NCSX Modular Coil Welded Interface Engineering Details and Status

Compendium of Information:

1. Stelalloy and weld wire chemical composition

	C	Mn	Si	Cr	Ni	Mo	P	S	N
Min. %	.040	2.3	--	18.0	13.0	2.1	--	--	.24
Max. %	.070	2.8	0.7	18.5	13.5	2.5	0.035	0.025	.28

Table 3-1 Weight % of Chemical Constituents in Casting Alloy

	C	Mn	Si	Cr	Ni	Mo	P	S	Cu	N
Min. %	--	5.0	--	19.0	15.0	2.5	--	--	--	--
Max. %	0.03	9.0	1.0	22.0	18.0	4.5	0.03	0.02	0.3	0.3

Table 3-2 Weight % of Chemical Constituents of Bare Weld Wire

2. Specified properties for Stelalloy and the weld wire (ref. NCSX-CSPEC-101-03-14).

Temperature	77K	293K
Elastic Modulus	21 Msi (144.8 Gpa)	20 Msi (137.9 Gpa)
0.2% Yield Strength	72 ksi (496.4 Mpa)	30 ksi (206.8 Mpa)
Tensile Strength	95 ksi (655 Mpa)	78 ksi (537.8 Mpa)
Elongation (Casting)	32%	36%
Elongation (Weld Material)	25%	28%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	50 ft-lbs (67.8 J)

Table 3-4 Minimum Mechanical Properties

3. Data on the actual casting & weld material properties

updated 2/15/07

AVERAGES

Type C

Casting Comparison	77K (-320F)							293K (RT)						
Property	**Required**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Required**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Elastic Modulus	21 Msi (144.8 Gpa)	23.3	25.5	24.9	26.5	30.2	28.8	20 Msi (137.9 Gpa)	23.1	22.7	21.6	23.1	27.3	24.1
0.2% Yield Strength	72 ksi (496.4 Mpa)	98.4	93.2	97.1	97.8	102.5	99.5	34 ksi (234.4 Mpa)	35.1	36.6	38.3	37.4	38.8	44.5
Tensile Strength	95 ksi (655 Mpa)	170.3	163.8	163.1	164.8	170.9	159.9	78 ksi (537.8 Mpa)	83.7	82.4	82.7	83.1	87.0	83.7
Elongation	32.0%	55.7%	54.3%	55.7%	54.0%	42.4%	42.3%	36.0%	52.0%	53.5%	52.5%	55.7%	58.0%	40.3%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	77.7	84.3	99.7	86.7	80.3	85.3	50 ft-lbs (67.8 J)	142.0	150.7	157.3	175.7	139.0	152.3

Type A

Casting Comparison	77K (-320F)							293K (RT)						
Property	**Required**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**Required**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**
Elastic Modulus	21 Msi (144.8 Gpa)	25.5	25.3	26.7	28.9	26.4	27.9	20 Msi (137.9 Gpa)	21.7	22.2	21.9	22.9	23.1	22.6
0.2% Yield Strength	72 ksi (496.4 Mpa)	97.3	99.9	98.9	100.0	101.0	103.2	34 ksi (234.4 Mpa)	36.6	43.3	43.2	43.8	42.4	44.5
Tensile Strength	95 ksi (655 Mpa)	166.3	165.3	166.0	165.9	165.2	163.0	78 ksi (537.8 Mpa)	82.4	83.7	82.6	84.6	82.2	89.2
Elongation	32.0%	56.0%	56.3%	51.0%	46.0%	48.7%	38.3%	36.0%	53.2%	56.0%	53.3%	50.3%	50.0%	49.0%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	78.7	79.0	87.3	76.7	70.3	73.0	50 ft-lbs (67.8 J)	163.7	164.0	158.0	150.3	146.3	126.7

Type B

Casting Comparison	77K (-320F)							293K (RT)						
Property	**Required**	**B-1**	**B-2**	**B-3**	**B-4**	**B-5**	**B-6**	**Required**	**B-1**	**B-2**	**B-3**	**B-4**	**B-5**	**B-6**
Elastic Modulus	21 Msi (144.8 Gpa)	25.9	27.4	29.3	25.3	29.3		20 Msi (137.9 Gpa)	22.7	22.5	22.6	22.8	22.6	
0.2% Yield Strength	72 ksi (496.4 Mpa)	98.7	103.9	107.4	100.2	107.4		34 ksi (234.4 Mpa)	43.3	58.9	42.7	42.6	42.7	
Tensile Strength	95 ksi (655 Mpa)	164.9	177.5	172.5	166.1	177.5		78 ksi (537.8 Mpa)	86.0	86.6	84.1	85.6	84.1	
Elongation	32.0%	46.3%	50.3%	56.3%	53.3%	56.3%		36.0%	47.3%	49.5%	44.7%	43.5%	44.7%	
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	88.0	63.7	74.7	65.7	74.7		50 ft-lbs (67.8 J)	146.7	135.7	115.0	119.7	115.0	

Weld Material	77K (-320F)							293K (RT)							
Property	**Required**	**Lincoln 3018926/78 309**	**Lincoln Lot # 3012668/82 743**	**Lincoln 3018513/78 308**	**Lincoln Lot # 3017006/72 262**	**Metrode Lot # WO21735**	**Metrode Lot # WO19711**	**Required**	**Lincoln 3018926/78 309 Doc #10**	**Lincoln Lot # 3012668/82 743** see previous info ->	**Lincoln 3018513/78 308**	**Lincoln Lot # 3017006/72 262**	**Metrode Lot # WO21735**	**Metrode Lot # WO19711**	**Previously Reported Heat/Lot # 3012668/82 743**
Elastic Modulus	21 Msi (144.8 Gpa)	23.3	27.1 Doc#9	27	23.2	24.3	26.4 Doc#9	20 Msi (137.9 Gpa)	24.5 Doc 10	22.6	23.4	24.9	23	23.1 Doc#10	25.5 Doc#10
0.2% Yield Strength	72 ksi (496.4 Mpa)	114.3	126.3 Doc#9	128.2	112.4	102.1	109.5 Doc#9	34 ksi (234.4 Mpa)	56.9 Doc #10	57.4	65.2	54.9	54.8	63.9 Doc#10	56.5 Doc#10
Tensile Strength	95 ksi (655 Mpa)	157.5	187.7 Doc#9	182.1	176.4	166.6	166.9 Doc#9	78 ksi (537.8 Mpa)	93.9 Doc #10	93.7	95.2	92.1	88.2	98.1 Doc#10	85 Doc#10
Elongation	32%	16.0%	33% Doc#9	34.0%	48.0%	38.0%	34% Doc#9	36.0%	42% Doc #10	41.5%	38.0%	42.5%	37.5%	54% Doc#10	55% Doc#10
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	36.33	51 Doc#11	54	53	48	48 Doc#11	50 ft-lbs (67.8 J)	100 Doc #10	98	103	117	93	111 Doc#12	102 Doc#12

4. Derivation of S_m: Per the NCSX Structural Design Criteria, S_m shall be the lesser of 1/3 of the ultimate strength or 2/3 of the yield strength at temperature. Since the weld region includes the Stelalloy casting, weld metal, and shims that will probably be made of 316-LN, the strength values shall be the lesser of all 3.

At this time, the shim material has not yet been chosen, so for the present we shall use the lowest values between the Stellalloy and the weld material at 77K. For the yield, this is 93.2 ksi for the C2 casting; 2/3 of yield =61.5 ksi. **The lowest ultimate strength is 157.5 for the weld wire; 1/3 of this =52.5, so this is what we shall use. We'll have to re-visit this after the shim material is determined.**

A <u>"knock down" factor</u> of 0.6 shall be applied to this, since it is a *butt joint*. ***Therefore, the Sm=0.6*52.5=31.5 ksi.***

<u>Current Status As of 5/25:</u>

Based on Kevin Freudenberg's global model analysis of the B-C modular coil winding form welded connections on 5/23, we believe that the welded shim design is viable and the details of the welded interface are nearing finalization. The following is concluded from the conference call reviewing this analysis (attendees: W. Reiersen; H. Neilson; R. Ellis; I. Zatz; M. Zarnstorff; M. Viola; K. Freudenberg, HM Fan, and P. Heitzenroeder).

- Static stress appears acceptable based on what is believed to be the worst case flange (50% margin).
- Fatigue life based on base metal fracture test properties appears to be acceptable. This can be confirmed with a simple test coupon, if thought necessary.
- Weld distortion controllability needs to be confirmed. Based on stress margins, we expect that the weld size can be reduced and this would reduce the distortion. Tests planned at PPPL next week.
    - 316 LN is being annealed to demonstrate permeability reduction in plates which have mu>1.02.
    - Peening will be tested to reduce distortion, but will cold work the weld and possibly increase mu above 1.02. However, this weld metal with Stelalloy has never had mu>1.02.
    - The effectiveness of clamping to control distortion will also be investigated.
    - Weld size can be reduced in low stress areas as a way to minimize distortion.
    - Welding experts are being sought for thoughts on distortion control.
    - Final distortion demonstration will be performed on two actual winding forms. PPPL's welders confirmed that this is reasonable to do and relatively easy to clean up.

Analyses need to be completed in the following areas:

- K. Freudenberg needs to do similar stress analyses on B-A and A-A winding forms.