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PROPERTIES OF CAST CF-8 STAINLESS-STEEL WELDMENTS AT CRYOGENIC TEMPERATURES*

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INTRODUCTION

ISABELLE is a 400 x 400 GeV proton-proton colliding beam accelerator now under construction at Brookhaven National Laboratory. The beams will be guided and focused by superconducting magnets. A total of 722 dipole beam bending magnets and 280 quadrupole beam focusing magnets are required. Centrifugally cast CF-8 stainless steel tubes were selected to provide a rigid support and to house the superconducting magnet assembly. The selection of this material for the support tubes is discussed by Dew-Hughes and Lee.[1] Their study indicates that the presence of delta ferrite strengthens the material but causes a decrease in ductility if the ferrite content is greater than ten percent. Brown and Tobler[2] found that the fracture toughness is also decreased as the delta ferrite content is increased.

An isometric view shows the details of construction of a dipole magnet for ISABELLE, Fig. 1. The outside diameter of the support tube is 0.495 m (19.5 in.) with a wall thickness of 0.019 m (0.75 in.). The dipole magnets are 4.95 m long (16.2 ft); the quadrupole magnets are 1.89 m (6.2 ft) long. The magnet assembly is enclosed at both ends with a 0.019 m (0.75 in.) thick wrought Type 304 stainless steel plate. The closure at the ends is a circumferential weld joining the wrought Type 304 plate to the cast CF-8 stainless steel tube.

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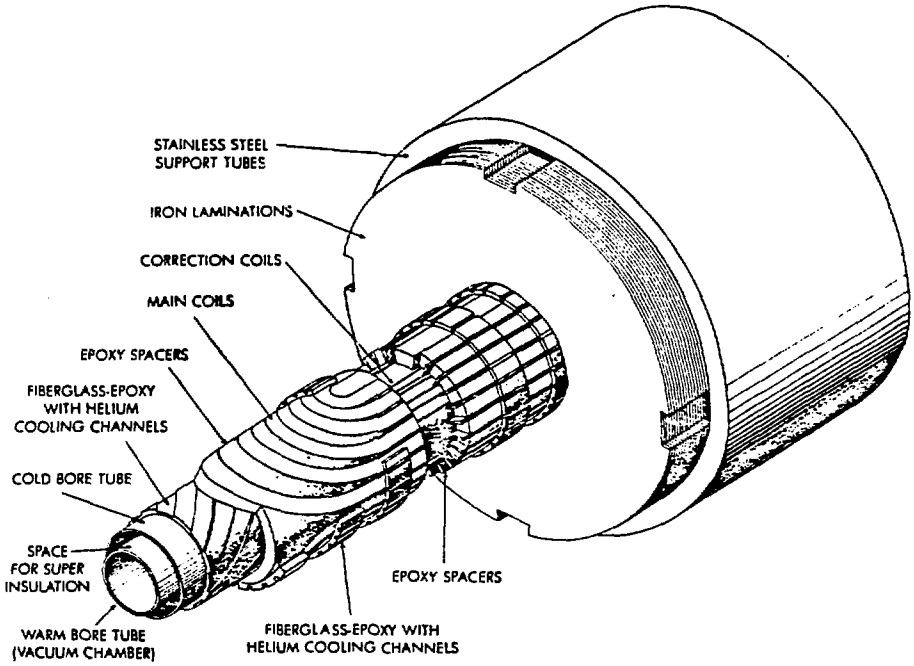

Fig. 1. Isometric view of the dipole magnet showing the configuration of the coil ends and the stainless steel support tubes.

The objectives of this investigation are to determine the mechanical properties of this weldment at cryogenic temperatures.

TESTING PROCEDURE

Seven centrifugally cast tubes with delta ferrite contents varying from 3 to 16% were selected for test. The ferrite content was determined by the use of the Ferritescope.[3] The probe of this instrument measures the relative permeability hence the ferrite content of an area of an object. The ferrite contents measured by the Ferritescope agree fairly well with the WRC number as calculated by the DeLong[4] diagram which takes into account the nitrogen content of the material. All the tubes were within the composition limits of ASTM A743 Grade CF-8 except the 16% ferrite material which contains 2.2% Mo. The tubes were in the solution annealed condition. Flat slabs, 1/2 inch thick were machined from the tubes. These slabs were welded to 1/2 inch thick wrought ASTM A240 Type 304

stainless steel plates. A double V groove weld joint was used. Welding was by the TIG process and filler rods of Type 308, 308L, and 316L were used. Tensile specimens having 1/4 inch in diameter reduced area gauge sections and standard Charpy V-notch specimens were machined from these weldments. The tensile specimens were oriented so that the length of the specimens were perpendicular to the weld. The gauge length of the specimens included all the weld metal, wrought, and cast material. The Charpy specimens were also machined perpendicular to the weld and the notch was located in the weld metal.

Tensile tests were performed at 4 K and impact tests were made at 77 K.

Compositions of the cast materials tested are shown below:

Ferrite Content	C	Mn	P	S	Si	Cr	Ni	N
3	.05	0.37	.03	.02	1.12	18.6	9.5	.03
6	.06	1.01	.01	.01	1.25	20.2	10.21	.02
7-8	.07	0.74	.02	.02	1.62	19.6	8.40	.05
14	.05	0.69	.02	.02	0.97	20.9	8.50	.08
16*	.06	0.78	.03	.02	0.93	21.2	10.40	.03

*Grade CF-8M - contains 2.2% Mo.

RESULTS

The tensile test results are shown in Table I. When considering these results, it should be kept in mind that weld joints are being pulled apart and the weld metal, cast material and the wrought material are being strained simultaneously. Most of the fractures occurred in the weld zone while some of the specimens failed in the cast materials, none failed in the wrought material. For those specimens that failed in the weld zone, the failures were located in the transition between the weld metal and the heat affected zone of either the wrought or cast materials.

Metallographic examination of the tensile fractures indicated that if the delta ferrite content was low, the fracture usually occurred near the heat affected zone of the wrought material. If the ferrite content was high the fracture occurred at the weld to cast material transition. This is illustrated in Fig. 2 for specimens with 3% and 16% delta ferrite in the cast material.

The 0.2% offset yield strengths generally increase with increasing delta ferrite content of the cast materials. The tensile

TABLE I

Tensile Properties at 4 K of Weldments of CF-8 Casting to Wrought Type 304 SS

Ferrite Content* In Cast Mat. (%)	TIG Welding Filler Rod	Yield Strength (MPa)	Tensile Strength (MPa)	Elong. (%)	Reduction of Area Wrought (%)	Reduction of Area Weld and Cast (%)
3	308	448	1217	45	12	16
3	308L	490	1612	48	19	15
4	308L	448	571	2	0	15**
6	308	312	785	20	15	18
6	308L	-	1120	42	16	29**
7	308L	556	1230	34	18	21
7	316L	556	1458	34	20	23
8	308	779	1098	19	14	19
8	308L	-	691	2	5	15**
14	308	679	1070	17	0	15**
16	308	712	920	28	11	10
16	308L	712	1109	39	0	15

*Ferrite content measured by "Ferritescope."
**Failed in cast material, others failed in weld metal.

strengths, however, vary widely and are not consistent with the ferrite content. In Fig. 3(a) the relationship of yield strengths with delta ferrite contents are plotted. Also shown in the plot is the curve from reference 1. It can be seen that the yield strengths of the welded joint are comparable to the solution annealed cast pipe.

The ductility of each specimen as indicated by the total elongation, and reduction of area in the wrought material and in the cast material is shown in Table I. Except for the specimen with 4% delta ferrite, the ductility is somewhat lower if the cast material has high delta ferrite. The deformation during tensile testing of these specimens is generally uniform over the gauge length and there is very little neck down at the fracture. It is interesting that in some cases the wrought material shows no reduction of area which indicates that the wrought material is stronger in yield than either the cast or weld metal. In general, the ductility values for most specimens are quite high and the materials should be suitable for use at 4 K.

It was found that all the filler rods used produced sound welds. The tensile test results indicate that Type 308, 308L, and 316L filler rod materials can be used in these welds.

The Charpy V-notch impact properties at 77 K are presented in Table II. The results show that the energy absorption and lateral expansion of the weldments is not adversely affected if the delta ferrite content of the cast material is 8% or lower. However,

3% FERRITE

16% FERRITE

Fig. 2. Fractures of tensile tests at 4 K of weldments with 3% and 16% ferrite, 250X.

weldments on 14% and 16% ferrite material have lower impact values and lower lateral expansions. These results confirm previous investigations which indicate that it is prudent to limit the delta ferrite content to about 10% maximum. Figure 3(b) shows the changes in Charpy V-notch energy absorption values with delta ferrite content. Also shown in this figure are the results from reference 1. The figure shows that the impact properties of the weldments are lower than those of the centrifugally cast tube

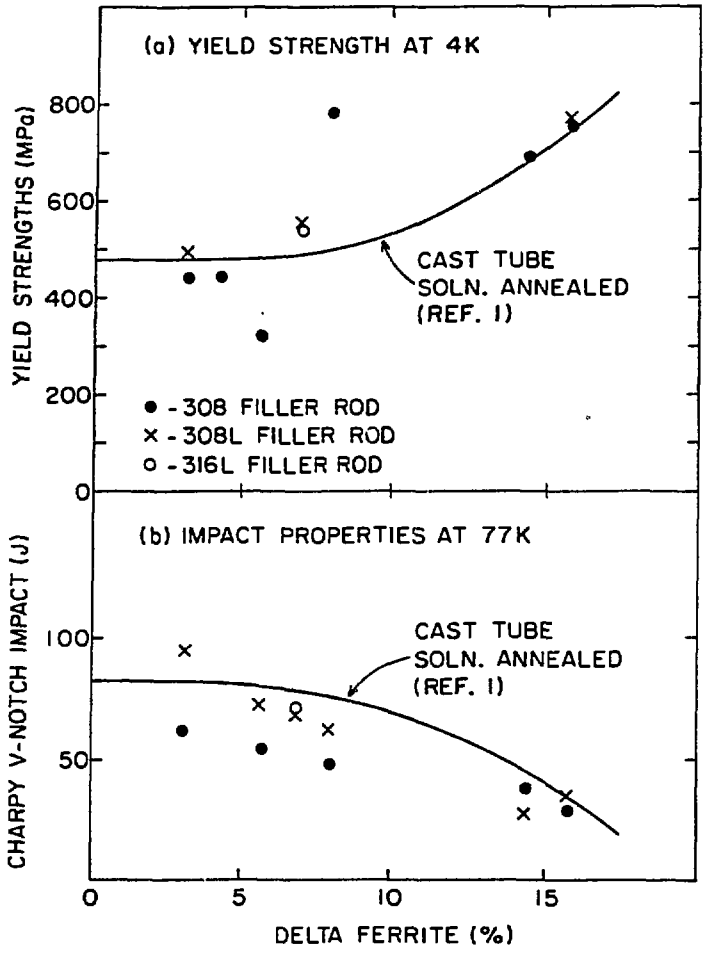

Fig. 3. Effects of ferrite contents on mechanical properties of weldments of cast CF-8 and wrought Type 304 SS. (a) yield strength at 4 K, (b) impact strength at 77 K.

materials. The lower impact properties of the weldments may be a result of not heat treating the welds.

CONCLUSIONS

The results show that sound and ductile weldments of centrifugally cast CF-8 and wrought Type 304 stainless steel can be made using the TIG process and filler rods of either Type 308, 308L or

TABLE II

Impact Properties at 77 K of Weldments of Cast CF-8 to Wrought Type 304 SS

Ferrite Content (%)	TIG Welding Filler Rod	Charpy V-Notch* (J)	(Ft-Lbs)	Lateral Expansion (Mils)	(mm)
3	308	61	45	20	5.1
3	308L	95	70	48	12.2
6	308	44	32	21	5.3
6	308L	72	53	30	7.6
7	308L	71	52	35	8.9
7	316L	68	50	30	7.6
8	308	48	35	23	5.8
8	308L	61	45	30	7.6
14	308	38	28	15	3.8
14	308L	27	20	12	3.0
16	308	27	20	12	3.0
16	308L	34	25	18	4.6

*Average of 3 tests.

316L stainless steel. Weldments with higher toughness and better ductility are obtained if the delta ferrite in the cast material is limited to 10% maximum. These results generally confirm previous investigations which indicate that delta ferrite over 10% is not desirable. Based on this information the procurement specification for the ISABELLE magnet support tube modified the ASTM A743 Grade CF-8 specification to limit the maximum acceptable delta ferrite content to 10%.

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