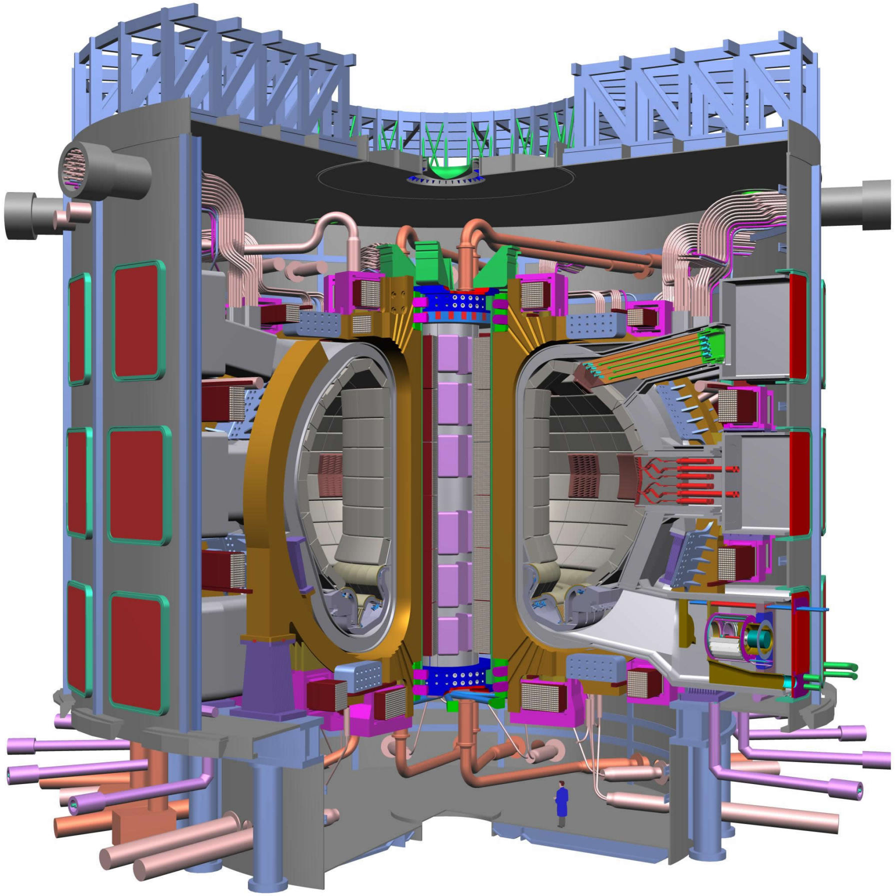
COLD WORK STUDY ON A 316LN MODIFIED ALLOY FOR THE ITER TF COIL CONDUIT

R. P. Walsh, V. J. Toplosky, D. McRae, K. Han
National High Magnetic Field Laboratory
Florida State University

N. N. Martovetsky
US-ITER Project, Magnet Group
Oak Ridge National Laboratory



BACKGROUND

The ITER-TF Magnets use CICC Technology
- the conduit is a primary structural component and is required to have good low temperature ***strength*** and ***ductility***.

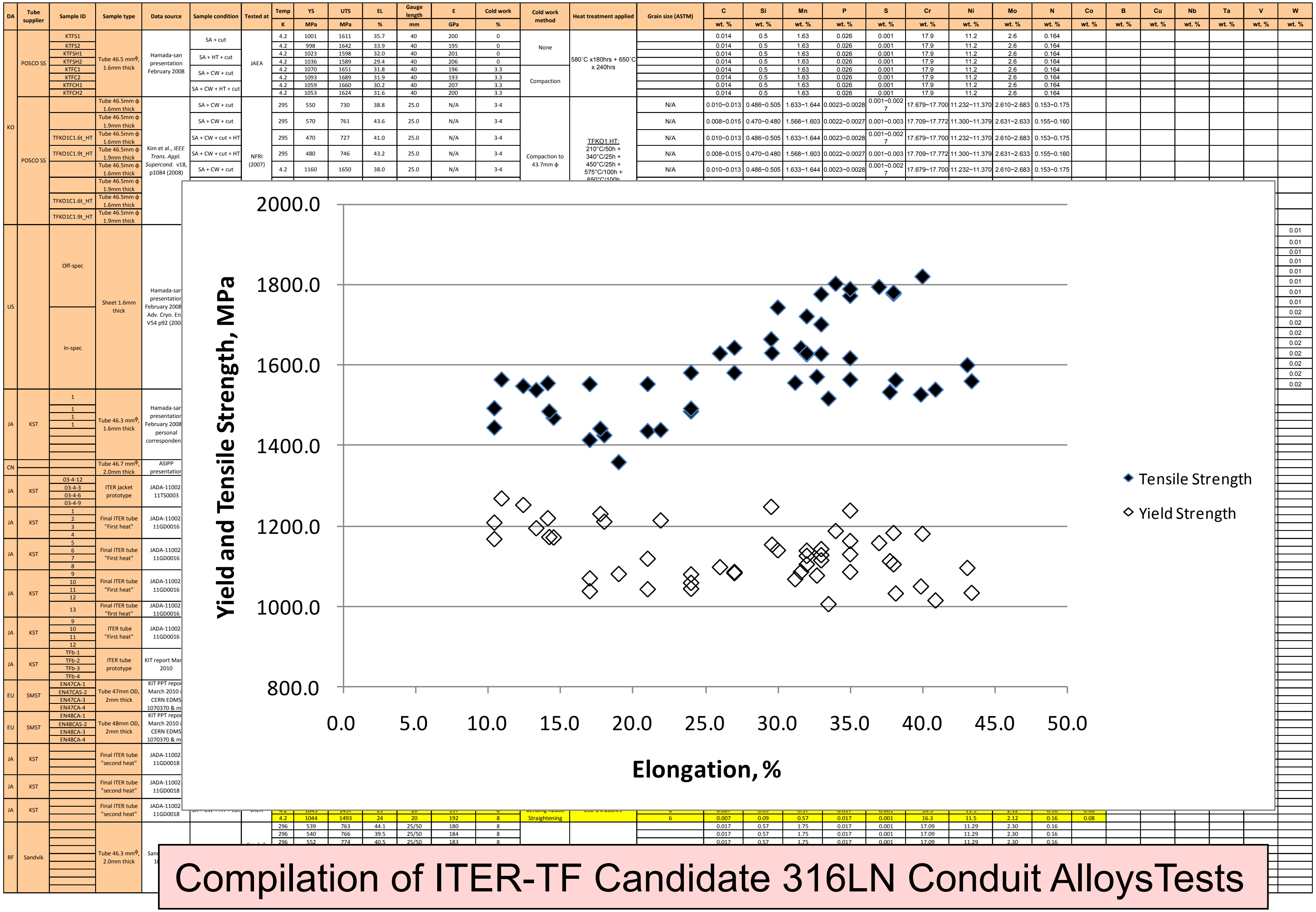
Strength and ***ductility*** are dependent on the alloy's ***microstructure*** and ***chemistry***.

While the chemistry is controlled with compositional specifications,
the microstructure is dependant on processing parameters
such as cold work (CW) and heat treatment (HT).

Although ***annealed*** 316LN is known to have excellent 4 K ductility
the annealed TF conduit experiences subsequent
CW and ***HT*** processes prior to service
that influence the ***strength*** and ***ductility***.

The ITER –TF conduit base and weld metal's were originally
required to meet elongation specification $\geq 30\%$
which has since been relaxed to a value of $\geq 20\%$.

REASONS for CONCERN



Compilation of ITER-TF Candidate 316LN Conduit AlloysTests

TEST PLAN

A test program to evaluate the effect of CW and Aging, on the 4K properties of 316LN base and weld metal, is undertaken by testing available material in four conditions.

Test Material Conditions:

1. 316LN Solution Treated (ST)
2. 316LN (ST) plus Cold Work (CW)
3. 316 LN (ST) plus CW plus Aged
4. 316LN Weld (ST) plus CW plus Aged

MATERIAL

- ITER grade 316LN precursor material for R&D is not readily available.
- The 316LN modified alloy used for this study is from the NHMFL 45T Hybrid Magnet Project.
- Commercially Produced Seam welded tube (19 mm OD X 1.5 mm wall)
- The composition and as received tensile properties are shown below.

TABLE 1. Chemistry (wt.%)

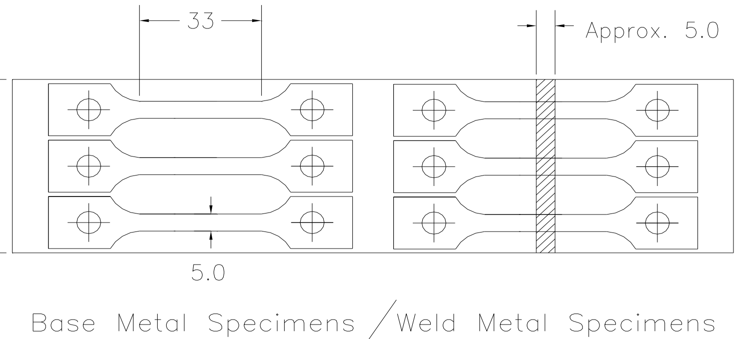
C	N	Mn	Si	P	S	Cr	Ni	Mo	Nb+Ta
0.010	0.15	1.53	0.32	0.01	0.01	17.2	12.8	2.12	0.08

TABLE 2. 316LN Tube As-Received tensile properties.

Temp K	Condition	0.2% offset Yield Strength MPa	Tensile Strength MPa	Elongation in 25 mm %	Reduction in Area %
295 K	As Received condition is Solution Treated	322	645	56	58

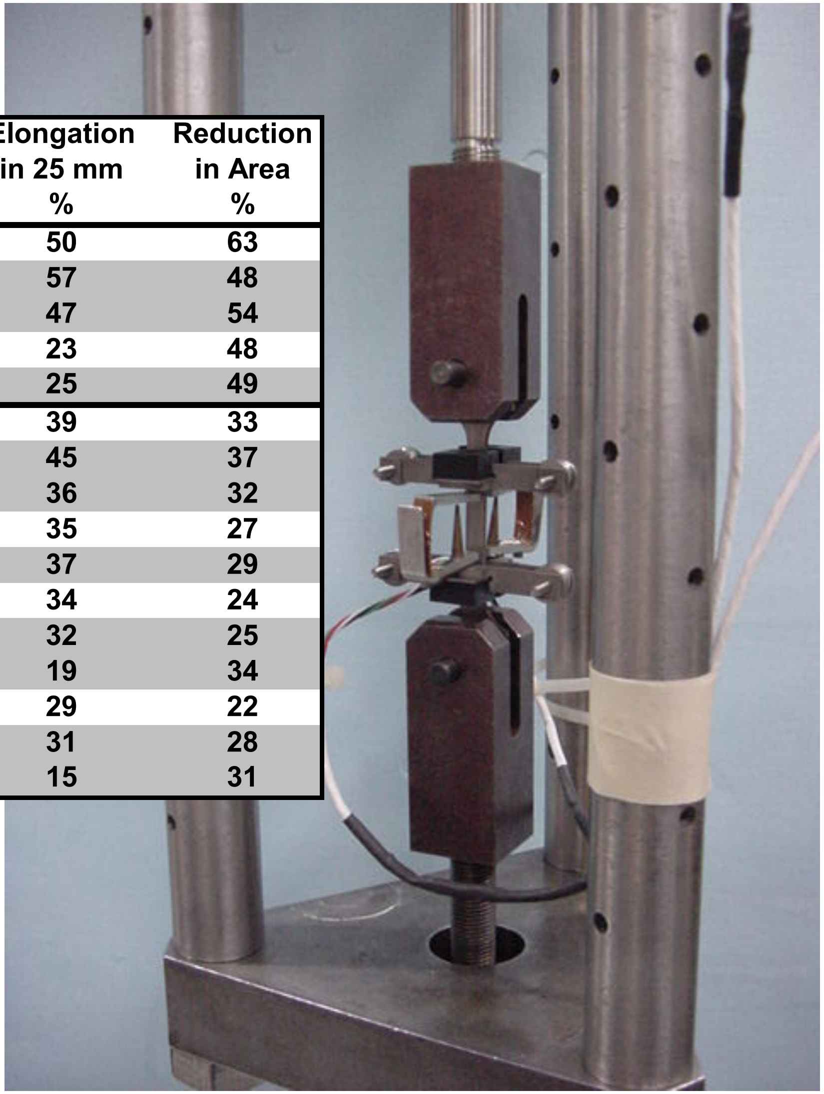
MATERIAL PREPARATION

1. Short sections of tube are butt welded together, (optimized automated TIG welds)
2. Tube is converted to strip by slitting and flattening.
3. Strips are Solution Treated to obtain a uniform starting condition.
4. Next the strips are cold rolled to introduce the desired amounts of CW.
5. The length change of the strip is used to track the amount of CW.
6. The strips to be used for the effect of Aging are heat treated after the introduction of CW.
7. Aging; 210C/50h, 340 C/25h, 450C/25h, 575C/100h, 650C/100h, AR atm., ramp rates = 5C/hr.
8. Tensile specimen EDM fabrication is a final step.

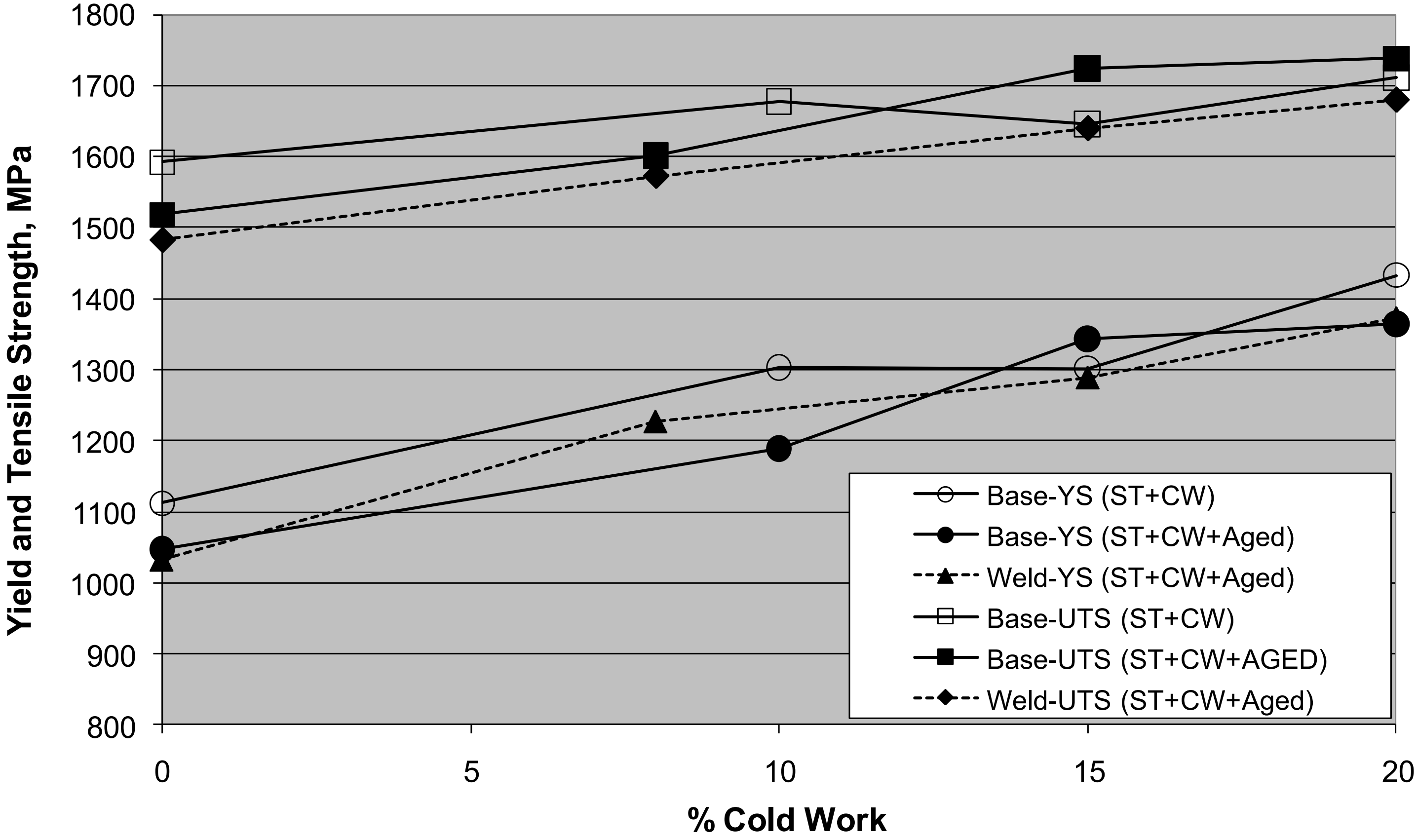


TENSILE RESULTS

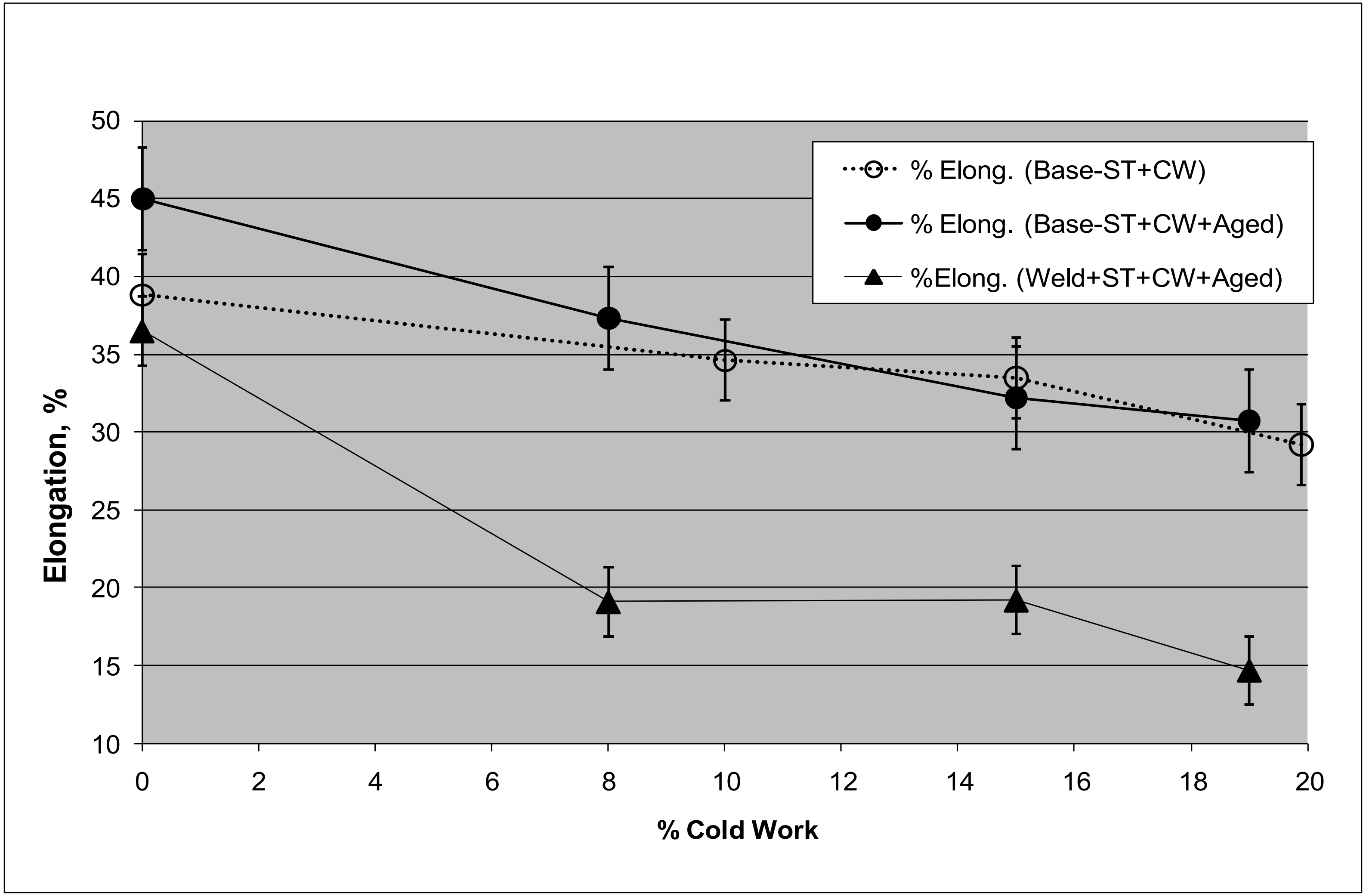
Temp K	Condition	0.2% offset Yield Strength MPa	Tensile Strength MPa	Elongation in 25 mm %	Reduction in Area %
295	ST	353	666	50	63
	ST + AGED	329	678	57	48
	W+ST+AGED	339	644	47	54
	ST+20%CW	782	832	23	48
	ST+20%CW+AGED	n/a	873	25	49
4	ST	1112	1592	39	33
	ST+AGED	1047	1518	45	37
	W+ST+AGED	1032	1482	36	32
	ST+10%CW	1303	1677	35	27
	ST+8%CW+AGED	1189	1602	37	29
	ST+15%CW	1302	1646	34	24
	ST+15%CW+AGED	1343	1724	32	25
	W+ST+15%CW+AGED	1289	1639	19	34
	ST+20%CW	1433	1712	29	22
	ST+20%CW+AGED	1365	1738	31	28
	W+ST+20%CW+AGED	1373	1679	15	31



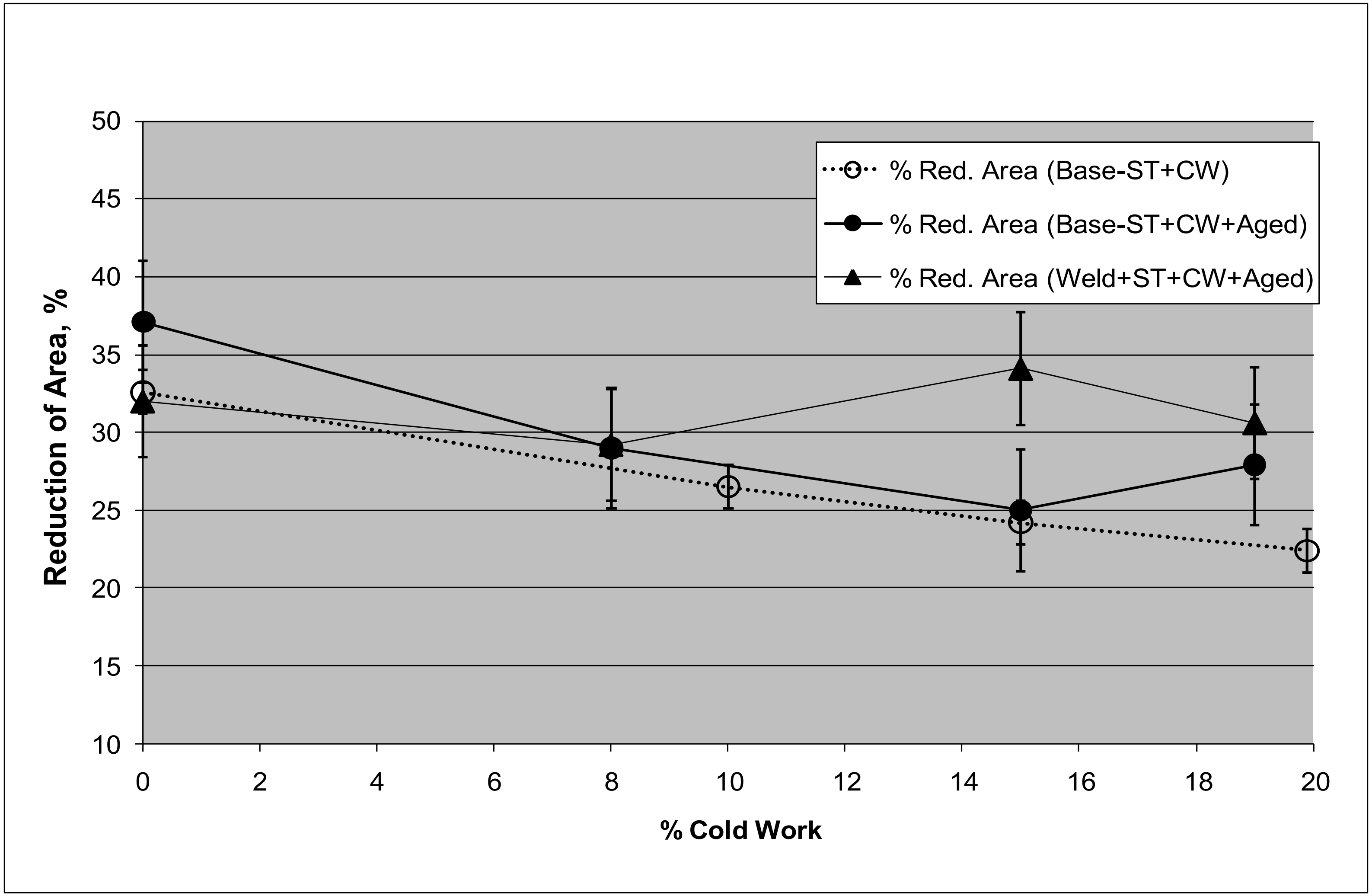
EFFECT of CW on 4 K STRENGTH



EFFECT of CW on 4 K ELONGATION



EFFECT of CW on
4 K REDUCTION of AREA



DISCUSSION

- **GOOD:**
  The 4K yield and tensile strengths increase as prior cold work is increased.
  Another favorable result - the reaction HT has little effect on the 4 K strength or ductility.

  BAD:
  The welds exhibit a larger loss of tensile elongation with increased prior CW than the base metal, and fall below the ITER requirement of ≥20%.
  2. The ductility of the weld (and base metal) should not be evaluated by elongation to failure.

  BECAUSE:
  1. Elongation is dependent on specimen geometry and the degree of specimen necking, especially for samples with a composite geometry such as the cross-weld tensile specimen.
  2. Specimen necking is exacerbated by the composite nature of the cross-weld tensile specimen with its 5 mm long weld section, sandwiched in the middle of a 37 mm gage length.

  BETTER:
  1. The reduction of area data show excellent agreement for base and weld metal, indicating that the weld metal has approximately the same ductility as the base metal.

  2. The weld and base metal ***strengths*** are approximately equivalent and it should be of no surprise that the ***ductility*** (as judged by **reduction of area**) is also equivalent.

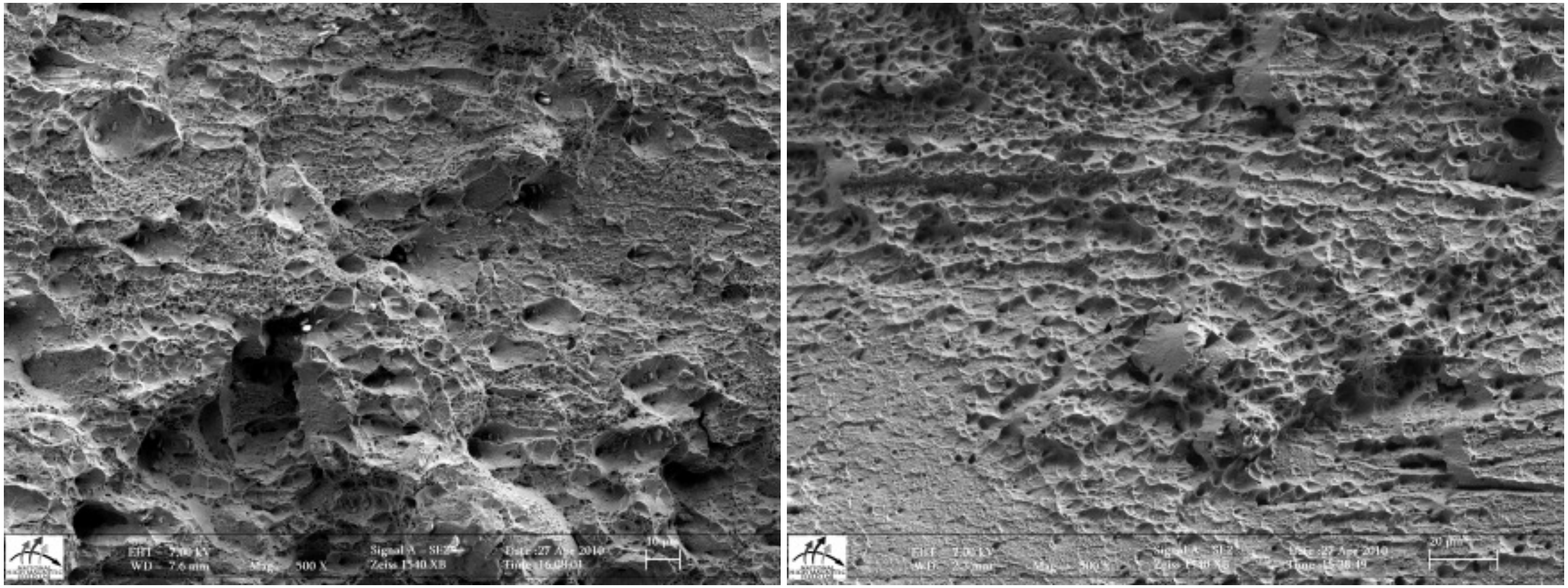


FIGURE 7. SEM images of the 4 K fracture surface of 15% CW and Aged base metal (right side) and weld (left side). While both samples show primarily ductile dimple features the weld also reveals the presence of a dendritic structure with fracture paths following the dendrites.

CONCLUSIONS on EFFECT of CW Study

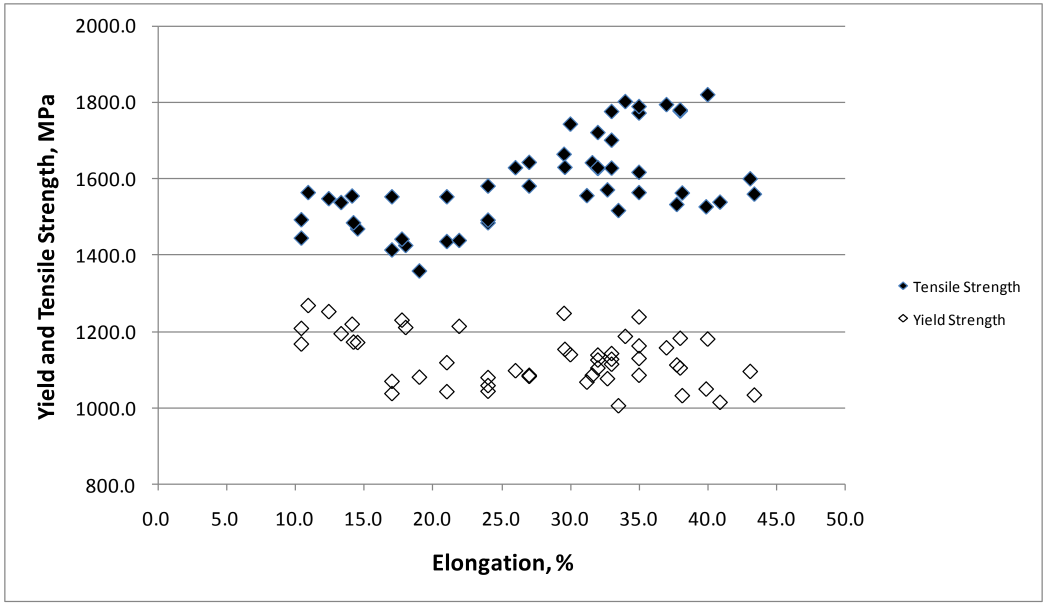
1. The 4K yield and tensile strength increase, and the ductility decreases, as prior CW increases.

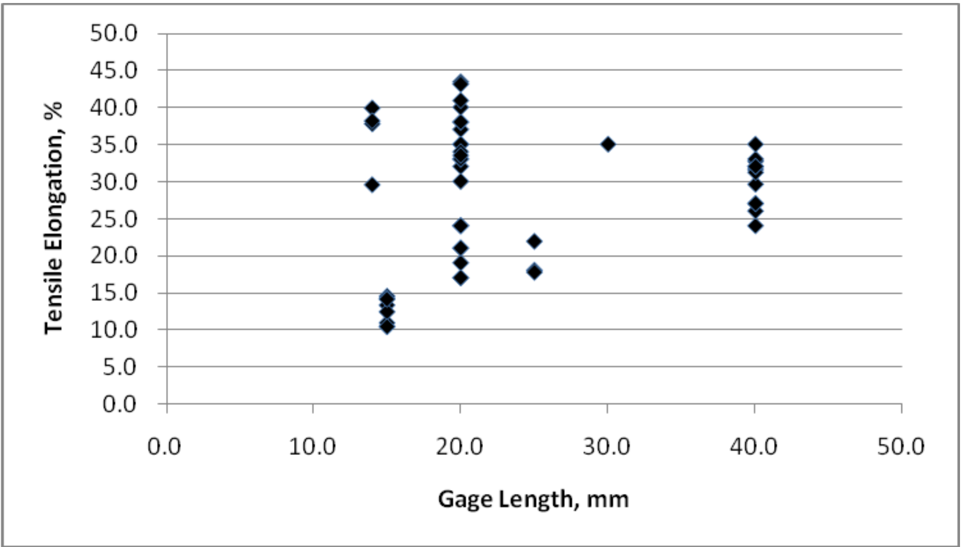
   No unexpected or irregular behavior such as a ductile to brittle transition is observed for the base metal or its welds.

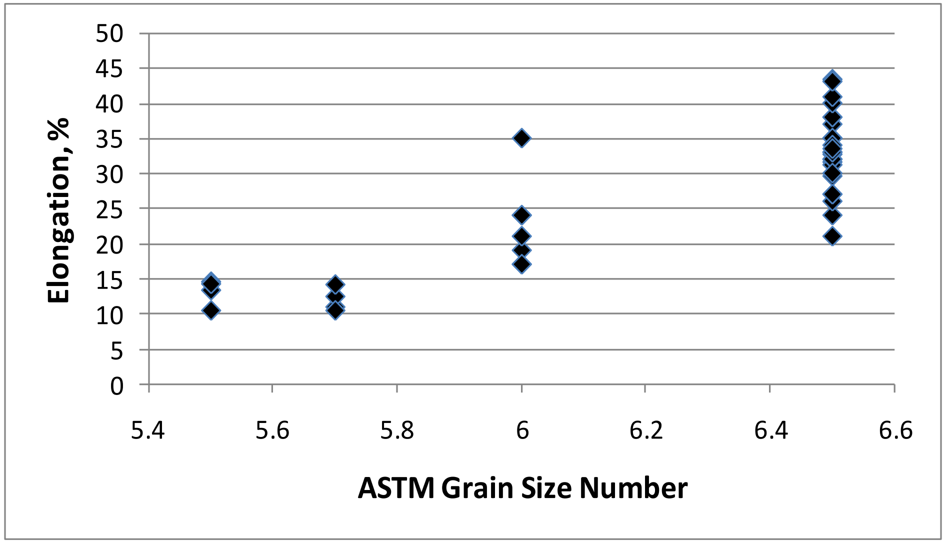
   The sheet metal’ s cross-weld ductility is not readily evaluated using tensile elongation due to geometric sensitivity and is better evaluated by using the tensile reduction of area.

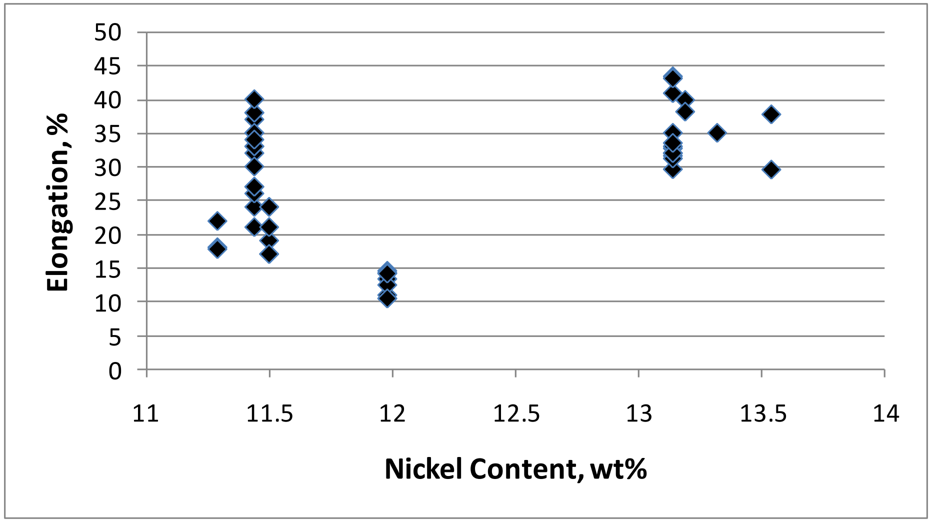
   The effects of the aging HT appear to be too small to be of engineering significance.

COMMENTS on
ITER-TF 316LN
CANDIDATE MATERIAL DATABASE









I. Conclusions:

1. The ITER TF 4 K Tensile Properties Database indicates that 316LN modified alloy can exhibit low tensile elongation to failure given the right set of circumstances.

2. Meeting the ITER elongation criteria of ≥ 20 % at 4 K is not a sure thing if the material contains ≥ 7% CW. (13) samples out of (49) tests (or 26%) did not meet the criteria.

3. Nickel content appears to play a role in the 4 K ductility of the 316LN materials. All the materials with > 13% Ni meet the stringent ITER criteria of ≥ 30%.

4. The ITER TF database indicates that small grain size appears to benefit 4 K elongation. The smaller grain size materials, with ASTM grain size number ≥ 6.5 meet the stringent ITER criteria of ≥ 30% elongation at 4 K.

5. ***The combination of small grain size and high Ni content are probably two of the key parameters to help ensure good 4 K ductility in the TF conduit alloy.***