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REPORT OF WORKSHOP ON MATERIALS AT LOW TEMPERATURES

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NATIONAL BUREAU OF STANDARDS AND DEPARTMENT OF ENERGY

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REPORT OF WORKSHOP ON MATERIALS AT LOW TEMPERATURES SPONSORED BY NATIONAL BUREAU OF STANDARDS AND DEPARTMENT OF ENERGY - Held October 23 - 26, 1978 at Vail, Colorado By W.B. Hanson and Mark Leininger

The NBS-DOE workshop on Materials at Low Temperatures was aimed primarily at bringing together the cryogenic materials specialists and the designers of superconducting magnets used in various areas of the fusion programs presently underway. As a result, some of the information exchanged related to very large mechanical structures and enormous welding projects. Much of the information exchanged was relevant to the magnet program at Fermilab, both in the area of stainless steel metallurgy and cryogenic properties of various nonmetallics.

Results of the materials studies on various stainless steels and aluminum gave interesting data for the designers. Several things seemed to standout: yield strength of most stainless steels (eg. 304, 316) at 4K goes up tremendously with additional nitrogen content. Fracture toughness drops off in all stainless steels with increasing yield strength. One anomalous result was the yield strength dependence of 304L on temperature: one maximum at 200k, one minimum at 100k and increasing yield strength as temperature goes down. 1

Another study verified what designers assume and hope to be true, that is a small variability in the elastic constants (bulk, Young's, shear, and Poisson's) of 304 S.S. Tests of many samples verified that these constants vary from .9 to 1.4%. In addition, several temperature vs. elastic constant studies were made. These showed varied results depending on the constant in question. Young's modulus generally increases with decreasing temperature; the shear modulus reaches a maximum at 50k then decreases with temperature; the bulk modulus is relatively unaffected by temperature and Poisson's ratio decreases with temperature. 2

Magnetic properties of several stainless steels were examined. The austenitic (non-magnetic) stainless steels, including 304, all exhibit an increase in remanent moment due to handling and especially machining. Annealing decreases the susceptibility at 4k. 3

It was pointed out that the specific heat for 304 stainless had never been measured at low temperatures. This was done between 1 and 10k and yielded the results expected: it increases smoothly from 1 J/kgK at 1K to about 15 J/kgK at 10K. 4

Nitrogen generally has a strengthening effect on stainless but the Nitronic series has never gained popularity because there has never been a tough weld metal developed for use on the high nitrogen stainlesses. 304 N has become a popular choice because it combines strength of nitrogen with weldability. It was shown that high nitrogen causes microfissuring and so it must be kept low trading off some strength for weldability. 5

Oak Ridge National Laboratory (ORNL) is responsible for building the large coil test facility which will be used to test large magnet coils. Type 304 stainless steel was selected principally because stiffness rather than strength was required to hold an internal vacuum; also, weldability and contractor experience caused 304 to be the first choice. Another component, the bucking post, is a single large forging requiring tremendous strength. The bucking post will not require significant welding and the alloys under consideration are 310S, 304 N, and 304LN. 6

General Electric is building an 8-Tesla superconducting coil which weighs $\sim$ 44 tons. 316 LN stainless steel was selected due to its tremendous strength and excellent weldability. 7

Probably the most interesting point which came out the conference was in regards to G-10 and G-11. These insulating laminates whose mechanical properties are taken so much for granted are not suitable for cryogenic applications. Because they were originally intended as insulating laminates, the only NEMA specification they are required to meet is an electrical insulation specification. This insulation specification can be met by using an infinite number of combinations of glass patterns and content, weave and glass fabric, types of epoxy systems and many other factors all of which have gross effects on cryogenic properties.

This variation in mechanical properties was demonstrated by test results on random samples from different manufacturers. New laminates designated G-10CR and G-11CR are standardized as to method of manufacture and components. Test results indicate they have mechanical properties at least as good as the best G-10 and G-11, and their properties are very consistent. G-11CR (an aeromatic amine) is expected to be more radiation resistant than G-10CR (bisphenol solid epoxy with dicyandiamide hardener) but this has not been verified yet. In general, the CR materials have a higher glass content and a tighter control on all aspects of the formulation and curing cycle. The data presented by M.B. Kasen of the National Bureau of Standards shows some surprising information that G-11CR drops in strength between liquid nitrogen temperature and liquid helium temperature, especially in compression in the warp direction of the fiberglass. G-11 in general is preferable over G-10 however, because of higher radiation resistance. NBS donated samples of both G-10CR and G-11CR to us as Fermilab representatives for radiation testing. This will take place in the Proton-East Target Box. It is important to note that work done by E. Erez indicates that there are situations where G-10 may be superior to G-10CR. Her paper indicates that G-10 is superior to G-10CR in regards to interlaminar shear strength and edgewise compressive strength. There is some scatter in her data for G-10 which reinforces the fact that G-10 does not exhibit constant cryogenic properties. Neither interlaminar shear strength nor edgewise compressive strength are especially important in applications of G-10 found in the Doubler program at Fermilab.

The work done by E. Erez at MIT indicates that for spacers used in coils where the loads are applied in all directions, regular G-10 produced by GE is generally superior to G-10CR. 8

Radiation studies on several commonly used cryogenic materials were presented. Samples were bombarded with 2 x 10^9 rads at 5K (primarily gamma). Among other things, this showed severe embrittlement of aluminized Mylar superinsulation. This is only a problem if attempts are made to move the insulation. It does not flake apart until touched. This could be a problem in doubler magnets where differential contraction might cause mechanical cycling of the mylar and lead to its decomposition. 9

Cryogenic lubricants were discussed, several points being related to Doubler magnets. First, graphite is a poor dry lubricant under cryogenic or vacuum conditions. Graphite is presently used to lubricate the G-10 suspension which must slide as the cryostat contracts. This takes place in an area of high vacuum. Second, the recommendation of the presentation was that Molybdenum Disulfide (M_oS_2) be used as a substitute for graphite.

About the best anti-friction material for use at cryogenic temperatures in a vacuum has been found to be a thin layer of soft lead between hard layers of, say, stainless steel. Teflon is one of the best anti-friction materials but its' radiation resistance is low (about 5%). Teflon imbedded in bronze has proven to be a good anti-friction material. 10

Studies have been made by NBS on various composits. Carbon fibers with carbon filled epoxy resin has the feature that the expansion coefficient can be adjusted to various amounts because of the negative coefficient of expansion of carbon fibers. Alumina is often added to composits to minimize expansion. A conference was recently held in Munich, West Germany, exclusively on the subject of non-metallic materials used in cryogenic applications. The proceedings of this conference will be soon available by writing to N.B. Kasen of NBS, which we have done.

Reference:

1. D.T. Read, R.P. Reed, "Fracture and Tensile Properties", Thermophysical Properties Division, National Bureau of Standards

2. M.W. Austin, N.V. Frederick, H.M. Ledbetter, "Elastic-Constant Variability in Stainless Steel 304," Thermophysical Properties Division, National Bureau of Standards.

3. E.W. Collings, S. Hart, "On the Magnetic Properties of Some Commerical Austenitic Stainless Steels," Battelle Columbus Laboratories, Department of Physics, Ohio State University.

4. F.R. Fickett, "Some Magnetic and Thermal Properties of the Nonmagnetic Stainless Steels," Thermophysical Properties Division, National Bureau of Standards

5. R.H. Espy, "Production of Alloys for Low Temperature Service," Armco Inc.

6. C.J. Long, "Materials Engineering in the Large Coil Test Facility," Oak Ridge National Laboratory

7. F.N. Mazandarany, "Materials Utilization in the General Electric Coil for the Large Coil Program," General Electric Company

8. E.A. Erez, P.G. Marston, J.B. Thompson, Some Mechanical Properties of G-10. GRP at Low Temperatures

9. C.J. Long, R.H. Kernohan, R.R. Coltman, Jr., "Irradiation Effects on Organic Insulators," Oak Ridge National Laboratory

10. R.L. Tobler, "Friction Coefficients and Anti-Friction Design," Thermo Physical Properties Division, National Bureau of Standards