Superconducting Accelerator Magnets

An Introduction to Mechanical Design and Construction Methods

Carl L. Goodzeit (Retired BNL, SSCL)

MATERIAL PROPERTIES REFERENCE DATA

This supplement contains general reference data for some materials that are commonly used in superconducting magnets.

This compilation will be needed for examples given in the lecture. It should also be a handy reference for your future consideration of magnet mechanical designs.

1. Mechanical Properties
    a. Metals and alloys
    b. Plastics and Composites
    c. Rutherford cable coil sections
2. Stainless steel composition effects
    a. Schaeffler Diagram
    b. Permeability vs. ferrite content
3. Thermal contraction data
    a. Metals and alloys
    b. Plastics and composites
    c. Rutherford cable coil sections

1. MECHANICAL PROPERTIES OF METALS AND ALLOYS

	1100 Aluminum		6061-T6 Aluminum		304 Stainless Steel		316 Stainless Steel		316 LN Stainless Steel	
Temp (K)	298	20	298	20	298	20	300	4	300	4
Y. S. (MPa)[1]	48	66	283	365	241	448	238	610	238	610
T. S. (MPa)[2]	97	338	303	600	610	1551	565	1455	342	988
E (GPa)	69	77	69	79	193	200	192	208	184	213
Note	1		1		1		2		2	

	OFHC Copper		70/30 Brass 3/4 hard		Invar 12-15% Cold reduction	
Temp (K)	298	20	298	20	298	20
Y. S. (MPa)	69	86	414	510	627	1103
T. S. (MPa)	172	455	655	910	655	1172
E (GPa)	131	145	103	107	139	134
Note	1		1		1	

	Yoke iron		Nitronic 40		Hi Mn steel	
Temp (K)	295	4	295	4	295	4
Y. S. (MPa)	137	705	682.51	1427.06	675.61	1482.21
T. S. (MPa)	268	744	889.33	1813.12	813.49	1695.92
Elongation	89.40%	1.70%	29%	23	33%	29%
μ			1.0019	1.0021	1.0009	1.001
E (GPa)	207		192		188	
Note	3		4		5	

Notes:
1. Brookhaven National Laboratory, Selected Cryogenic Data Notebook, Rev. 8/80, BNL 10200-R
2. Structural Materials for Superconducting Magnets, Prepared by Simon and Reed, National Bureau of Standards, 1982
3. BNL Report 45541, "Brittle Behavior of SSC Yokes", March 1991 (Compostion: 0.007 C, 0.5 Mn, 0.012 P, 0.02 S, 0.005 Si, 0.01 Al, Bal. Fe)
4. 10% cold reduction, Nippon Steel Corp. Report on YUS 130 (Equiv. To Nitronic 40), December 1989
5. After 13.6% cold reduction, collar material, Kawasaki Steel Corp., March 1991

[1] Y. S. = the stress at which the plastic strain is 0.2% of the original gauge length of the specimen.
[2] T. S. = the maximum tensile load divided by the original cross sectional area of the specimen.

MECHANICAL PROPERTIES OF SOME PLASTICS AND COMPOSITES

	Nylon Type 101		TFE Teflon 66.2 % crystallinity	
Temp (K)	300	77	300	20
Y. S. (MPa)	51	241	14	110
T. S. (MPa)	72	241	28	110
E (GPa)	2.8	8.3	0.7	4.1
Note	1		1	

MECHANICAL CHARACTERIZATION OF GIO-CR AND G11-CR MANUFACTURER A-PILOT PLANT (AVERAGE OF AT LEAST THREE SPECIMENS) Note 2

												Shear strength		Shear strength	
G10-CR	Young's Modulus (E)		Poisson's ratio, ν		Tensile strength		Compressive strength			Tensile failure strain		(short beam)		(Guillotine)	
Temp.	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Normal	Warp	Fill	Warp	Fill	Warp	Fill
(K)	(Gpa)	(Gpa)			(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(%)	(%)	(MPa)	(MPa)	(MPa)	(MPa)
295	28	22.4	0.15	0.144	415	257	375	283	420	1.75	1.55	60	45	42	
76	33.7	27	0.19	0.183	825	459	334	557	693	3.43	2.53	131	93	61	73
4	35.9	29.1	0.211	0.21	862	496	862	598	749	3.67	2.7		105	73	79
G11-CR															
295	32	25.5	0.157	0.146	469	329	396	315	461	1.82	1.73	72	45	41	
76	37.3	31.1	0.223	0.214	827	580	804	594	799	3.21	2.85	120	92	57	57
4	139.4	32.9	0.212	0.215	872	553	730	632	776	3.47	2.67		89	56	57

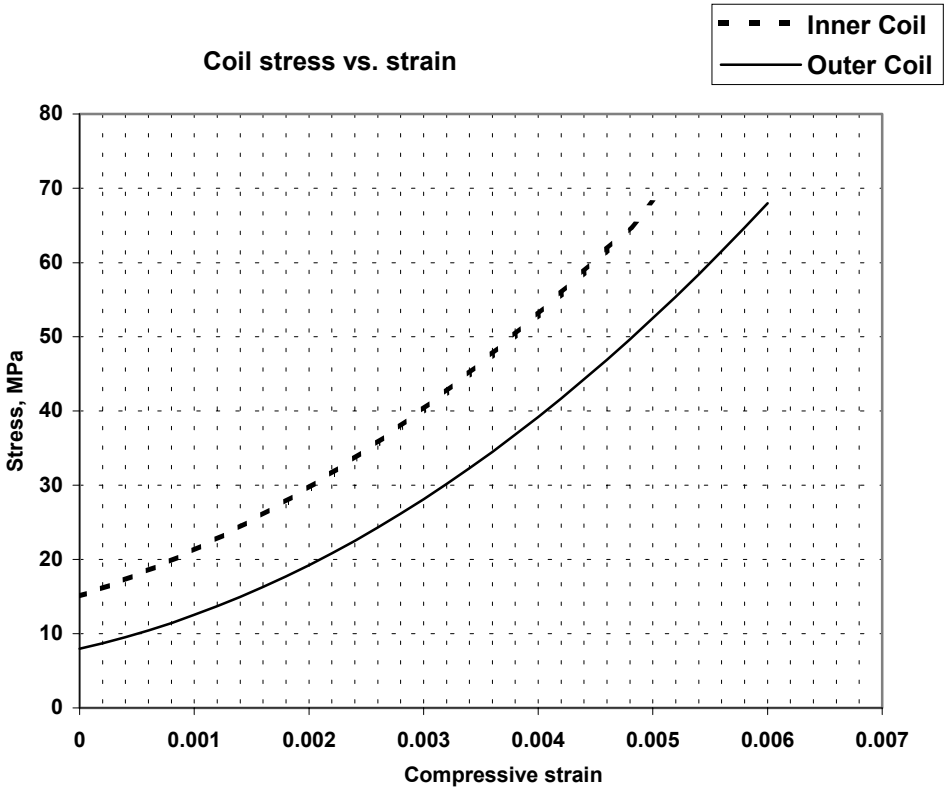
Notes:
1. Brookhaven National Laboratory, Selected Cryogenic Data Notebook, Rev. 8/80, BNL 10200-R
2. Data from ca. 1960, Source Unknown

MECHANICAL PROPERTIES OF RUTHERFORD CABLE COIL SECTIONS

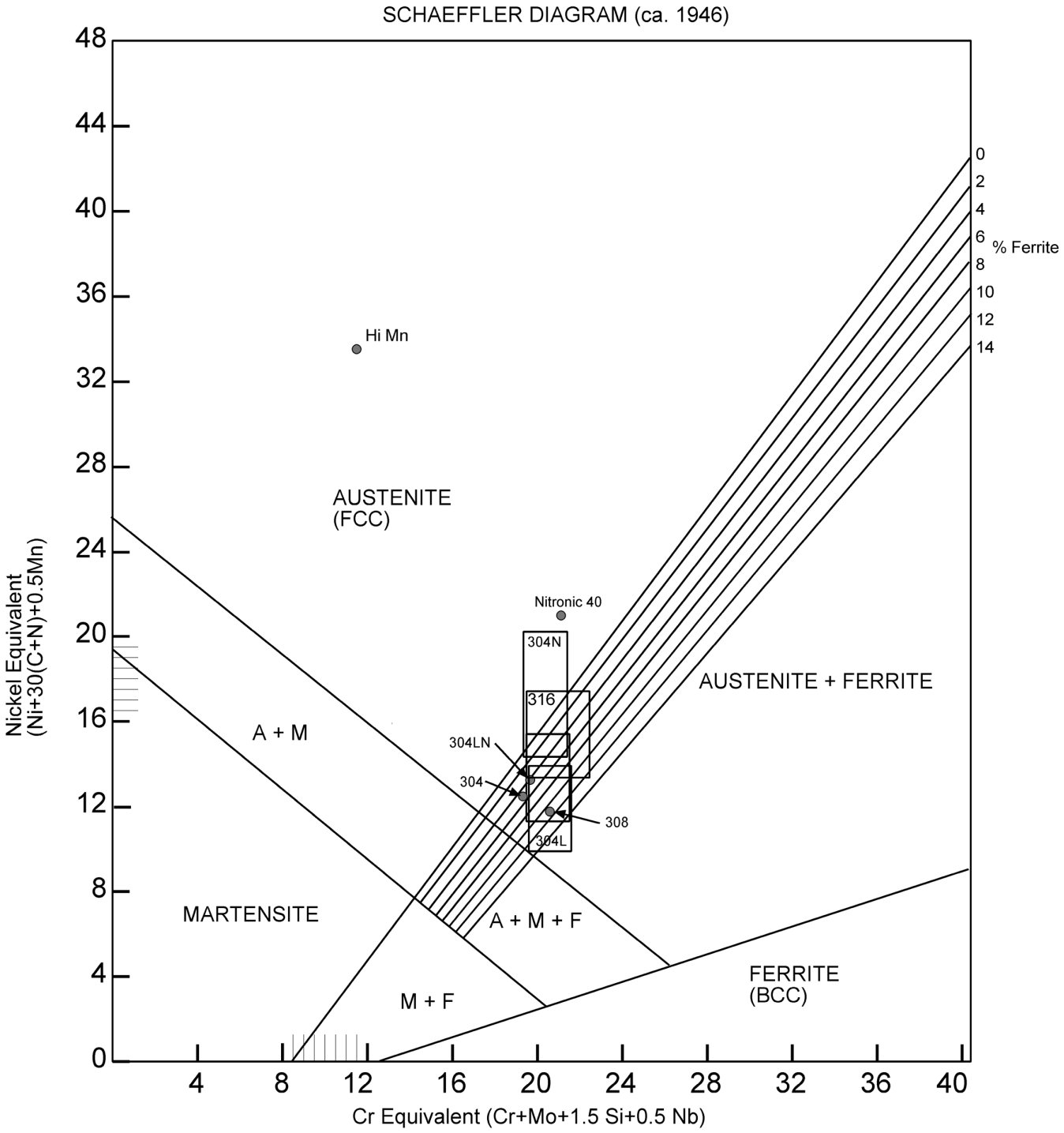
The stress-strain curves shown below were obtained by compressing samples of molded coil sections of SSC inner and outer coils and measuring the stress (force/area) and the strain ($\Delta L/L_0$). Because molded coils have a certain amount of looseness under zero load, the zero strain condition was taken at 15 MPa and 8 MPa for the inner and outer coils respectively. The stress (σ) vs. strain (ε) relation is given by the following least squares fit of the data:

Inner coil: $\sigma = 15.0 + 5100\varepsilon + 1.10\times10^6\varepsilon^2$ MPa

Outer coil: $\sigma = 8.0 + 3400\varepsilon + 1.10\times10^6\varepsilon^2$ MPa



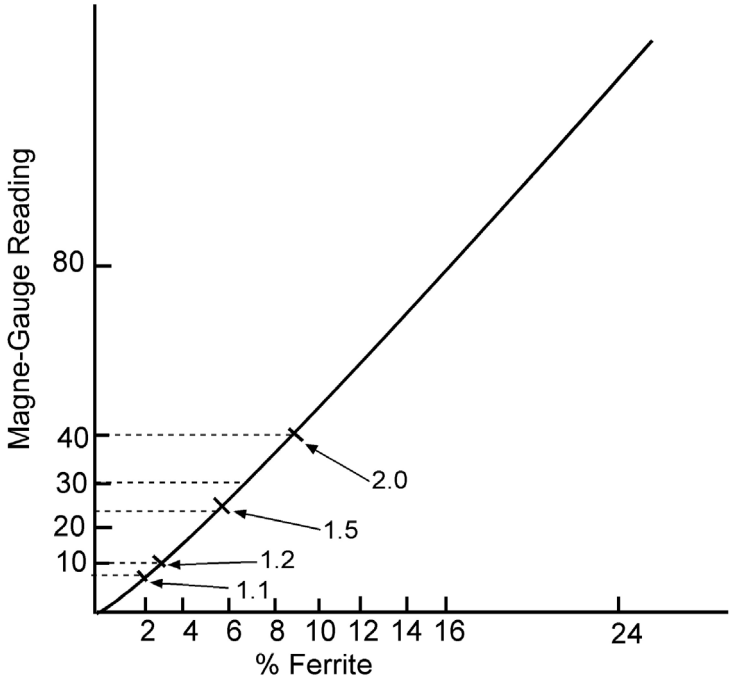
2. STAINLESS STEEL COMPOSITION EFFECTS



For reference: Ms=75(14.6-Cr)+110(8.9-Ni)+60(1.33-Mn)+50(0.47-Si)+3000(0.068-[C+N])

2. STAINLESS STEEL COMPOSITION EFFECTS, CONTINUED

Approximate room temperature permeability of stainless steel based on ferrite content



3. THERMAL CONTRACTION DATA

Source: "Thermal Contraction Measurements Relative to Titanium Silicate From 293 K to 4.2 K", BNL Magnet Division Note 455-15 (SSC-MD-287), July 1992

Note: The thermal contraction of titanium silicate in the range 293 K to 4.2 K is virtually zero. Thus, strain gauges can be used to measure thermal contraction if a set of identical gauges is mounted on the sample to be tested and also on a piece of titanium silicate. The resistance change from 293 K to 4.2 K is measured for each gauge; if the change for the titanium silicate is subtracted from that for the test sample, the result is proportional to the thermal strain of the material in that range. Certain materials tested have orthotropic contraction characteristics (e.g. composite materials and molded coil samples). In this way, thermal contraction in three orthogonal directions was determined for such materials.

3.1 METALS AND ALLOYS (293K TO 4.2K)

MATERIAL	$\varepsilon = \Delta L / L_0$	COMMENT
Nitronic 40, SSC collar material	0.00241	High strength stainless steel used for collars
HiMn, collar material (KHMn30L)	0.00157	High strength stainless steel used for collars
Naval brass	0.00347	Shims, spacers, etc
HiMn, 4mm thick	0.00156	
HiMn, 10 mm thick	0.00154	
Aluminum, 6061T6	0.00386	Collars, spacers
Stainless steel, 304	0.00284	Helium shell
Stainless steel, 316	0.00282	Various parts
Invar	0.00044	For reference
Stainless steel, A286	0.00277	Strain gauge beams
Yoke iron, 1/4 inch	0.00194	Yokes
Yoke iron, 16 gauge	0.00194	
Copper, OFHC	0.00312	

3.2 PLASTICS AND COMPOSITES (293K TO 4.2K)

MATERIAL	$\varepsilon = \Delta L / L_0$	COMMENT
Spaulrad, azimuthal	0.00195	Candidate material for coil end parts
Spaulrad, longitudinal	0.00261	"
Spaulrad, transverse	0.00218	"
Lexan, azimuthal	0.01202	For reference
Lexan, longitudinal	0.01191	"
Lexan, transverse	0.00945	"
RX630, azimuthal	0.00316	RHIC insulator/ spacers

RX630, longitudinal	0.00346	“
RX630, transverse	0.00326	“
G10, azimuthal	0.00247	Insulators and other parts
G10, longitudinal	0.00256	“
G10, transverse	0.00240	“
Ultem 2200, azimuthal	0.00605	RHIC support posts, final
Ultem 2200, longitudinal	0.00643	“
Ultem 2200, transverse	0.00570	“
Ultem 2100, azimuthal	0.00740	RHIC support posts, preliminary
Ultem 2100, longitudinal	0.00732	“
Ultem 2100, transverse	0.00639	“
RTV, Silicone cement	0.01623	Bulk adhesive
Teflon, longitudinal	0.01742	For reference
Teflon, transverse	0.01367	“
Torlon, transverse	0.00507	Possible for coil end parts
Torlon, longitudinal	0.00621	“
Green putty (epoxy-glass mixture)	0.00340	Filler material (glass powder+epoxy)
Nylon, azimuthal	0.01336	For reference
Nylon, longitudinal	0.01742	“
Nylon, transverse	0.01367	“

3.3 RUTHERFORD CABLE COIL SECTIONS (293K TO 4.2K)

Note: A is azimuthal direction, L is longitudinal direction and R is radial.

MATERIAL	$\varepsilon = \Delta L / L_0$	TYPE OF CABLE INSULATION WRAP
SSC dipole inner coil, K-A	0.00563	Kapton wrap with adhesive
SSC dipole inner coil, K-L	0.00262	“
SSC dipole inner coil, K-R	0.00418	“
SSC dipole inner coil, G-A	0.00511	Fiberglass cloth impregnated with epoxy
SSC dipole inner coil, G-L	0.00247	“
SSC dipole inner coil, G-R	0.00395	“
SSC dipole outer coil, K-A	0.00626	Kapton wrap with adhesive
SSC dipole outer coil, K-L	0.00249	“
SSC dipole outer coil, K-R	0.00444	“
SSC dipole outer coil, G-A	0.00498	Fiberglass cloth impregnated with epoxy
SSC dipole outer coil, G-L	0.00257	“
SSC dipole outer coil, G-R	0.00415	“