

RHIC Combined Element Magnet End Volume Sleeve Evaluation

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AD/RHIC/RD-90

RHIC PROJECT

Brookhaven National Laboratory

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Abstract

The End Volume on the RHIC Combined Element Magnet consists of a cylindrical sleeve welded to flat, circular end plates to form a volume within which magnet electrical connections are located. The drawing specifies ASME/ASTM SA-312/A-312 pipe or ASTM A-182 forgings are to be used to make the cylindrical sleeve. The vendor claimed to use the A-312 option. Instead, plate was rolled and welded using the shielded arc process. Thirty magnets (CQS-101 through CQS-130) were assembled using these sleeves. ASME/ASTM SA-312/A-312 mechanical testing was conducted to determine compliance. The test data shows the non-conforming material meets American Society of Mechanical Engineers Boiler & Pressure Vessel Code requirements.

Background

The RHIC Combined Element Magnet (CEM) cold mass has a 14.25" outside diameter volume installed on each end. This volume provides the room necessary for magnet electrical components, such as diodes, lead connections, and lead expansion joints. The volume is formed by a cylindrical shell, or sleeve, 0.375" thick, which increases to 0.425" thick at the ends for attachment to the 1.00" thick flat plate (cold mass yoke containment end plate) which forms the inner head of the volume, and the 1.50" thick flat plate which forms the outer head of the volume. Leaks were detected in the sleeves for two completed Combined Element Magnet cold masses, and subsequent preparation for repair revealed weld slag and voids. Drawings 12050049 and 12050056 specify ASME/ASTM SA-312/A-312 pipe or ASTM A-182 forgings are to be used to make the sleeve. The ASME/ASTM SA-312/A-312 standards are identical. The American Society of Testing and Materials (ASTM) Standard A-312, Standard Specification for Seamless and Welded Austenitic Stainless Steel Pipes, specifically requires that the pipe be seamless or manufactured using "an automatic welding process, with no addition of filler metal in the operation." The presence of slag at the leak sites indicates a weld using the shielded arc process, which adds filler metal during the process.

Investigation at the vendor found the rough sleeves were subcontracted. The subcontractor provided a certification indicating the material was ASTM A-312 pipe. Radiograph inspection of the rough sleeves revealed voids and other discontinuities. Six finished sets of uninstalled end volumes also were inspected at Brookhaven National Laboratory, with additional discontinuities found. The subcontractor's procedures were examined to determine the weld processes used, and the subcontractor was later visited to determine their capabilities. The rough sleeves were manufactured using three different processes. The joint was tack welded using shielded arc welding, and the groove was filled using submerged arc welding. Finally, the back of the weld

was finished using the metal arc process and flux core consumable. All these processes use filler metal and flux, and do not conform to ASTM A-312.

The discontinuities in the finished end volume sets that were radiograph inspected at Brookhaven National Laboratory were repaired. Six sets of rough sleeves were selected from the radiograph results for finishing by the subcontractor to fulfill the quantity requirements of the first procurement; a total of 60 end volumes.

The issue to be addressed became the acceptability of the non-conforming materials installed on completed Combined Element cold masses. Longitudinal welds using filler metal in cylindrical shells are permitted under the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code. Additionally, ASTM A-312 specifies testing to determine compliance with the standard. Therefore, satisfactory completion of the mechanical tests required by both American Society of Testing and Materials and American Society of Mechanical Engineers will demonstrate compliance with both standards.

ASTM A-312, paragraph 9, requires three mechanical tests:

- 9.1 Transverse or Longitudinal Tension Test
- 9.2 Flattening Test
- 9.3 Hydrostatic Test

The Tension Test procedure is prescribed by ASME/ASTM SA-370/A-370, Test Methods and Definitions for Mechanical Testing of Steel Products. The Flattening Test is prescribed by ASTM A-530, and serves the same purpose as the guided bend tests specified by Paragraph QW-160, Section IX, Welding and Brazing Qualifications, American Society of Mechanical Engineers Boiler & Pressure Vessel Code, except that the pipe is loaded radially and flattened. The weld is located perpendicular to the load direction, thus imposing the greatest bending stress on the weld. These tests are similar for any welded pressure vessel complying with the American Society of Mechanical Engineers Boiler & Pressure Vessel Code. Finally, Paragraph UG-84, Section VIII, Division 1, of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code requires Charpy Impact Testing to be performed at the operating temperature of the device. Most austenitic stainless steels, including Type 304L used for the end volume sleeves, are exempted from this requirement for operating temperatures down to 20°K. However, RHIC magnets will be operating at 4.2°K, so testing is required. Complicating matters, Charpy Testing has been shown to be invalid for temperatures below 76°K.

Procedure

A two-phase program was developed to determine the acceptability of the non-conforming Combined Element Magnet end volumes.

Phase 1 - Determine Minimum Mechanical Properties

Select two unmachined sleeves for mechanical testing. These sleeves will be sectioned for the following testing:

- Flattening test (ASTM A-312)
- Tensile test (ASTM A-312)
- 76°K Charpy Impact Testing (American Society of Mechanical Engineers Boiler & Pressure Vessel Code)

Acceptance Criteria:

Acceptance criteria will be in accordance with ASTM A-312 and American Society of Mechanical Engineers Boiler & Pressure Vessel Code.

Phase 2 - Acceptability of In-House End Volumes

Uninstalled End Volumes

All uninstalled End Volumes shall be radiographed. All defects shall be repaired by grinding and re-welding using gas tungsten arc welding (GTAW).

Acceptance Criteria:

Acceptance criteria will be in accordance with American Society of Mechanical Engineers Boiler & Pressure Vessel Code and the specified vacuum leak rate.

Installed End Volumes

1. All installed End Volumes shall be conditioned for testing by a cold shock to at least nitrogen temperature, followed by a pneumatic pressure test to 180 psi. Units already having these tests performed do not require retesting.
2. All installed End Volumes shall be vacuum leak checked.

Acceptance Criteria:

Acceptance criteria will be in accordance with American Society of Mechanical Engineers Boiler & Pressure Vessel Code and the specified vacuum leak rate.

Phase 1 - Determine Minimum Mechanical Properties

The radiographs were reviewed, and serial numbers 6 and 30 were selected for testing because there were no voids or imperfections visible on the radiographs. The subcontractor was instructed to remove one inch from both ends of each article to eliminate weld discontinuities created by weld starting/stopping. The next cut yielded the four inch wide flattening ring, with the remainder for tensile and Charpy specimens. This is shown in Figure 1. The sections were metal stamped for identification prior to cutting. The stamp was located such that the identification was preserved through the subsequent machining processes, or relocated prior to elimination of the original marking.

The flattening test requirements are prescribed by American Society of Testing and Materials Standard A530, Standard Specification for General Requirements for specialized Carbon and Alloy Steel Pipe. Paragraph 18.2, Welded Pipe, requires the specimen to be flattened cold

between two parallel plates in two steps. In both steps, the weld is located 90° from the direction of the applied force, generating the greatest bending in the weld. The first step is a test for ductility. The specimen is to be flattened until the distance between the plates is less than the value of H calculated as follows:

$$H = \frac{(1+e)t}{(e+t/D)}$$

where:

- H = distance between flattening plates, inches
- t = specified wall thickness, inches
- D = specified or calculated (from the specified inside diameter and wall thickness) outside diameter, inches
- e = deformation per unit length (constant for a given grade of steel;
0.09 for austenitic steel)

This value is calculated to be 5.7 inches. No cracks or breaks on the outside, inside or end surfaces are permitted. The second step is a test for soundness. The flattening of the test article is continued until the specimen breaks or the opposite walls of the pipe meet. Evidence of laminated or defective base material or weld material is cause for rejection.

The transverse tension testing for pipe having a wall thickness 3/4" and greater requires a standard round tensile specimen. This requires the stock to be flattened. Both ASTM E-8, *Standard Test Methods of Tension Testing of Metallic Materials*, and ASME SA-370, *Specifications for Test Methods and Definitions for Mechanical Testing of Steel Products*, permit the stock to be flattened before or after separation from the ring. It was essential to have the weld centered within the length of the specimen, and to minimize bending in the weld during flattening.

Flattening was not required for the Charpy specimens because of the 3/4" thickness and the 10+ diameter of the rough sleeve. The stock was machined parallel and flat to 0.394" ±0.003" with a finish of 125 µin maximum. The transverse width of the resulting "plate" was machined to 2.165" +0"/-0.100", with the weld centered. The preparation of the tensile and Charpy specimens from the initial ring section is shown in Figure 2.

Phase 2 - Acceptability of In-House End Volumes

Uninstalled end volumes were radiograph inspected and individually leak-checked. All defects were repaired and re-inspected prior to installation. The test plan for the first 30 Combined Element Magnets included a warm pressure/leak test to 125% of the design pressure. In this test, the cold mass is suspended in a dewar and pressurized internally to 345 psi with helium gas, while simultaneously drawing a vacuum on the dewar. The dewar vacuum was then monitored for fifteen minutes for helium leakage in excess of 2×10^{-10} std cc He/sec. After horizontal cold

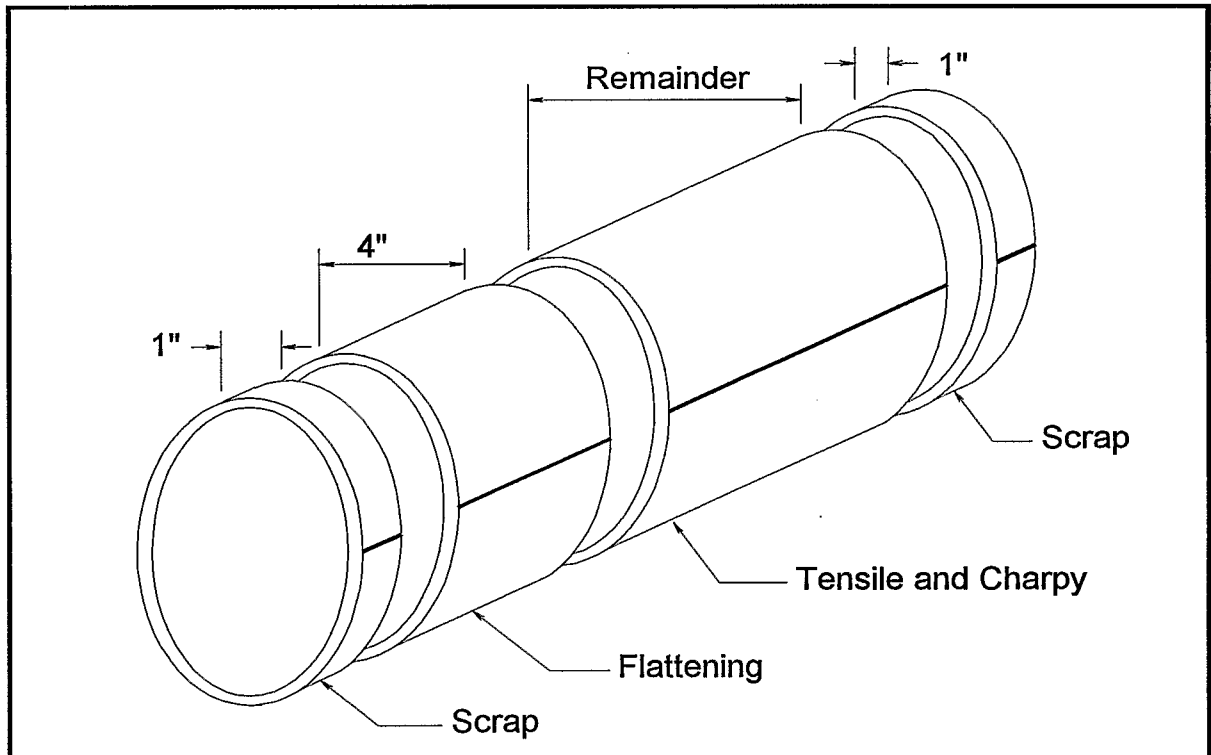


Figure 1. Initial Test Specimen Sectioning Diagram

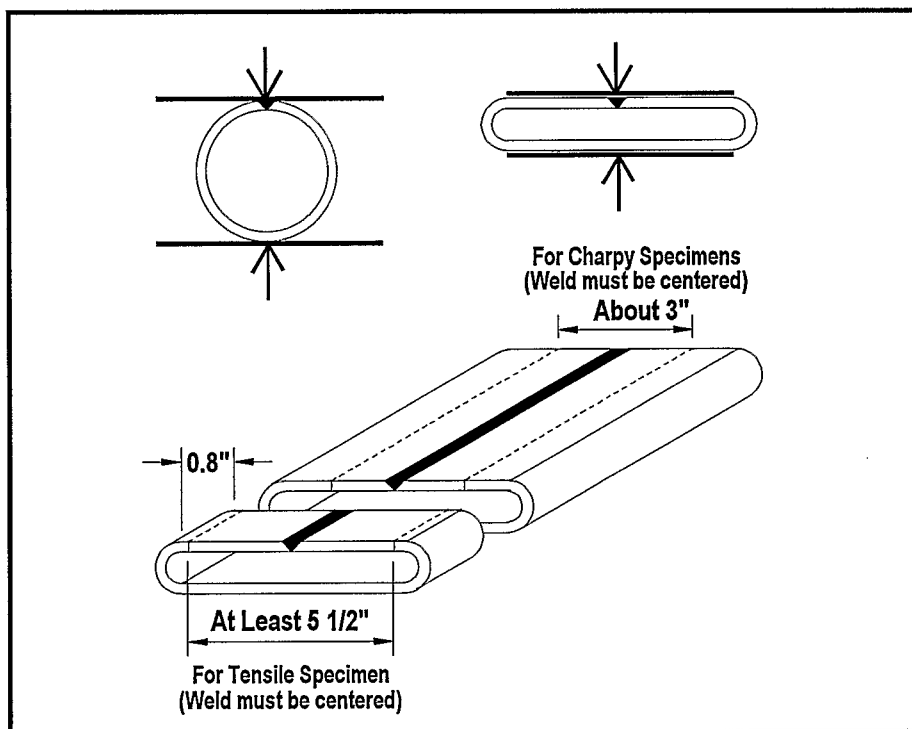


Figure 2. Tensile & Charpy Specimen Sectioning Diagram

testing of the full, cryostated magnet was completed, but prior to removal from the cold bay, the magnets were cold pressure tested to the facility maximum pressure of 180 psi and vacuum leak checked to 2×10^{-10} std cc He/sec. At the time the test plan was implemented, Magnets CQS-101 and CQS-102 had completed cold testing and were removed from the cold bay. These magnets were retested warm to 305 psi and vacuum leak checked to 2×10^{-10} std cc He/sec.

Results and Discussion

Determine Minimum Mechanical Properties

The flattening tests and tensile tests were conducted by a laboratory selected by the subcontractor. A-LAB Corporation, 3050 Dryden Road, Dayton Ohio determined the test specimens had passed both steps of the flattening test, using a calculated H value of 5.2 inches. The tensile test results are compared to the minimum specified values in Table 1. A copy of their test certification is included as Appendix A.

Table 1
Tensile Test Results

	12050049	12050056	Minimum Required
Tensile Strength, psi	89,720	89,980	70,000
Yield Strength, psi	51,740	53,430	25,000
Elongation, % (in 2 in.)	43	42	25 (transverse)

The machined plate for the Charpy specimens was received by Brookhaven National Laboratory and the Charpy specimens were cut using electro-discharge machining to the required dimensions (10mm x 10mm x 55mm) and notched. The yield from each plate was seven specimens. These specimens were immersed in a small open dewar of liquid nitrogen on a raised grid at least 25mm from the bottom, with at least 25mm of liquid above the specimens. The specimens remained in the bath until the liquid stopped boiling; at least 15 minutes. The specimens were then placed in the machine and broken within five seconds, as provided in ASTM E-23, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. The results are shown in Table 2, and a copy of Impact Test Report #2353 is included as Appendix B.

Acceptability of In-House End Volumes

Two installed end volumes were found to leak, but it was these leaks which precipitated this effort. Eight uninstalled end volumes were repaired prior to installation. No installed end volumes were found to leak subsequent to the implementation of this test program.

Table 2
Charpy Impact Test Results

Specimen Number		Impact Energy (ft-lbs)	Lateral Expansion (inches)
95-011052	#1	41	0.0326
	#4	42.5	0.03
	#5	43	0.0315
	#6	40.5	0.0295
	#7	41	0.035
95-011053	#1	37	0.025
	#2	33	0.019
	#3	37	0.021
	#4	44	0.02
	#5	37	0.017
	#6	35	0.0215

Assessment of the Test Results

The weld integrity is evaluated by the flattening test, which is the equivalent of a bend test. Both specimens passed this test. Table 1 clearly shows the actual weld metal yield and ultimate strengths — and its ductility, as measured by the elongation — exceeds the minimum requirements for the base materials. The minimum requirements for the base materials are the values used in design, thus the weld material has adequate strength and ductility.

The notch toughness of weld material is compared in Table 3 to the values for the BNL superalloy developed for cryogenic magnet welding and the values for welded Type 304L plate¹. One may see that the values for the Combined Element Magnet end volumes are very much lower than for the BNL superalloy, but still higher than previously documented values. The American Society of Mechanical Engineers requires impact energies greater than 15 ft-lbs for most materials, and imposes a lateral expansion requirement of at least 0.015 inches for austenitic stainless steels. While the Combined Element Magnet end volumes do not possess the notch toughness desired for RHIC², it meets the requirements of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code³.

¹ *Mechanical and Physical Properties of the Austenitic Chromium-Nickel Stainless Steels at Subzero Temperatures*; The International Nickel Company, Inc., Third Edition, March 1970

² Kane, S., *Fracture Toughness Requirements for RHIC Cryogenic Design*; RHIC Project Tech Note AD/RHIC/RD-40, May 1992

³ *Rules for Construction of Pressure Vessels, UG-84(c)(4)(b)*, ASME Boiler and Pressure Vessel Code, Section VIII, Division 1; American Society of Mechanical Engineers, 1992 Edition, July 1, 1992

Table 3
Comparison of CEM End Volume Sleeve
Weld Average Impact Test Results At 77°K

	Impact Energy (ft-lbs)	Lateral Expansion (inches)
CEM End Volumes	39.2	0.026
BNL Superalloy	122	0.048
Welded Type 304 Plate	14 - 20	—

Conclusions

The Combined Element Magnet end volume longitudinal welds for magnet serial numbers CQS-101 through CQS-130 do not conform to the BNL drawing requirements, but satisfy the material mechanical properties requirements of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code.

APPENDIX A

RHIC Combined Element Magnet

End Volume Sleeve

Mechanical Testing Certification



A-LAB CORP.

3050 DRYDEN ROAD • DAYTON, OHIO 45439
513/293-0333 • 1/800/462-2522 • FAX 513/294-6667



REPORT TO: Mutual Tool & Die
725 Lilac Street
Dayton, Ohio 45427
Attn: Mr. Don Gray

DATE: January 23, 1995
LAB REPORT NO: 95-011052-53
P.O. NUMBER: 6955

REPORT ON: Two (2) samples submitted for mechanical testing.

SAMPLE IDENTIFICATION: P/N 12050049, S.O. 5610
P/N 12050056, S.O. 5611
Parts are longitudinally welded pipe
Austenitic Stainless Steel.

TEST REQUIRED: Flattening test per ASTM A312.
Tensile test per ASTM A312.

TEST RESULTS:

Part Number:	12050049	12050056
TENSILE STRENGTH, PSI (1)	89,720	89,980
YIELD STRENGTH, PSI (2)	51,740	53,430
ELONGATION, % (IN 2 INCHES)	43	44

- (1) Transverse Tensile
(2) .2% Offset Method

Flattening Test (3)

Step 1 - Ductility	Pass	Pass
Step 2 - Soundness	Pass	Pass

(3) Using a calculated H value of 5.2" per ASTM A530.

Respectfully submitted,

James G. Fulton
James G. Fulton, Supervisor
Metallurgical Testing

JGF/cjm

APPENDIX B

RHIC Combined Element Magnet

End Volume Sleeve

Impact Test Results

MST REPORT # 2407

DEPARTMENT OF APPLIED SCIENCE

MATERIALS SCIENCE DIVISION

Mechanical Service Work

Date : 1/25/95

Service For : S. Kane

Account # : 76121

ILR # : 345013

Material Type : 304SS welded w/ 308 filler rod

Job Type : Charpy impact tests

Results : ---Attached---

IMPACT TEST REPORT # 2353

<u>Specimen#</u>	(ft lbs) <u>Impact Energy</u>	(in.) <u>Lateral Expansion</u>	(*F) <u>Test Temperature</u>
95-011052			
#1	41	0.0326	-320
#4	42.5	0.03	"
#5	43	0.0315	"
#6	40.5	0.0295	"
#7	41	0.035	"
95-011053			
#1	37	0.025	"
#2	33	0.019	"
#3	37	0.021	"
#4	44	0.02	"
#5	37	0.017	"
#6	35	0.0215	"