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TITLE: **MAGNETIC PERMEABILITY OF STAINLESS STEEL FOR USE IN ACCELERATOR BEAM TRANSPORT SYSTEMS**

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MAGNETIC PERMEABILITY OF STAINLESS STEEL FOR USE IN ACCELERATOR BEAM TRANSPORT SYSTEMS*

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Abstract

High-vacuum beam transport tubes are being designed for use in an accelerator under development at Los Alamos. In areas such as weld-heat-affected zones, the tubes will require localized magnetic permeability of less than 1.02. Seven austenitic stainless steel candidates, 304L, 310, 316L, 317LN, 20Cb-3, Nitronic 33, and Nitronic 40, have been evaluated to determine their permeability in cold-worked, annealed, and weld-affected zones. 310 and 20Cb-3 showed permeability after welding of less than 1.01.

I. INTRODUCTION

To limit the perturbation of the charged particle beam as it travels through the beam transport tube, it is desirable to have very low permeability induced into the beam tube materials by the fabrication process. The size of the structures makes it difficult to remove any residual or induced permeability by post-fabrication annealing. Preferably, the structure should be used in its as-fabricated condition. An analysis by Jason [1] indicates that a localized weld permeability of less than 1.02 is acceptable for the intended application.

Candidate materials for use in the beam tubes are 304L, 316L, 20Cb-3, 310, NIT33, NIT40, and 317LN stainless steel. In all of these stainless steel types (except 304L), iron ferrite is controlled by the alloy chemistry and processing conditions. A minimum of two coupon samples measuring approximately 4" x 4" x 1/4" were obtained and tested for permeability under the following conditions: as-received; after annealing; after electropolishing; after welding; and after post-weld annealing.

II. TEST DESCRIPTION

Permeability was tested on each sample coupon using a Severn Engineering Company (Annapolis, Maryland) permeability indicator #3988

The Severn permeability indicator works as follows: A permanent magnet is mounted on an arm that is free to pivot and has counterbalances on its opposite end. One end of the magnet is in contact with a "standard" of known permeability. The other end is in contact with the material under test. The test material and the wooden box on which the arm pivots are physically moved apart by the person performing the test (Fig. 1). The magnet (being free to swing) is

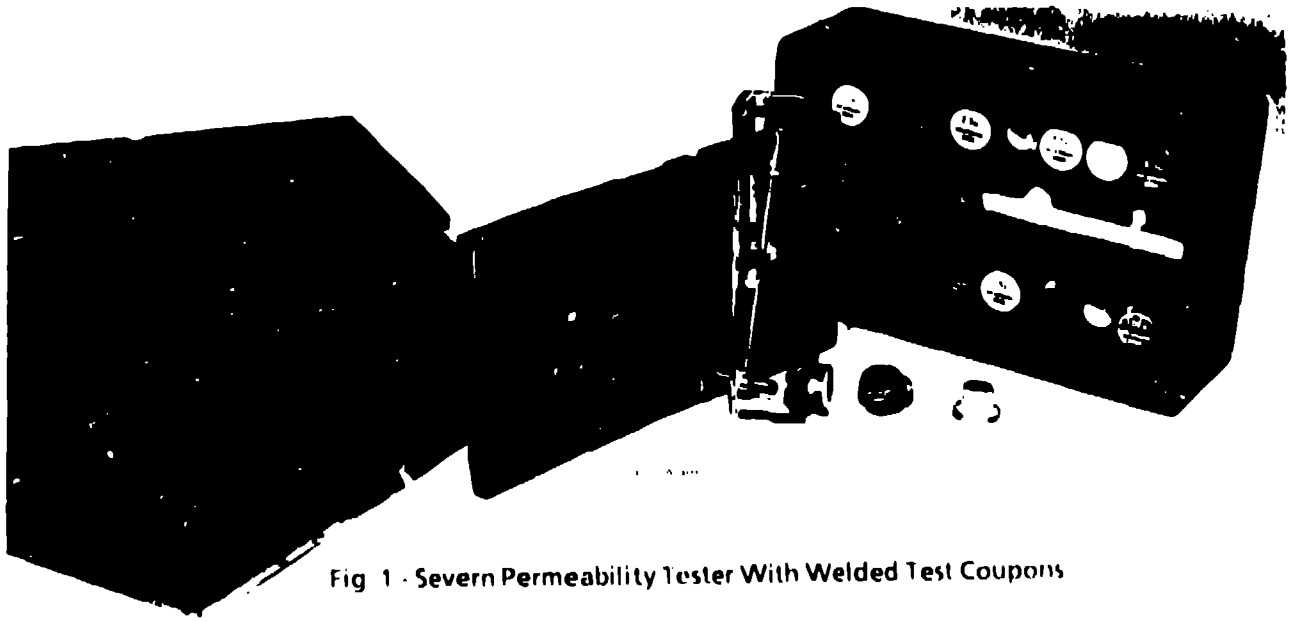

Fig 1 - Severn Permeability Tester With Welded Test Coupons

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attracted to the material that has the higher permeability. If the magnet "sticks" to the test specimen, it indicates that the test specimen has higher permeability than the "standard" permeability material. The test is repeated after replacing the known permeability "standard" material with others of known but sequentially higher permeability until, upon separation, the magnet "sticks" to the known permeability material. The test specimen is then accorded a permeability of less than the last "standard" but greater than the preceding one. The known "standard" permeability materials supplied by the manufacturer of the test instrument are of the following magnitudes: 1.01, 1.02, 1.05, 1.10, 1.15, 1.20, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 3.0, 3.5, 4.0, and 5.0.

III. RESULTS AND DISCUSSION

Since one of the characteristics of austenitic stainless steel is that its strength and permeability increase with cold working, and the methods that had been used to "cut" our samples was unknown, permeability tests were performed on one sample of each material as a function of distance from the edge of the sample. Some of the tested materials showed no detectable permeability, but others (304L in particular) showed the greatest permeability within 1/8 inch of the edge. Samples that we had annealed did not exhibit this higher permeability near the edge. We concluded that what permeability was present in the as-received condition (which we believe resulted from cold working induced in the coupons by the preparation procedure) was removed by the initial annealing process. All annealing conditions specified are those required for full solution heat treatment of the test coupons.

The as-received coupons were annealed in an industrial-grade vacuum furnace that was expected to operate "at temperature" at a vacuum level of less than 5×10^{4} torr. The thermal cycle controller was expected to control the temperature and time within approximately one percent of the set points. However, the actual furnace pressure was significantly above that expected, probably above 5×10^{-2} torr (later determined to be the result of a significant air leak in the furnace) and because of timer failure, the time at temperature was much greater than planned. The furnace temperature was within the expected range of one percent of the selected set points.

Visual inspection of the coupons after annealing revealed a dense, greenish coating, which we believe was chromium oxide. Permeability measurements of the discolored coupons revealed that Nitronic 33 had increased in permeability, from less than 1.01 to between 1.02 and 1.05; 20Cb-3 from 1.01-1.02 to 1.02-1.05; and the 304L coupon had decreased from 1.05-1.1 to 1.02-1.05; no change in permeability of the 316L, 310, Nitronic 40, or 317LN was observed. Table 1 summarizes the test conditions and results. Believing the greenish coating to be undesirable for further testing of the coupons, we decided to electrochemically remove it in a

Table 1 - Magnetic Permeability - μ

Material	As Received	After Anneal (1)	After Electropolish	Weld Rod	After TIG Welding	Post Weld Anneal (2)
304L	1.05-1.1	1.02-1.05	< 1.01	E/ER 309	2.2-2.5	1.4+
316L (3)	< 1.01	< 1.01	< 1.01	E/ER 316	1.6	1.10
				E/ER 316L	1.6	1.02-1.05
				E/ER 316L (4)	1.4 (4)	1.02-1.05
				E/ER 310	1.02-1.05	< 1.01
20Cb-3	1.01-1.02	1.02-1.05	< 1.01	E/ER 20Cb3	< 1.01	< 1.01
310	< 1.01	< 1.01	< 1.01	E/ER 310	< 1.01	< 1.01
Nitronic 33	< 1.01	1.02-1.05	< 1.01	NIT 33	1.1	< 1.01
Nitronic 40	< 1.01	< 1.01	< 1.01	NIT 40	1.1-1.15	1.02+
317LN	< 1.01	< 1.01	< 1.01	E/ER 317	1.2-1.4	< 1.01

1. Anneal conditions: 1800°F for 25 min on 20Cb-3; 1980°F for 40 min on all other types
2. Post weld anneal conditions: 1825°F for 60 min in nitrogen at a pressure of approximately 4×10^{-5} torr on all samples
3. The same 316L coupons were welded with four different weld rods
4. Arc welded with coated rod

commercial "Summa"® (Molectrics, Inc., Cleveland, OH) electropolishing solution (mechanical removalwas not acceptable because it would have the effect of cold working the surface). The permeability of each coupon was measured again after removal of the coating; all measured less than 1.01.

We believe that evaporation of chromium from the coupon surface during annealing produced an iron-rich surface, probably less than a few micro inches deep, is responsible for the increased permeability of those coupons exhibiting increased permeability. The decrease of the 304L permeability from 1.05-1.1 to 1.02-1.05 is probably the result of reduction of cold working and solution-annealing of the ferrite known to be present in 304 alloys. The resulting permeability is close to that observed in the 20Cb-3 and Nitronic 33 alloys. The absence of change in the 310, 316L, 317LN, and Nitronic 40 alloys is believed reasonable, because each of these alloys is formulated to strongly retain a homogeneous, iron ferrite solution throughout their working temperature ranges (which include the annealing temperatures).

The "Summa"® electropolish process (commonly used for cleaning of compatible metals, e.g., stainless steel, titanium) is known to chemically 'mill' the metal at rates up to .0004 inches per minute; the test coupons were processed so as to remove not more than .001 inches, which should have removed any iron-rich surface resulting from chromium evaporation. The electropolished coupons should then have been equivalent to the as-received ones, since the coupon procurement specification included full annealing. The reduction in permeability observed in the 304L and 20Cb-3 samples suggests that these coupons were not in an annealed condition when received. Confirmation of the metallurgical condition and surface effects will require considerable additional work, not planned at this time.

We prepared the samples for butt welding by grinding approximately a 45° bevel (one side only). Then we again tested for permeability in the area of grinding. No increase in permeability was detected from the grinding procedure on any of the samples. All of the samples of stainless steel were welded using a TIG weld process (316L was also arc-welded with coated rod) and the indicated weld rods shown in Table 1. Permeability was checked at a minimum of five places: the weld centerline and 1/4" and 1/2" on each side of the weld centerline. Permeability values obtained are shown in Table 1.

Permeability increased for all samples except 310 with 310 weld rod and 20Cb3 with 20Cb-3 weld rod combination. After welding, all samples were annealed in a vacuum furnace. Permeability checks of the centerline of the weld exhibited some residual permeability for 5 combinations but less than 1.01 for the other 5. The values are given in the last column of Table 1.

IV. CONCLUSIONS

The use of 310 with 310 weld rod or 20Cb-3 with 20Cb-3 weld rod appears to produce welds with the required permeability of not greater than 1.02, without the necessity of high-temperature solution annealing of large welded components. The availability of two metal/weld rod combinations allows the fabrication process and material to be selected on basis of cost of fabrication and availability of materials.

Reference

1 A. Jason, Group AT-3, Los Alamos National Laboratory. Private communication (August 1990)