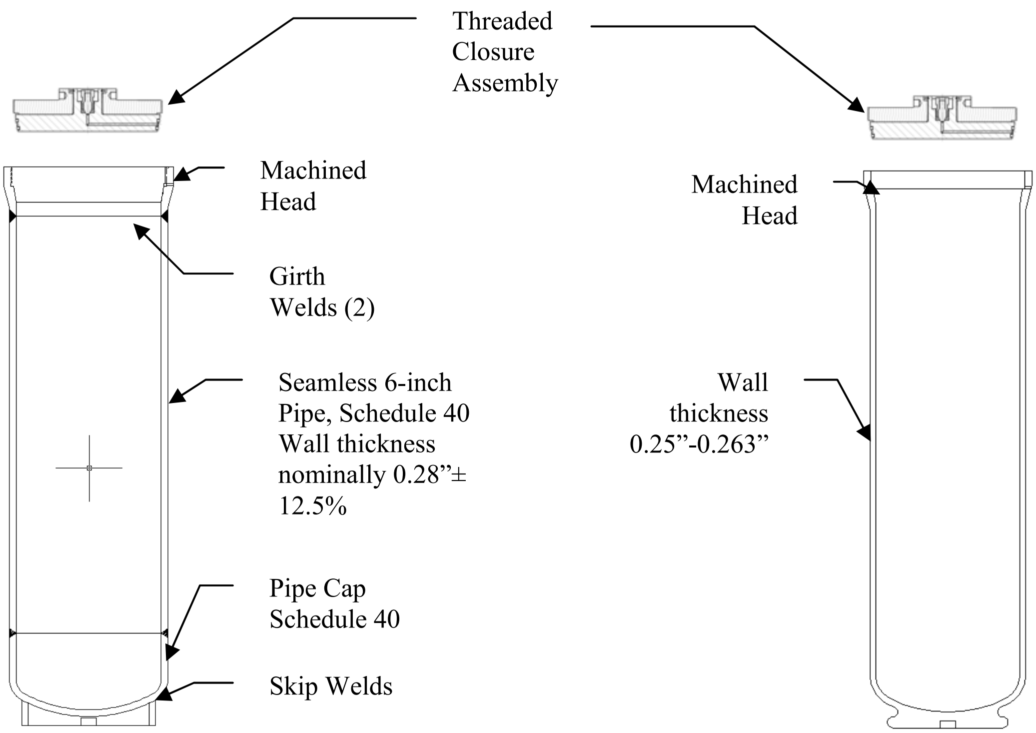
Reverse Flow Forming　　　　Forward Flow Forming

Figure 1 Types of Flow Forming

DISCUSSION

This paper reports on the fabrication and testing performed to demonstrate the use of flow forming as an alternate method of manufacturing containment vessels for use in radioactive material shipping packaging design. Specifically, this paper addresses the development and testing of flow formed vessels with thicker walls than previously fabricated using the flow forming process. The 6-inch diameter welded containment vessel design that is currently used in both the Savannah River National Laboratory (SNRL) designed 9975 and 9977 Shipping Packaging was selected for this evaluation. Because the flow formed vessel is a single part, its design is slightly different than the multi-part welded configuration currently used in the SRNL packages. Figure 2 shows the welded and flow formed CV body configurations compared in this evaluation. The threaded closure assembly for each vessel[1] is identical for the flow formed and welded CV designs. For the purpose of this paper the welded CV will be referred to as "wCV" and the flow formed CV as CV-FF.

Four flow formed vessels were fabricated, FF-1through FF-4. FF-1 was hydrostatically burst tested, FF-4 was destructively cut up for materials testing and FF-2&3 was left intact. Each of the vessels were fully assembled, hydrostatically pressure tested and helium leak tested in accordance with the requirements of the welded CV design specifications.[2,3] Each flow formed CV was 100% dimensionally inspected. Ultrasonic and liquid penetrant examination was used to verify vessel wall thickness and lack of defects of the flow formed vessels. Flowforming vessel wall thicknesses between 0.02 and 0.20 inches are typical per Precision Metal Forming Industries in Pennsylvania. The 9975 and 9977 6- CV designs incorporate 6-inch diameter schedule 40 pipe and pipe caps having a nominal wall thickness of 0.28 inches. Fabrication and inspection of these units will be used to verify flowforming as an applicable method of producing the thicker walled CV design.



Multi-Component Welded Assembly

Single-piece Flow Formed Unit

Figure 2 Containment Vessel Design Comparison

Containment Vessel Design

The welded 6-inch wCV design for the 9975 and 9977 Shipping packages is designed for 800 psig at 300ºF and is analyzed, fabricated, and examined in accordance with Section III, Subsection NB, of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, 2004 Edition. The wCV weldment is fabricated from Schedule 40, SA-312, Type 304L SS seamless pipe having a 0.280-inch nominal wall thickness. A standard weight SA-403, Type 304L SS pipe cap (also 0.280-inch nominal wall) is welded to one end. A stayed head fabricated from Type SA-479 304L SS bar stock is welded to the other end; following welding, a 6½-12UNS-2B thread and an interior conical sealing surface is machined into open end of the vessel. The wCV welded joints are circumferential, full-penetration ASME B&PV Code welds. A 5-inch diameter by 2-inch long Schedule 40 Type 304L SS pipe is welded to the closed end, forming a base; two notches are cut in the base used to prevent rotation during CV assembly. Following all welding, the internal diameter of the wCV is machined to final design dimensions.

The flow formed 6-inch CV-FF is fabricated from a single-piece "preform" of SA-479, 304L SS bar stock. After the flow forming process is complete, the finished component is machined to include 6½-12UNS-2B interior thread and an interior conical sealing surface. No bore machining is required. The outside is not machined.

Flow Form Fabrication, Annealing and Material Testing

Figure 3 shows an example of a "preform" and the final flow formed part. The time to produce the final CV-FF flow formed shape from its preform was a matter of only a few minutes. The flow formed CV-FFs were produced by Precision Metal Forming Industries in Pennsylvania under contract by Major Tool and Machine, Indianapolis, IN (MTM). MTM was selected by SRNL to produce the CV-FFs because they were uniquely qualified due to their experience in fabricating wCVs for the 9977 Package. Following inspection of the final shape the part was solution annealed to return the material to its base properties. Each of the CV-FF parts were heated to 1,900ºF under a hard vacuum for 60 minutes and then nitrogen quenched to below 150ºF.

Figure 3 – Preform and Finished Piece

Flow form unit FF-3 was cut up in order to produce test coupons for longitudinal and lateral tensile tests for tensile, yield and elongation measurements. Coupons were taken from the top, middle and bottom of the CV-FF. Table 1 compares the mechanical properties of the solution annealed material to the minimum requirements of the material used for the wCV configuration (reference: ASME B&PV Code , Section II, Part A, Ferrous Material Specifications, 2007 Edition). The base material properties for the SA-479 Preform (before forming) are: Tensile (86.5 ksi), Yield (40 ksi) and Elongation (59%). As can be seen from the measured properties listed in Table 1, the properties for flow formed and annealed material matches closely to the Preform base material properties.

Table 1 – Mechanical Properties of the Welded and Flow Formed Containment Vessel

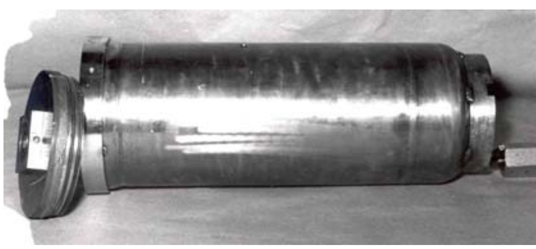
	Yield (ksi)	Tensile (ksi)	Elongation %
Welded Vessel (wCV)	B&PV Code Material Minimums		
Machined Head (SA-479)	70	25	30
Seamless Pipe (SA-312)	70	25	35 – Longitudinal 25 – Transverse
Pipe Cap (SA-403)	70	25	28 – Longitudinal 20 – Transverse
Flow Formed Vessel (FF-3) (SA-479)	Measurements (Post Anneal)		
Longitudinal - Top	83.5	34	62
Middle	83.5	33.4	63

Bottom	83.5	33.6	62
Transverse - Top	90.5	41.4	66
Middle	91.5	40.1	64
Bottom	92	44.1	70

Flow Form Burst Testing

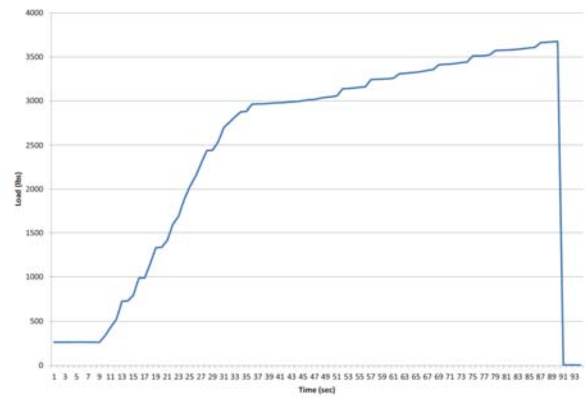
The welded 6-inch CV design (wCV) has a maximum design operating pressure of 800 psig and is proof tested at 1,235 psig. All vessels passed helium leak testing with a measured leakage rate of not greater than 1.72×10^{-9} atm-cc/sec ≤ to the acceptance criteria of 1×10^{-7} atm- cc/helium/sec. [4] A hydrostatic burst of one vessel was performed to determine if there was any difference in burst pressure or failure mode as compared to the welded design since the flow formed parts are more perfectly axisymmetric compared to the multi-part welded fabrication. The flow formed vessels showed no evidence of leakage or degradation at the proof test pressure.

Figure 4 compares the hydrostatic burst test results of a welded 6-inch diameter wCV and the 6-inch flow formed CV-FF-1. The welded wCV threaded closure failed at 4,400 psig. The flow formed 6CV pictured failed at about 3,700 psig after 90 seconds as indicated by burst test data plot. Both vessels maintained a seal until the vessel closure assembly failed. No external damage could easily be observed to the body of the hydro-tested vessels; only with the use of a straight edge could a very small deformation of the CV-FF-1 wall be observed near its closure and bottom end. The higher pressure failure for the wCV (4,400 psig) is attributed to a 1-inch collar welded to the machined head of the wCV to test the effects of a thicker wall for the CV closure.



6-inch wCV
SRS Photo DPSPF 31496-3

6-inch CV-FF-1
(Burst Tested)



6-inch CV-FF-1 Burst Test Results

Figure 4 – Welded versus Flow Form Burst Test Results

Figure 5 illustrates some of the damage observed to the closure assembly of the burst-tested CV-FF. Most of the damage occurred to the closure assembly threaded nut and cone-seal plug. Edges of the cone-seal plug threads were peeled back as the CV failed and the closure assembly was ejected from the flow formed CV. The bottom O-ring seal failed and the top O-ring showed some marring, but otherwise was found intact after the burst test.

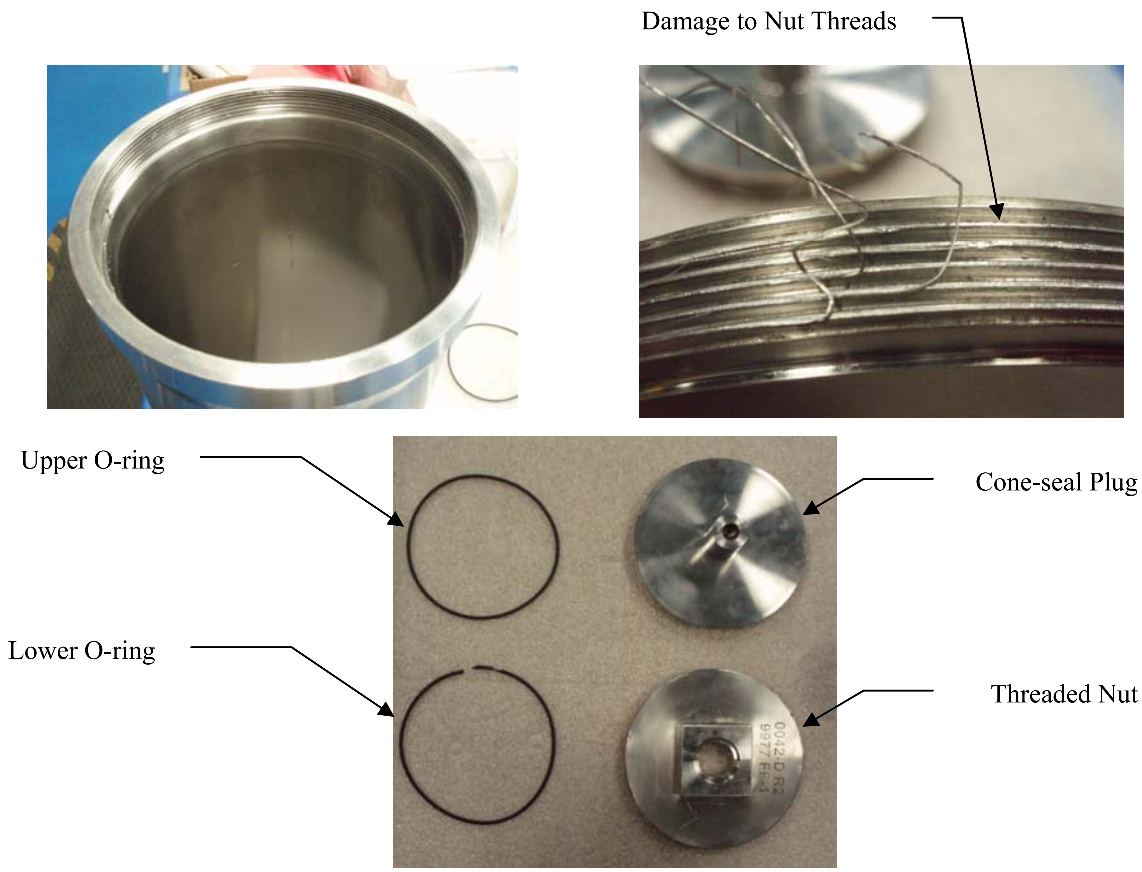


Figure 5 Hydrostatic Burst Test Damage FF-3

Code Compliance

Flow forming is not explicitly referenced as a method of fabrication for complying with Section III, Subsection NB of the in the ASME B&PV Code. SRNL has received concurrence from ASME that flow formed products can be considered a "conversion from one product form to another product form" as described in NCA-3851.2(a)(1).[5] Package designers at the DOE Y-12 Site have sited Forming and Bending Processes of ASME B&PV Code Section III, Subsection NB, Paragraph 4212 as reason for Code compliance. In addition, the DOE Office of Environmental Management Packaging Certification Program tasked their Regulatory Review Agencies, Lawrence Livermore and Argonne National Laboratories, to consider the applicability of this method of manufacturing as an alternate method to the fabrication techniques that have historically be used in the fabrication of ASME Code compliant Containment Vessels.[6] Because flow forming is a relatively new process used for radioactive material package designs, emphasis is be placed on the quality assurance associated with the control of the process(s) and personnel involved in the fabrication flow formed parts. Every phase of the flow formed process must be monitored, the specified material properties are verified and non-destructive examinations are performed to ensure product quality.

CONCLUSIONS

SRNL has completed fabrication development and the testing on flow formed containment vessels to demonstrate the use of flow forming as an alternate method of manufacturing a welded 6-inch diameter containment vessel currently used in the 9975 and 9977 radioactive material shipping packaging. Material testing and nondestructive evaluation of the flow formed parts demonstrate compliance to the minimum material requirements specified in applicable parts of ASME Boiler and Pressure Vessel Code, Section II. Destructive burst testing shows comparable results to that of a welded design. The benefits of flow forming as compared to typical welding of containment vessels are significant: dimensional control is improved due to no weld distortion; less final machining; weld fit-up issues associated with pipes and pipe caps are eliminated; post-weld non-destructive testing (i.e., radiography and die penetrant tests) is not necessary; and less fabrication steps are required. Results presented in this paper indicate some of the benefits in adapting flow forming to design of future radioactive material shipping packages containment vessels.

REFERENCES

[1] 9975 Shipping Package Primary (PCV) & Secondary (SCV) Containment Vessel Details (U), Rev 13, Savannah River Site, Aiken, SC.

[2] 9975 Shipping Package Containment Vessel Weldments (U), R-R3-F-0016, Rev 12, Savannah River Site, Aiken, SC.

[3] 9975 Shipping Package Primary and Secondary Containment Vessel Subassemblies (U), R-R2-F-0018, Rev 9, Savannah River Site, Aiken, SC.

[4] Major Tool Manufacturing Helium Leak Test Report, 9977 FF-1, Purchase Order Number AC82088A, Rev. 0.

[5] M.L. Vazquez, ASME Codes and Standards, Section III Standards Committee, ASME File: 10-640, November 10, 2010.

[6] G. Mok, M. DeMicco, L. Fishcer, et.al., On the Application of Flow Forming to the Fabrication of Type B Radioactive Material Package Containment Vessels, Rev. 1, LLNL-TR-442131, May 25, 2010.