ANNEX XXVIII

Measurement of the Magnetic Properties of ITER Vacuum Vessel Materials and Welds

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The magnetic and electrical properties of AISI 430 stainless steel and 316L(N)-IG welded joints were measured as a function of temperature. Also the effect of the annealing on the magnetic properties was studied.

One stainless steel AISI 430 sample was procured from Carpenter Technology (Europe) S.A. in the form of a bar and two SS AISI 430 by Allegheny Ludlum Corporation in the form of plates. The two Allegheny samples were from the same heat lot in the annealed condition. The following welds were supplied from NRG – Petten: a) EB weld 316 ERH II and b) TIG weld 316 ERH II.

The magnetic measurements were performed in the temperature range 5 to 900 K using at temperatures below room temperature a SQUID magnetometer and at temperatures above room temperature a Vibrating Sample Magnetometer (VSM). The maximum applied field for the magnetic loops was 1590 kA/m and a Hall sensor was used to monitor the magnetic field values.

The data of the coercive field, remanence magnetization and saturation magnetization for Carpenter AISI 430 FR, Allegheny(1) AISI 430, Allegheny(2) AISI 430, weld TIG 316 ERH II and weld EB 316 ERH II versus temperature are given in Table 1, Table 2, Table 3, Table 4Table 5 correspondingly.

Samples	Temperature T (K)	Coercive Field Hc (A/m)	dHc (A/m)	Remanence Magnetization[1] Mr (Am^2/kg)	dMr (Am^2/kg)	Saturation Magnetization Ms (Am^2/kg)	dMs (Am^2/kg)
m=91.5 mg	300	195.0	7.2	0.105	0.002	161.0	0.4
	400	73.2	2.4	0.0345	0.0005	155	3
	500	--	--	--	--	145	2
	600	--	--	--	--	137	2
	700	--	--	--	--	125	2
	800	40.3	4.1	0.0214	0.0021	102.6	1.3
	900	27.5	2.4	0.0145	0.0008	57.7	1.2
m=45.6 mg	300	215.8	1.0	0.1873	0.0008	164.9	0.8

Table 1 Magnetic properties of Carpenter AISI 430FR SS for different temperatures.

Samples	Temperature T (K)	Coercive Field Hc (A/m)	dHc (A/m)	Remanence Magnetization Mr (Am^2/kg)	dMr (Am^2/kg)	Saturation Magnetization Ms (Am^2/kg)	dMs (Am^2/kg)
m=39.3 mg	300	647	14	0.285	0.006	165.6	0.3
	400	636	14	0.283	0.006	161.1	0.5
	500	587	16	0.250	0.008	157.4	2.8
	600	542	18	0.219	0.009	152	3
	700	480	16	0.187	0.006	133.3	1.1
	800	267	16	0.038	0.009	68	4
m=20.97 mg	300	533	8	0.297	0.004	162.4	0.5
m=106.1 mg	300	691.5	1.0	0.2343	0.0008	167.3	2.2

Table 2 Magnetic properties of Allegheny(1) AISI 430 SS for different temperatures.

[1] Not corrected for the demagnetizing field.

Samples	Temperature T (K)	Coercive Field Hc (A/m)	dHc (A/m)	Remanence Magnetization Mr (Am^2/kg)	dMr (Am^2/kg)	Saturation Magnetization Ms (Am^2/kg)	dMs (Am^2/kg)
m=38.97 mg	300	853.9	6.0	0.524	0.007	175.7	0.9
	400	834.0	5.6	0.521	0.002	173.9	0.2
	500	786.2	5.6	0.4785	0.0007	166.7	0.4
	600	731.3	5.6	0.434	0.002	157.2	0.5
	700	634.2	5.6	0.3545	0.0007	147.2	0.9
	800	498.2	5.3	0.2390	0.0007	127.3	1.0
	900	339.0	5.6	0.0975	0.0007	88.2	0.4
m=39.10 mg	300	582.5	1.6	0.410	0.001	168.0	1.0

Table 3 Magnetic properties of Allegheny(2) AISI 430 SS for different temperatures.

Samples	Temperature T (K)	Coercive Field Hc (A/m)	dHc (A/m)	Remanence Magnetization Mr (Am^2/kg)	dMr (Am^2/kg)	Saturation Magnetization Ms (Am^2/kg)	dMs (Am^2/kg)
m=47.7 mg	300	2013.3	61.1	0.645	0.059	10.06	0.20
	400	1699.8	52.6	0.667	0.003	9.67	0.20
	500	1165.8	51.5	0.511	0.007	9.01	0.10
	600	887.3	48.6	0.409	0.003	8.30	0.20
	700	588.9	48.6	0.315	0.002	6.93	0.13
	800	325.5	49.6	0.144	0.009	4.54	0.09
m=42.5 mg	300	1878.0	31.8	0.268	0.003	5.34	0.02

Table 4 Magnetic properties of TIG 316 ERH II weld for different temperatures.

Samples	Temperature T (K)	Coercive Field Hc (A/m)	dHc (A/m)	Remanence Magnetization Mr (Am^2/kg)	dMr (Am^2/kg)	Saturation Magnetization Ms (Am^2/kg)	dMs (Am^2/kg)
m=46.50 mg	300	2275.9	78.4	0.256	0.014	3.85	0.04
	350	2061.1	73.8	0.245	0.014	3.65	0.15
	400	1893.9	101.0	0.237	0.009	3.60	0.06
	450	1734.8	78.4	0.230	0.010	3.46	0.06
	500	1512.0	73.8	0.210	0.010	3.31	0.04
	600	1098.2	73.8	0.166	0.013	2.84	0.06
	700	787.8	73.8	0.119	0.006	2.37	0.07
m=65.6 mg	300	2268.0	23.9	0.1675	0.0007	2.83	0.10
m=63.45 mg	300	2570.4	55.7	0.171	0.008	2.80	0.02

Table 5 Magnetic properties of EB 316 ERH II weld for different temperatures.

In order to examine the effect of the annealing on the magnetic properties the samples were annealed at 200 ºC under vacuum for one week and the magnetization loops were measured before and after the annealing. It is observed that the annealing has no effect on the magnetic properties –the differences are within the experimental errors.

The electrical resistivity of all the stainless steels AISI 430 and the welds were measured in the temperature range from room temperature up to 300 ºC. The results are presented in figs. 1-4.

In addition the chemical composition of the samples was determined by X-Ray fluorescence and chemical methods.

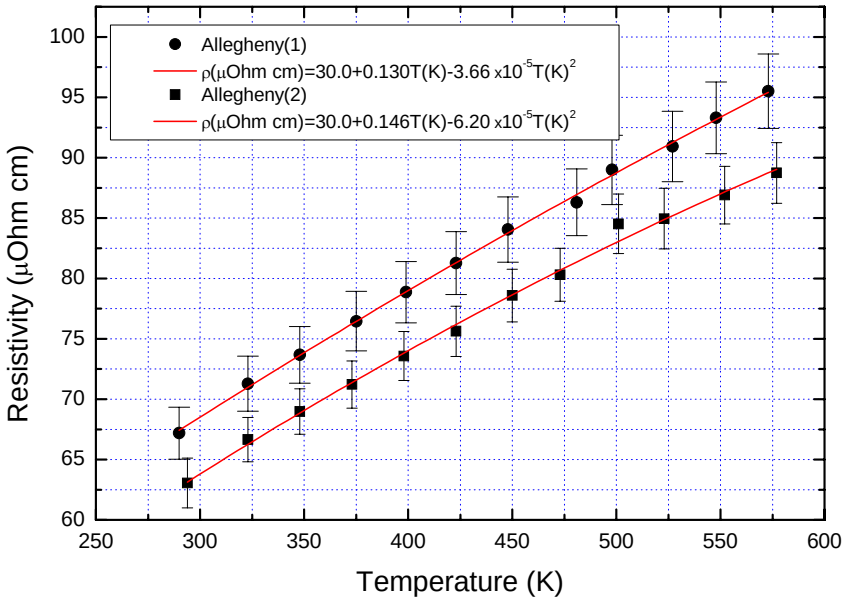

Fig. 1. The electrical resistivity versus temperature for Allegheny (1)&(2) SS AISI 430

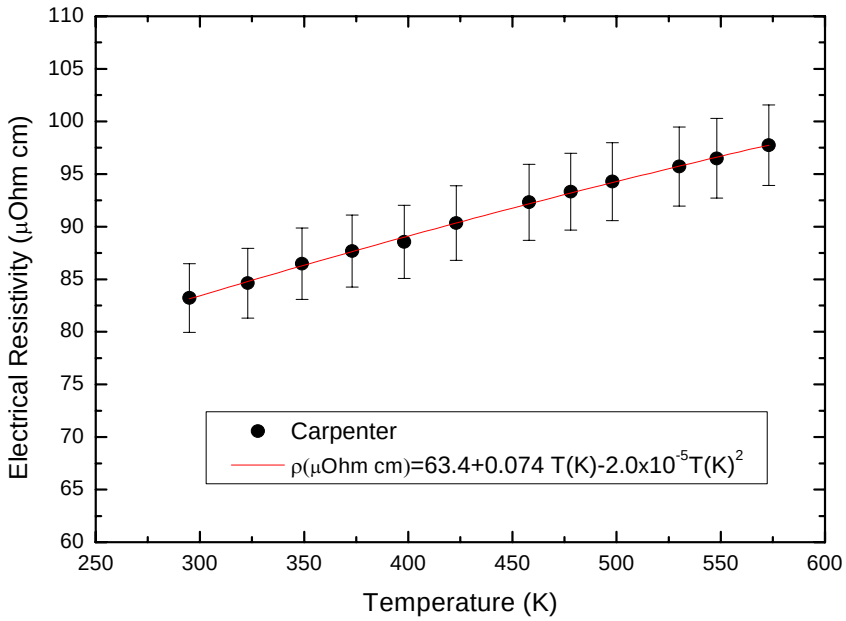

Fig. 2. The electrical resistivity versus temperature for Carpenter SS AISI 430

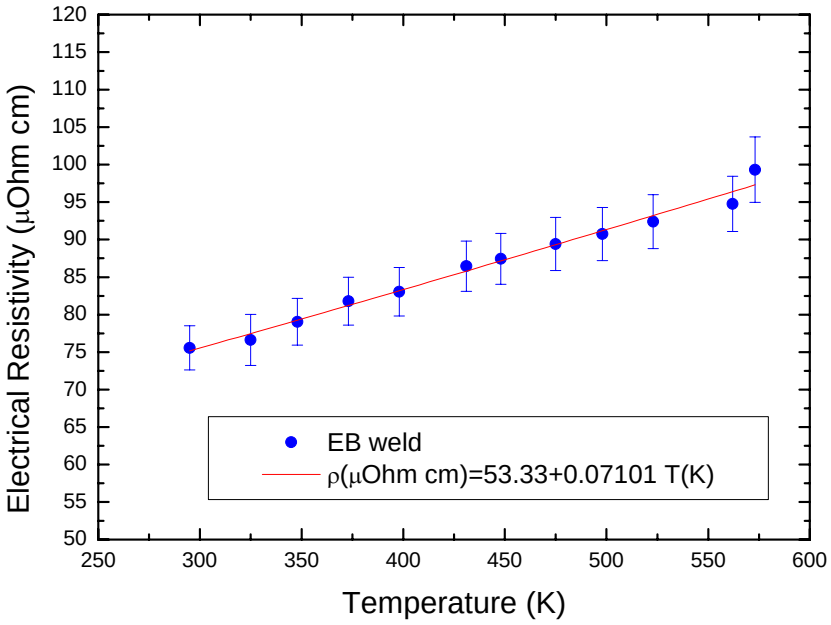

Fig. 3. The electrical resistivity versus temperature for EB 316 weld

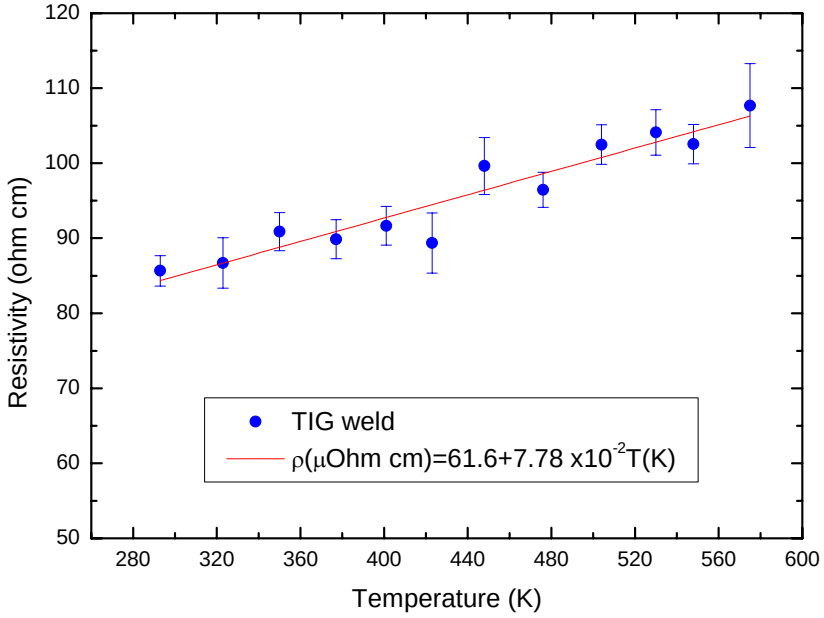

Fig. 4. The electrical resistivity versus temperature for TIG 316 weld