NISTIR 6662

Verification of the 100 kN Load Cell (Serial No. 850) of the 20 kips Load Frame (High Bay Lab)

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U.S. Department of Commerce
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Abstract

The so-called 20 kips frame (MTS table-top machine), equipped with a 100 kN load cell with serial No. 850, was used in the period April-December 2010 to perform tensile tests on several steels. The main purpose of these tests was to establish benchmark values for the tensile properties of a number of steels, to be later compared to data measured from micro-sized tensile specimens in the framework of the Microsystems Project [1].

Three of the steels tested allow performing a verification of the force values provided by the load cell, namely:

- Nimonic 75, commercialized by the Institute for Reference Materials and Measurements (IRMM – Geel, Belgium) with designation BCR-661, as Certified Reference Material for ambient tensile properties.
- Two zinc-coated sheet steels coded A and C, provided by ASTM to NIST for participation in the E28 Proficiency Testing Program (PTP), "Mechanical Properties of Steel".

This Internal Report presents the results obtained at NIST from tensile tests performed on conventional samples in accordance with ISO and ASTM standards, and the comparisons with IRMM certified values (Nimonic 75) and with the results provided by other laboratories participating in the ASTM PTP (September 2010) and statistically evaluated by ASTM International [2].

Keywords

Tensile tests; load cell verification; Nimonic 75; ASTM Proficiency Testing Program.

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1. Tensile tests on IRMM Certified Reference Material (Nimonic 75)

1.1 Material

The Institute of Reference Materials and Measurements (IRMM), located in Geel (Belgium), offers over 600 certified reference materials in the field of food and feed analysis, environmental analysis, engineering and health.

Among the materials certified for physical properties, the Nimonic 75 nickel base alloy, with designation BCR-661, is the certified reference material for the measurement of ambient tensile properties in accordance with ISO 6892-1:2009. Properties and certified values are given in Table 1.

Table 1 - Certified values for the IRMM reference material (Nimonic 75).

Property	*Certified value*
0.2 % *proof* stress, $R_{p0,2}$	(300 ± 8) MPa
0.5 % proof stress, $R_{p0,5}$	(310 ± 7) MPa
Ultimate tensile strength, R_m	(750 ± 14) MPa
Elongation to fracture, A	(40.9 ± 0.9) %
Reduction of area, Z	(60 ± 4) %

According to the IRMM certificate of analysis, certified values are unweighted mean values of the means of accepted data, each set being obtained in a different laboratory. The uncertainties given in Table 1 are the expanded uncertainties estimated in accordance with the Guide of the Expression of Uncertainty in Measurement (GUM, ISO/IEC Guide 98, 2008) with a coverage factor k = 2, corresponding to a level of confidence of about 95 %.

In addition to the certified values in Table 1, the certificate of analysis provided by IRMM also gives an indicative value for the Young's modulus E = 206 GPa, with an uncertainty of 21 GPa.

1.2 Specimens and test procedure

The material was supplied in the form of three bars each 150 mm long and with 14 mm diameter. From each bar, one cylindrical specimen with the dimensions shown in Figure 1 was obtained.

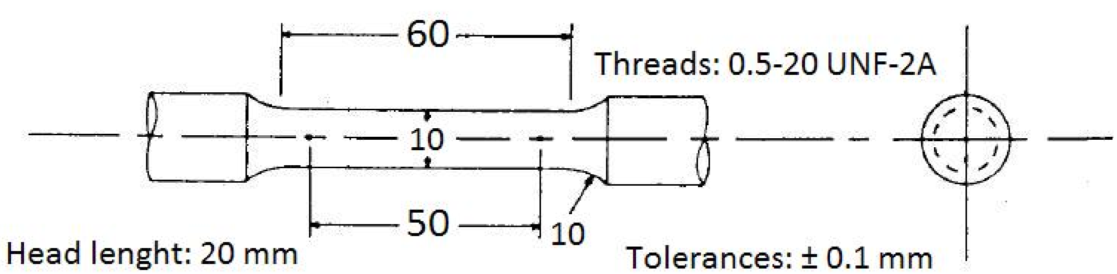

Figure 1 - Tensile specimen for the tests on Nimonic 75. (All dimensions in mm)

The test procedure prescribed by IRMM required a strain rate of 0.033 % s^{-1} up to 2 % strain to determine modulus and proof stress, followed by cross-head displacement control equivalent to a strain rate of 0.17 % s^{-1} until fracture. The required test temperature was (22 ± 2) °C.

Two of the three tested specimens were instrumented with foil strain-gages in the middle of the gage section, in order to compare values of elastic modulus E calculated using the signals from the extensometer and the strain-gage. The extensometer used had a base length of 2" (50.8 mm) and a measuring range of 50% (1" - 25.4 mm).

1.3 Results and comparison with certified values

Three tensile tests have been performed at room temperature, in accordance with ISO 6892-1:2009. The results are presented in Table 2, where:

- $R_{p0.2}$, $R_{p0.5}$, R_m are respectively 0.2 % proof stress, 0.5 % proof stress and tensile strength;
- *UE* and *A* are uniform and total elongation, corresponding to maximum force and specimen fracture respectively;
- *Z* is reduction of area at fracture;
- *E* is Young's modulus;
- *n* is the strain-hardening exponent, calculated in accordance with ASTM E646-07.

NOTE The results reported in Table 2 are calculated after multiplying the original force values by a correction factor equal to 0.99276. This factor was obtained using the most recent load cell calibration, executed by MTS Systems Corporation on January 4, 2011 (i.e. after the tensile tests were performed).

Table 2 - Results of the tensile tests on Nimonic 75 (IRMM reference material).

Specimen id	Strain rate (s^{-1})		$R_{p0.2}$ (MPa)	$R_{p0.5}$ (MPa)	R_m (MPa)	UE (%)	A (%)	Z (%)	E (GPa)		n
	Part 1	Part 2							Extens.	Strain-gage	
BCR_1	0.032%	0.13%	305	**327**	761	32%	41.0%	60.4%	199	203	0.34
BCR_2	0.032%	0.14%	304	324	758	31%	41.0%	59.0%	191	224	0.32
BCR_3	0.131%	0.14%	307	**329**	758	32%	41.2%	60.2%	203	-	0.36
Average values			305	**327**	759	32%	41.0%	59.9%	198	214	0.34
Certified values			300	318	750	-	40.9%	60%	206		-
Uncertainty (95% confidence)			8	7	14	-	0.9%	4%	21		-

In Table 2, data presented in red are outside the 95% confidence interval with respect to the certified value: this only occurs for two of the $R_{p0.5}$ values and the corresponding average value. Note that the 0.5 % proof stress is a relatively seldom used tensile parameter, much less common than the 0.2 % proof stress.

Although there is a tendency for strength results to be higher than certified values, the verification of the load cell can be considered successful.

Moreover, good agreement was found between values of elastic modulus obtained from strain-gages and extensometer.

Test results and certified values are graphically presented in Figure 2 (strength), Figure 3 (ductility) and Figure 4 (Young's modulus).

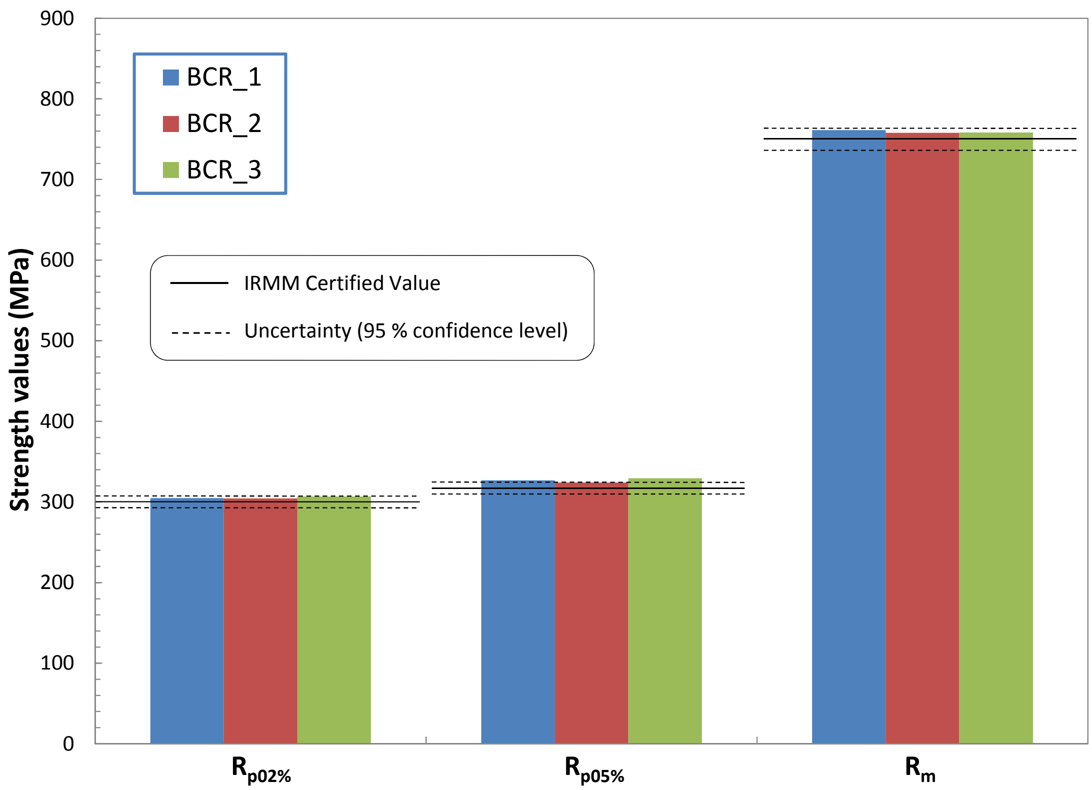

Figure 2 - Strength values obtained from tensile tests on Nimonic 75 and comparison with IRMM certified values.

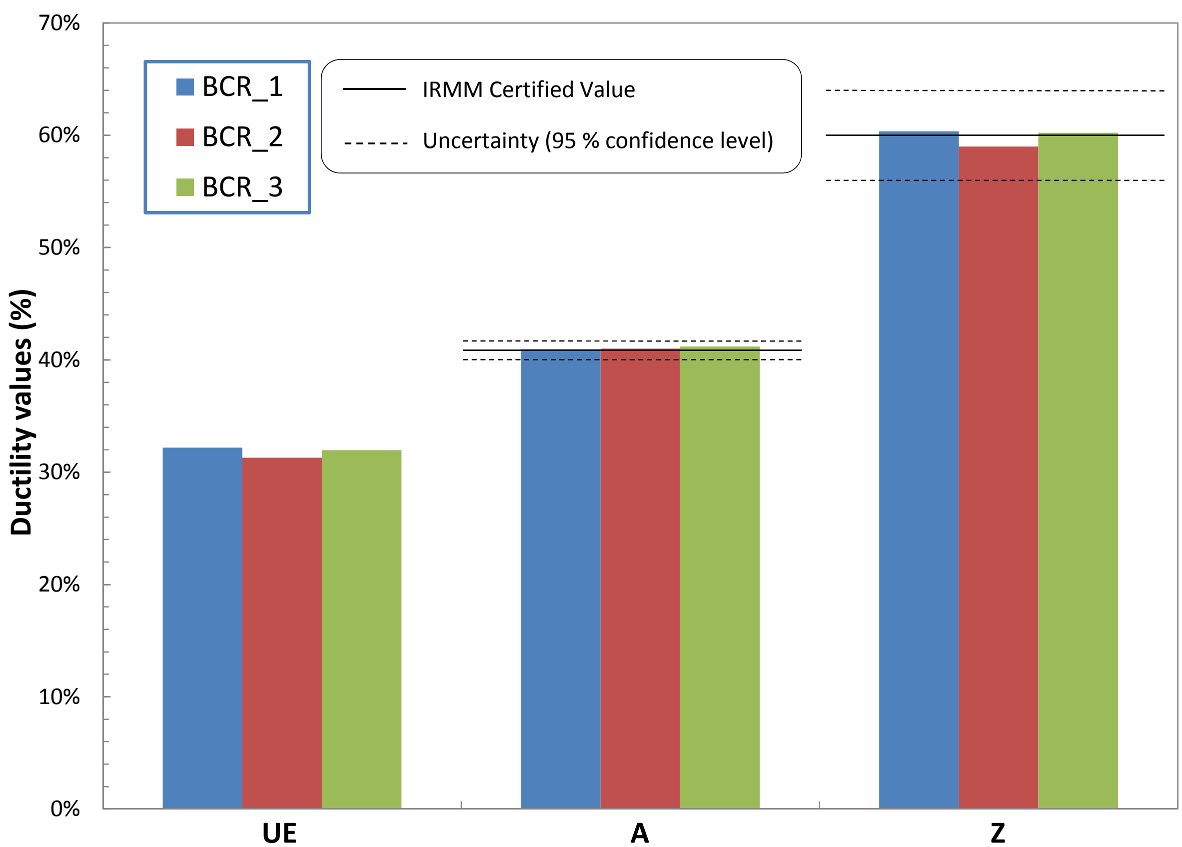

Figure 3 - Ductility values obtained from tensile tests on Nimonic 75 and comparison with IRMM certified values.

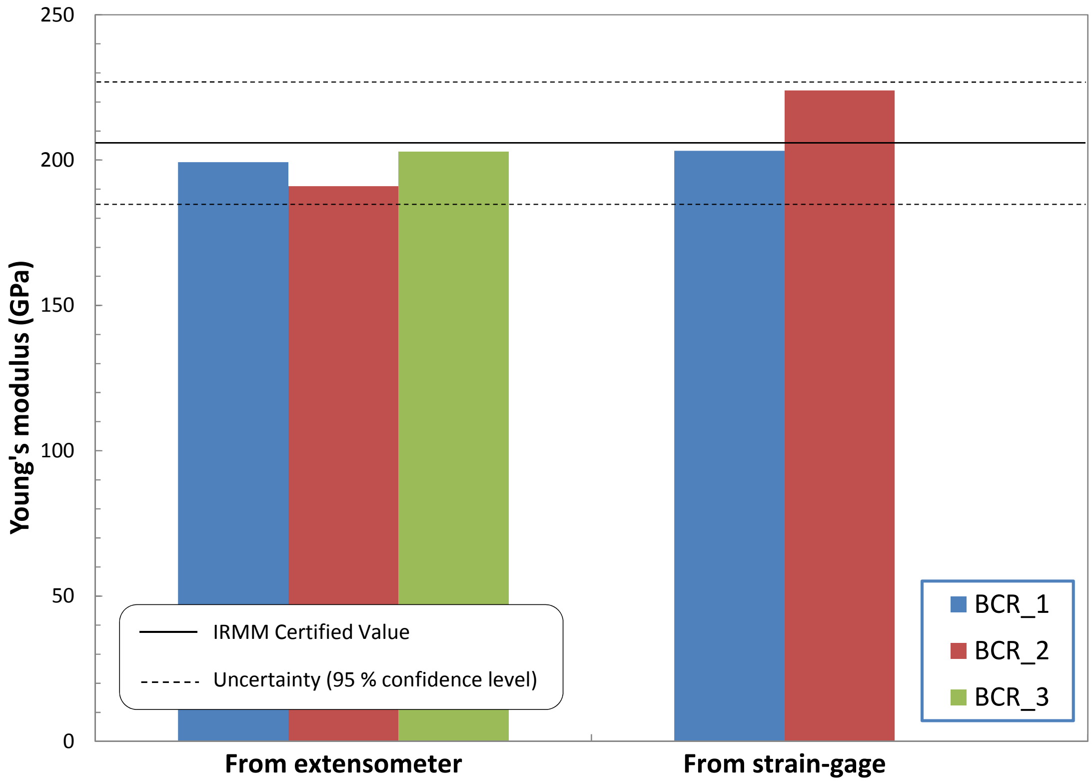

Figure 4 – Young's modulus values obtained from tensile tests on Nimonic 75 and comparison with IRMM indicative values.

2 Participation in ASTM Proficiency Testing Program (Mechanical Testing of Metals)

2.1 Background

The Proficiency Testing Program (PTP) run by ASTM International enables labs to compare, improve and maintain performance in conducting tests in accordance with ASTM Test Methods E8-E8M (Tension Test), E18 (Hardness Test), E646 (*n* value) and E517 (*r* value) on steel sheet materials.

The PTP is run biannually (May and September), and for each cycle provides participating labs a set of machined specimens and additional material in the form of sheet metal, using two materials of different thickness. Currently, the program disposes of three materials (coded A, B and C), all zinc-coated sheet steels meeting the ASTM A653 properties guidelines for "Forming Steel". For every test cycle, every participating lab receives three already machined specimens for each of two steels, plus additional thin plates to be used for extracting four additional samples per material (three to be tested and one to be returned untested). In September 2010, the selected steels were A and C.

Tensile and hardness results are returned to ASTM International by filling out a web-based report form. The two untested lab-prepared specimens are also returned to ASTM for dimensional tolerance measurements.

Test results and related information are used to generate a statistical summary report, which contains:

- anonymously coded laboratory test results;
- statistical analysis of test data;
- charts plotting test results versus lab code;
- additional information.

Outlier data are identified and segregated.

The summary report for the September 2010 cycle [2] was e-mailed by ASTM International to participating labs on Friday, January 7th, 2011. The lab code for NIST results is 038.

2.2 Specimens and test procedure

The geometry selected by ASTM for the program-supplied samples is the sheet-type, 12.5 mm (0.5”) wide standard rectangular specimen shown in Figure 1 of ASTM E8/E8M-09.

For lab-prepared specimens, we selected the 6 mm (0.250”) wide subsize specimen included in the same figure; see also Figure 5.

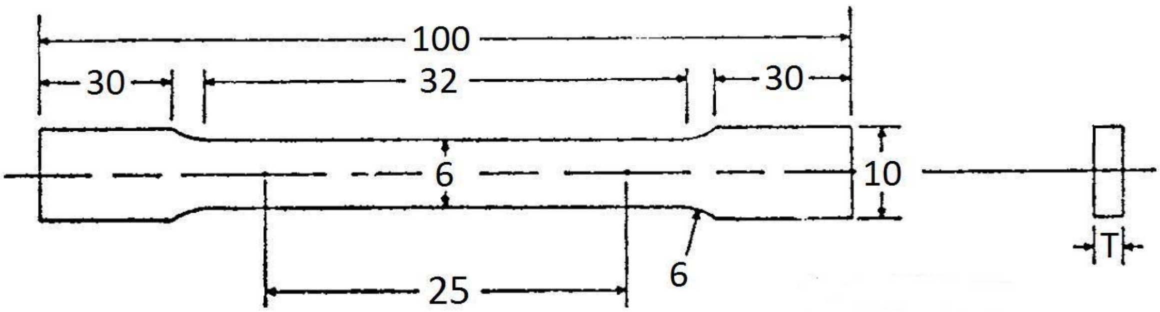

Figure 5 - Sub-size tensile specimen geometry used for the lab-prepared specimens (T is the thickness of material). All dimensions in mm.

Tests were performed in accordance with ASTM E8/E8M-09 at room temperature, using a constant crosshead displacement rate of 1.5 mm/min throughout the test. Specimens were instrumented with extensometers having base length of 2” and 1” for program-supplied and lab-prepared specimens, respectively. Both extensometers have a measuring range of 50 % (corresponding to 1” and 0.5”, respectively).

2.3 Results

The results of the tensile tests performed on materials A and C are summarized in Table 3 (steel A) and Table 4 (steel C), where, in addition to the parameters already defined in Table 2 above, the following quantities are reported:

- R_{LYS}, lower yield strength;
- $R_{EUL0.5}$, yield strength corresponding to an extension-under-load (EUL) corresponding to 0.5 % of the initial gage length;
- *YPE*, yield point elongation, corresponding to the strain separating on the stress/strain curve the first point of zero slope from the point of transition from discontinuous yielding to uniform strain hardening;
- *r*, plastic strain ratio for sheet metals, defined and determined in accordance with ASTM E517-00.

Note that, in the Tables, $P_{p0.2}$, $P_{EUL0.5}$, and P_{max}, are the force values corresponding to $R_{p0.2}$, $R_{EUL0.5}$, and R_m.

Table 3 - Results of tensile tests on zinc-coated galvanized sheet steel A (ASTM PTP material).

Specimen type	Specimen id	R_{LYS} (MPa)	$P_{p0.2}$ (N)	$R_{p0.2}$ (MPa)	$P_{EUL0.5}$ (N)	$R_{EUL0.5}$ (MPa)	P_{max} (N)	R_m (MPa)	YPE (%)	UE (%)	A (%)	Z (%)	E (GPa)	n	r
Standard	A014-3-11	296	5530	297	5527	297	7056	379	1.78%	17%	28%	82%	199	0.163	0.569
	A014-7-11	296	5441	298	5396	296	6973	382	1.62%	18%	28%	81%	199	0.162	0.749
	A015-2-11	299	5631	299	5658	301	7148	380	1.76%	18%	27%	81%	179	0.170	0.753
Subsize	A015-B	304	2620	303	2658	308	3338	387	1.79%	18%	26%	77%	196	0.161	0.580
	A017-A	295	2586	299	2593	300	3316	383	1.62%	17%	29%	78%	154	0.168	0.712
	A017-B	293	2597	300	2584	298	3323	384	1.32%	17%	28%	80%	186	0.165	0.869
Average values		**297**	**4067**	**299**	**4069**	**300**	**5192**	**382**	**1.65%**	**17%**	**28%**	**80%**	**185**	**0.165**	**0.705**
Standard deviation		**4.0**	**1607.9**	**2.1**	**1599.3**	**4.3**	**2045.7**	**2.7**	**0.18%**	**0.6%**	**1.0%**	**1.9%**	**17.4**	**0.0034**	**0.1144**

Table 4 - Results of tensile tests on zinc-coated galvanized sheet steel C (ASTM PTP material).

Specimen type	*Specimen id*	*R_{LYS} (MPa)*	*$P_{p0.2}$ (N)*	*$R_{p0.2}$ (MPa)*	*$P_{EUL0.5}$ (N)*	*$R_{EUL0.5}$ (MPa)*	*P_{max} (N)*	*R_m (MPa)*	*YPE (%)*	*UE (%)*	*A (%)*	*Z (%)*	*E (GPa)*	*n*	*r*
Standard	**C053-6-11**	236	3585	235	3663	240	5087	334	0.55%	25%	42%	86%	185	0.192	1.118
	C054-4-11	245	3596	240	3670	245	5060	337	0.55%	26%	41%	85%	170	0.192	1.284
	C055-2-11	238	3551	235	3641	241	5028	333	0.75%	25%	41%	86%	187	0.192	1.062
Subsize	**C056-A**	242	1676	242	1711	247	2398	346	0.41%	24%	48%	82%	150	0.192	1.770
	C056-B	245	1669	240	1707	246	2387	344	0.46%	26%	46%	84%	172	0.190	1.394
	C058-A	244	1662	242	1696	247	2394	348	0.41%	26%	50%	83%	185	0.192	1.308
Average values		**242**	**2623**	**239**	**2682**	**244**	**3726**	**340**	**0.52%**	**25%**	**45%**	**84%**	**175**	**0.192**	**1.323**
Standard deviation		**3.9**	**1045.5**	**3.1**	**1069.9**	**2.9**	**1460.0**	**6.6**	**0.13%**	**0.9%**	**3.9%**	**1.4%**	**14.5**	**0.0007**	**0.2516**

Test results are represented graphically in Figure 6 (strength, material A), Figure 7 (ductility, material A), Figure 8 (strength, material C) and Figure 9 (ductility, material C). Good agreement is found between tensile properties measured from specimen of different type/size.

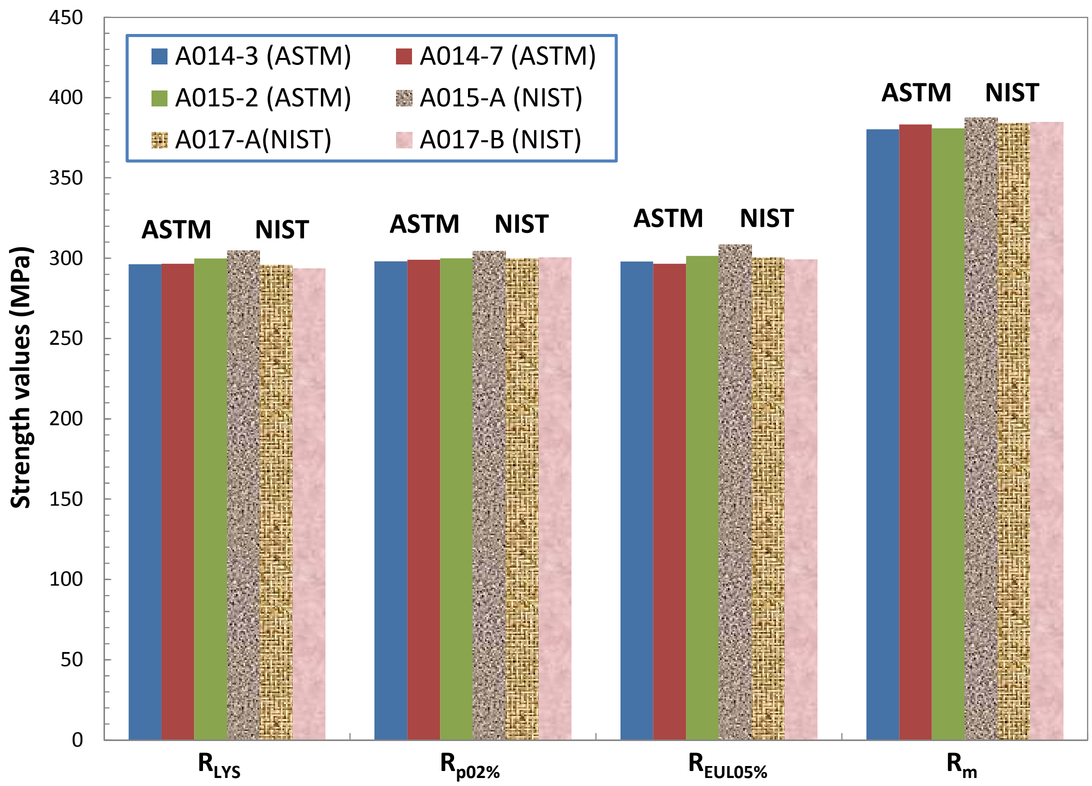

Figure 6 - Strength values measured for ASTM PTP material A. Note: ASTM and NIST indicate standard and subsize rectangular tensile specimens, respectively.

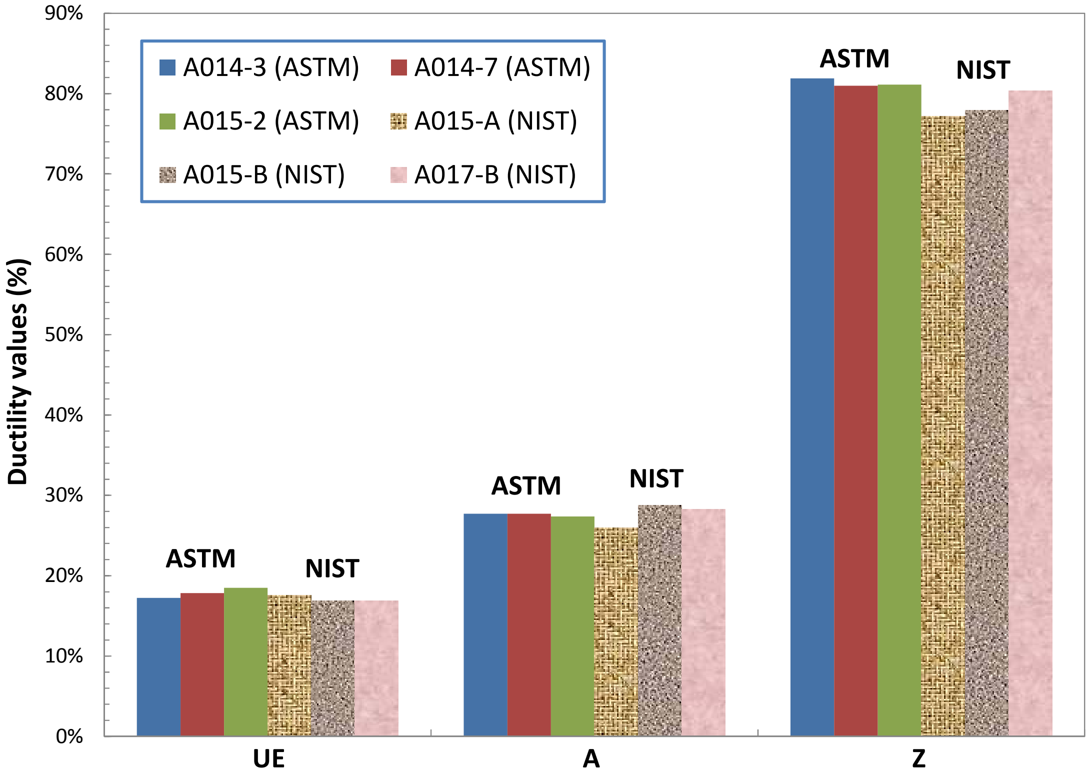

Figure 7 - Ductility values measured for ASTM PTP material A.

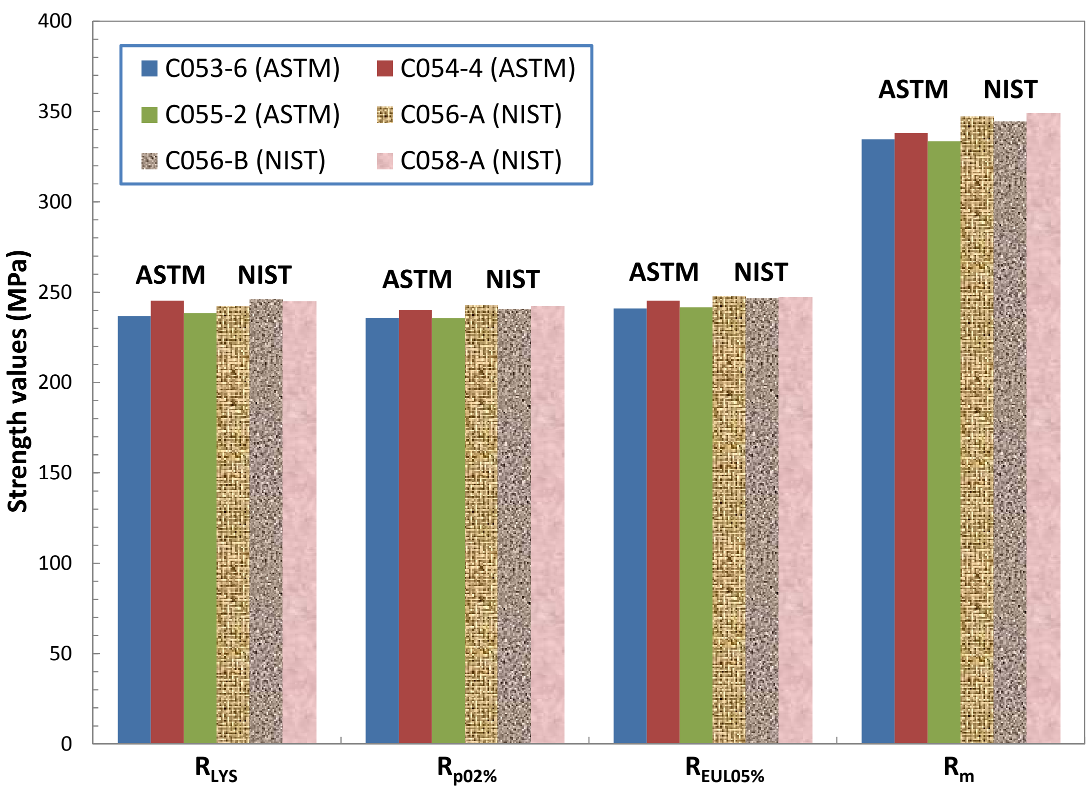

Figure 8 - Strength values measured for ASTM PTP material C.

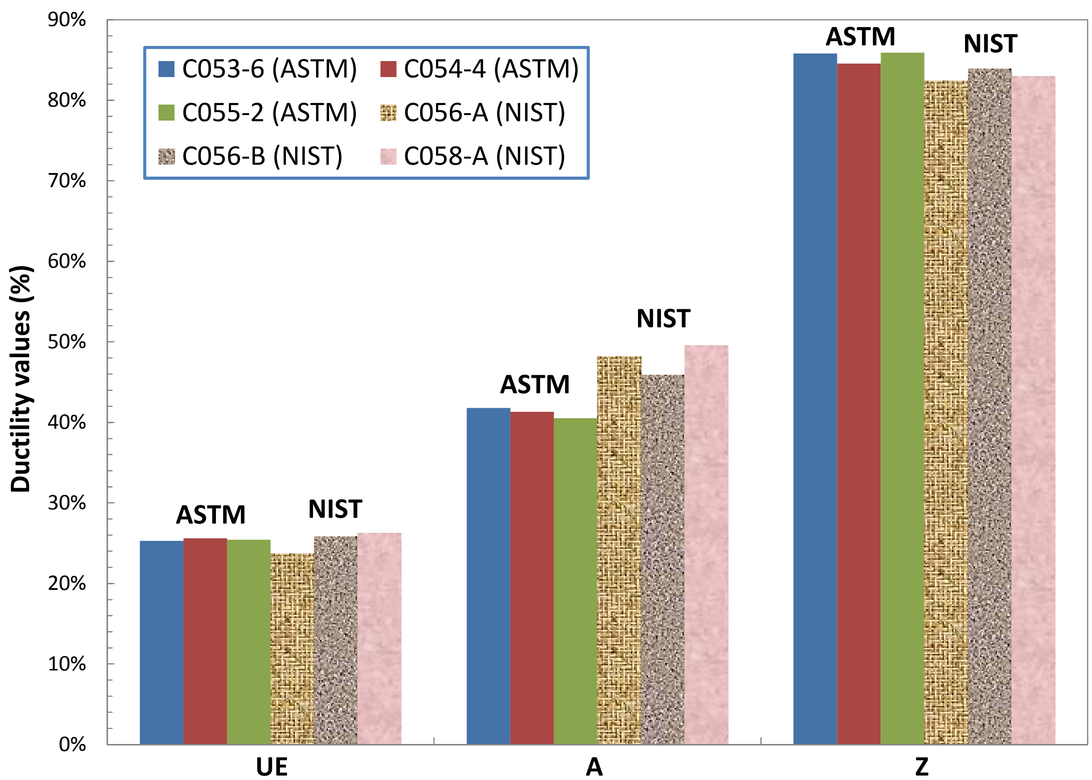

Figure 9 - Ductility values measured for ASTM PTP material C.

2.4 ASTM PTP statistical analyses

2.4.1 Tensile results - Material A

Using data and analyses provided by ASTM International in [2], tensile results obtained at NIST (lab code: 038) for material A are summarized in Table 5, along with:

- number of analyzed results (*Count*);
- average of all analyzed results ($\overline{X}_{ALL}$);
- standard deviation of analyzed results ($\overline{\sigma}_{ALL}$);
- Z-score of NIST results, representing their deviation in units of standard deviation; in other words, the Z-score is the ratio of the lab's deviation to the overall standard deviation[1]. An absolute Z-score smaller than 1 means the lab's mean value lies within $\pm\sigma$ from the overall mean value.

NOTES:
1) Separate analyses are provided for program-supplied (PS) and lab-prepared (LP) specimens.
2) ASTM only uses the first two results provided by each lab, keeping the third one in reserve.
3) Since NIST chose a different specimen geometry/size for LP specimens, non-normalized quantities (such as force values) cannot be compared with overall means and standard deviations and are therefore not reported in Table 5.

[1]Through two calculation iterations, labs that had a Z-score of $\pm$ 3 or more were identified as outliers and excluded by ASTM International from the statistical analyses.

Table 5 - Comparison between NIST tensile results (material A) and overall statistical analyses performed by ASTM.

Property	*Specimens*	*Count*	$\overline{X}_{ALL}$	$\overline{\sigma}_{ALL}$	$\overline{X}_{NIST}$	*Z-score*
$P_{EUL0.5}$ (N)	PS	56	5542.2	72.9	5477	-0.6
$R_{EUL0.5}$ (MPa)	PS	56	301.4	4.7	297.5	-0.8
	LP	56	300.4	5.3	301.0	0.9
$P_{p0.2}$ (N)	PS	80	5569.7	108.9	5500.5	-0.6
$R_{p0.2}$ (MPa)	PS	80	303.5	5.8	298.5	-0.9
	LP	76	302.4	4.6	302.0	-0.1
P_{max} (N)	PS	86	7155.2	82.6	7034	-1.5
R_m (MPa)	PS	86	389.5	5.4	381.5	-1.5
	LP	84	388.3	5.3	386.0	-0.4
A (%)	PS	88	28.5	0.9	28.0	-0.6
	LP	90	28.8	1.5	27.5	-0.9
YPE (%)	PS	20	1.0631	0.4672	1.70	1.4
	LP	18	1.3186	0.8554	1.705	0.5
n	PS	42	0.1641	0.0060	0.1625	-0.3
	LP	46	0.1628	0.0051	0.1645	0.3
r	PS	22	0.8358	0.0642	**Outside ± 3σ range**	
	LP	26	0.8114	0.0371	**Outside ± 3σ range**	

The overall average Z-score for NIST tensile measurements on material A is -0.34, indicating a slight general underestimation with respect to the data population of the participating laboratories, however well within ± 1σ. Using only results obtained on program-supplied specimens, the average Z-score is -0.6; for lab-prepared samples, the value is 0.05.

Considering only force or strength-related parameters, the mean Z-score for all material A specimens tested is -0.61. Referring to the most recent calibration of the load cell (see NOTE in Section 1.3 on page 6), using the correction factor 0.99276 would slightly increase the absolute value of the Z-score.

The comparison diagrams provided by ASTM International in [2], where NIST results are highlighted by a red rectangle, are reproduced in:

– Figure 10 (yield strength force – 0.5 % Extension Under Load, program-supplied specimens)
– Figure 11 (yield strength– 0.5 % Extension Under Load, program-supplied specimens)
– Figure 12 (yield strength– 0.5 % Extension Under Load, lab-prepared specimens)
– Figure 13 (yield strength force – 0.2 % offset, program-supplied specimens)
– Figure 14 (yield strength– 0.2 % offset, program-supplied specimens)
– Figure 15 (yield strength– 0.2 % offset, lab-prepared specimens)
– Figure 16 (tensile strength force, program-supplied specimens)
– Figure 17 (tensile strength, program-supplied specimens)
– Figure 18 (tensile strength, lab-prepared specimens)
– Figure 19 (elongation – percent increase, program-supplied specimens)
– Figure 20 (elongation – percent increase, lab-prepared specimens)
– Figure 21 (yield point elongation, program-supplied specimens)
– Figure 22 (yield point elongation, lab-prepared specimens)
– Figure 23 (strain-hardening exponent, program-supplied specimens)
– Figure 24 (strain-hardening exponent, lab-prepared specimens).

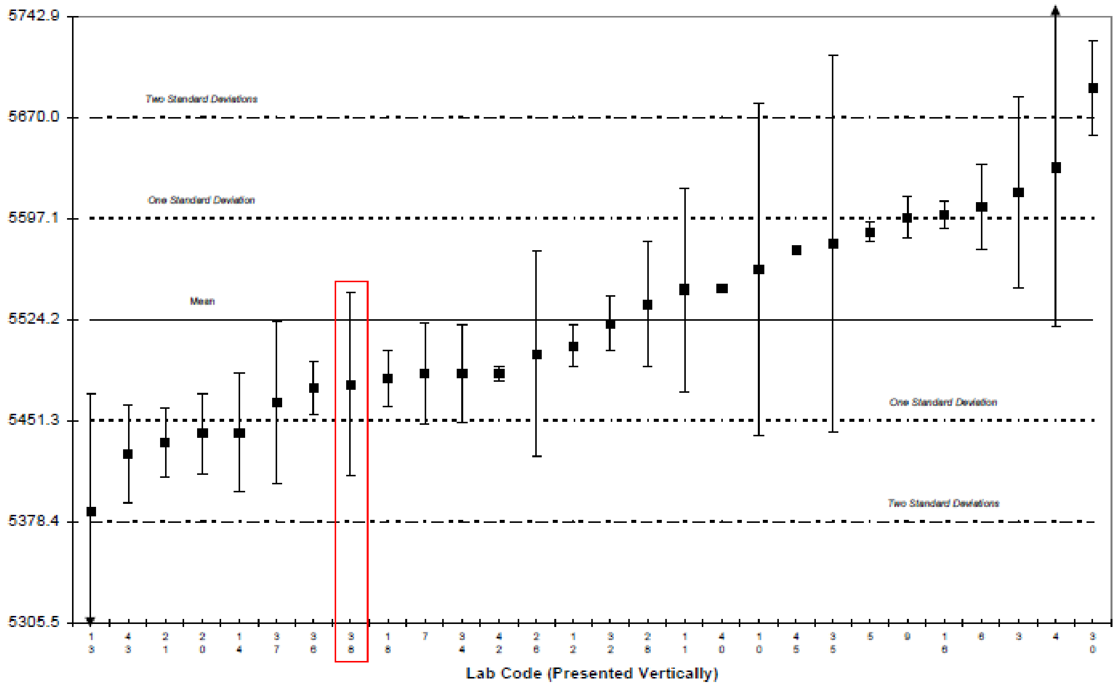

Figure 10 - ASTM PTP September 2010, Material A: values of $P_{EUL0.5}$ for program-supplied specimens.

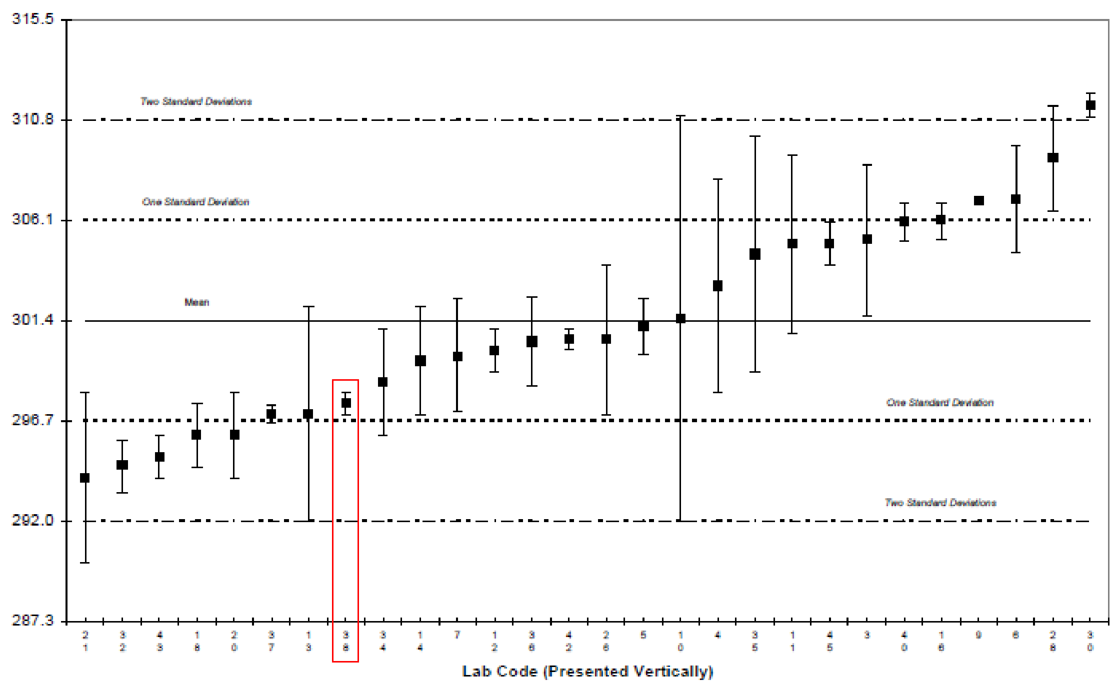

Figure 11 - ASTM PTP September 2010, Material A: values of $R_{EUL0.5}$ for program-supplied specimens.

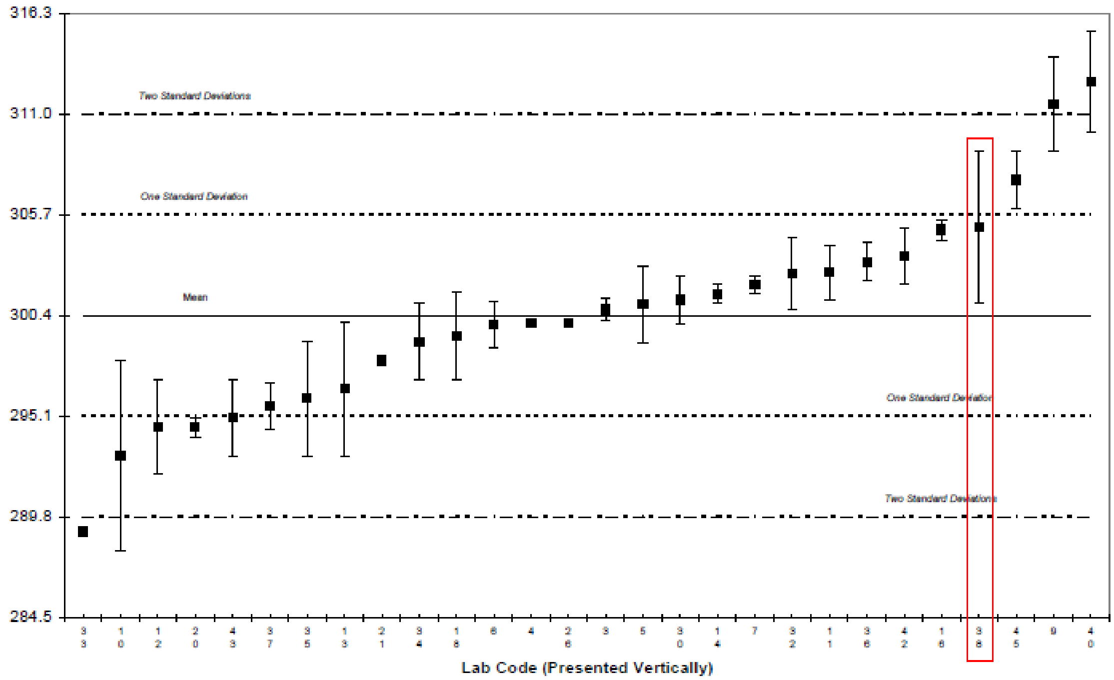

Figure 12 - ASTM PTP September 2010, Material A: values of $R_{EUL0.5}$ for lab-prepared specimens.

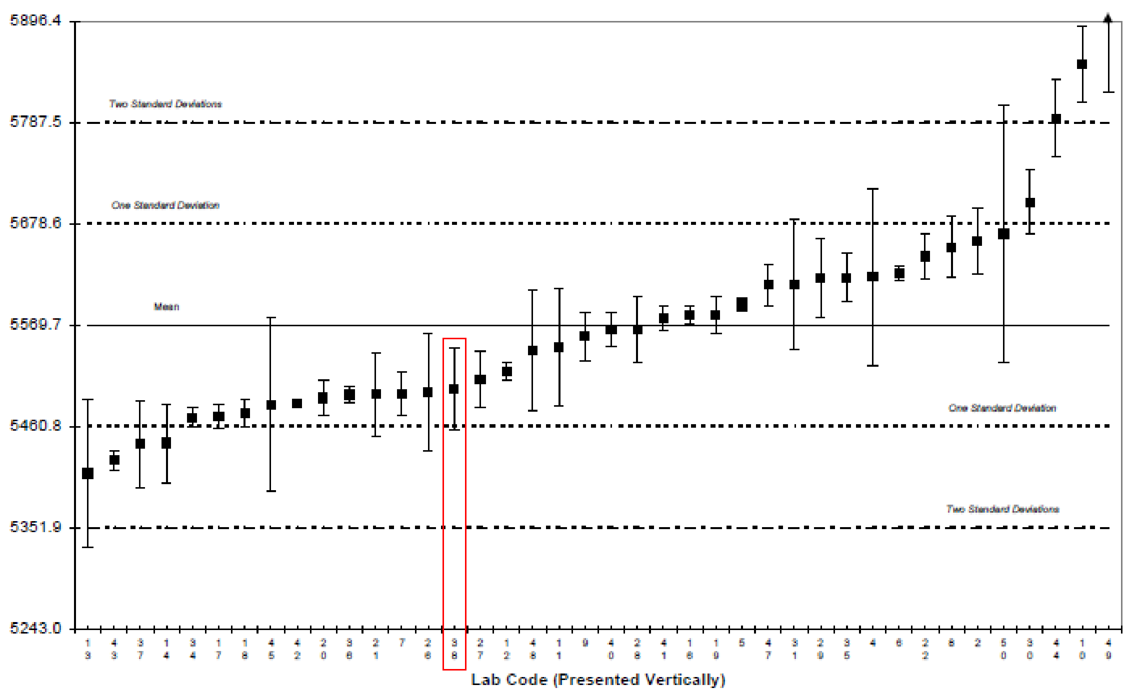

Figure 13 - ASTM PTP September 2010, Material A: values of $P_{p0.2}$ for program-supplied specimens.

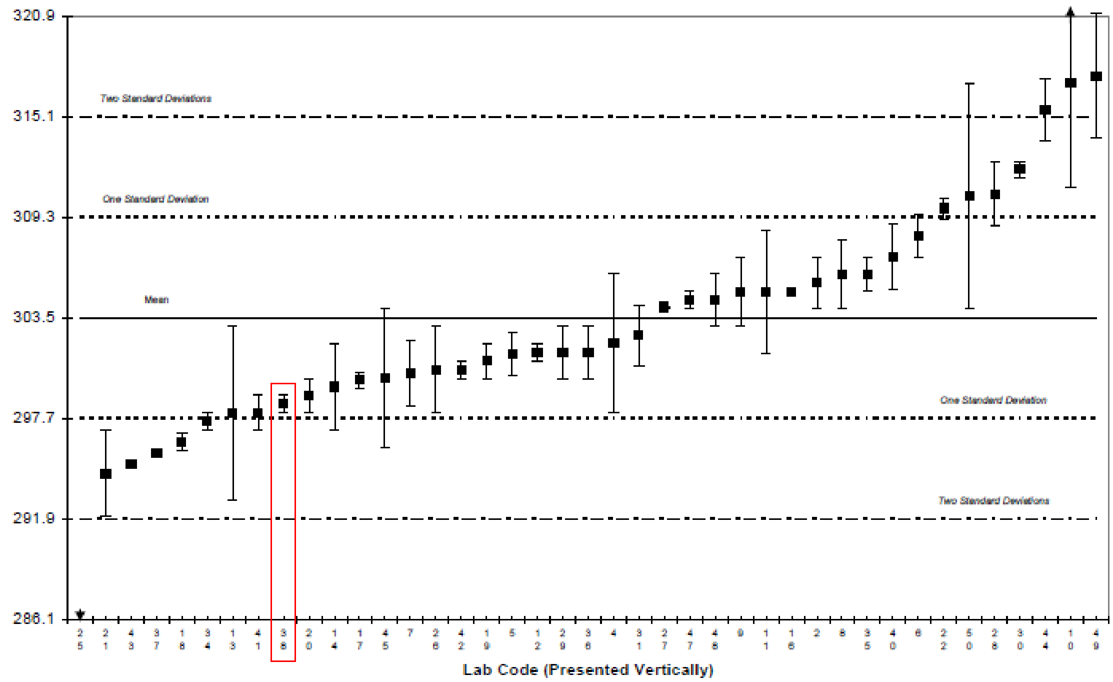

Figure 14 - ASTM PTP September 2010, Material A: values of $R_{p0.2}$ for program-supplied specimens.

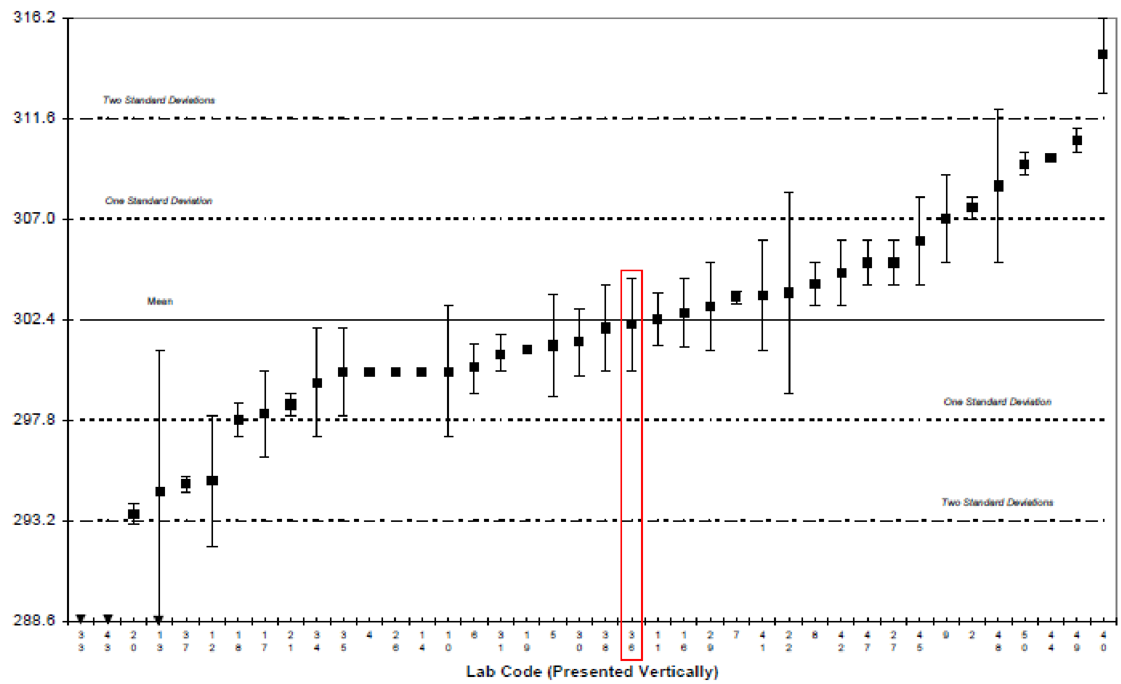

Figure 15 - ASTM PTP September 2010, Material A: values of $R_{p0.2}$ for lab-prepared specimens.

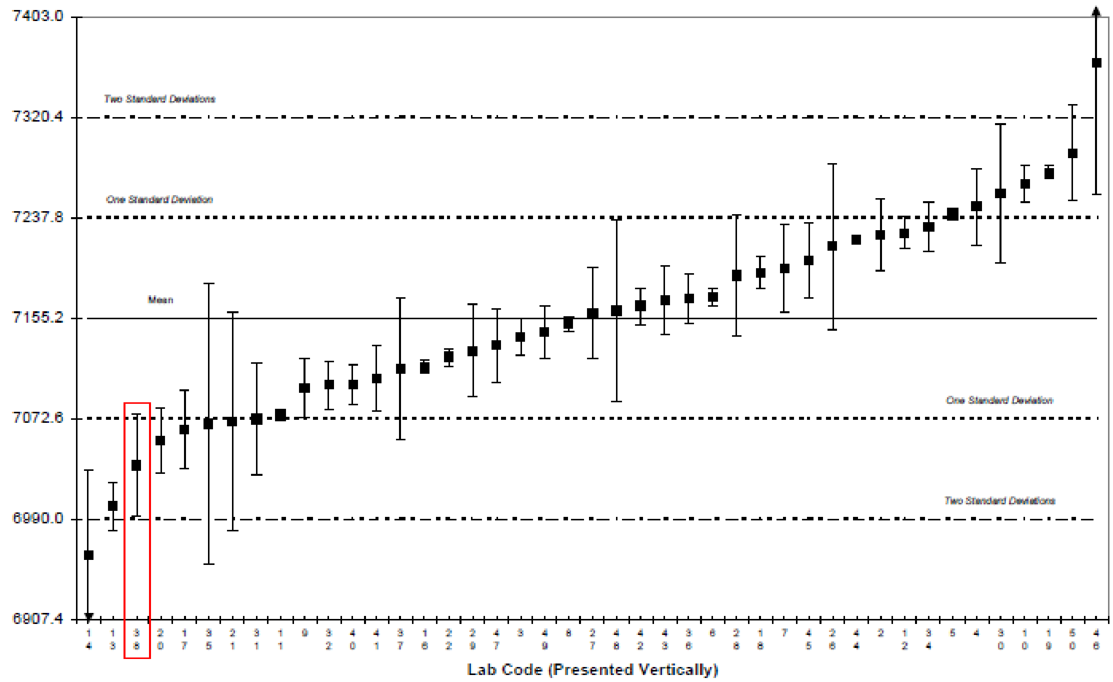

Figure 16 - ASTM PTP September 2010, Material A: values of P_{max} for program-supplied specimens.

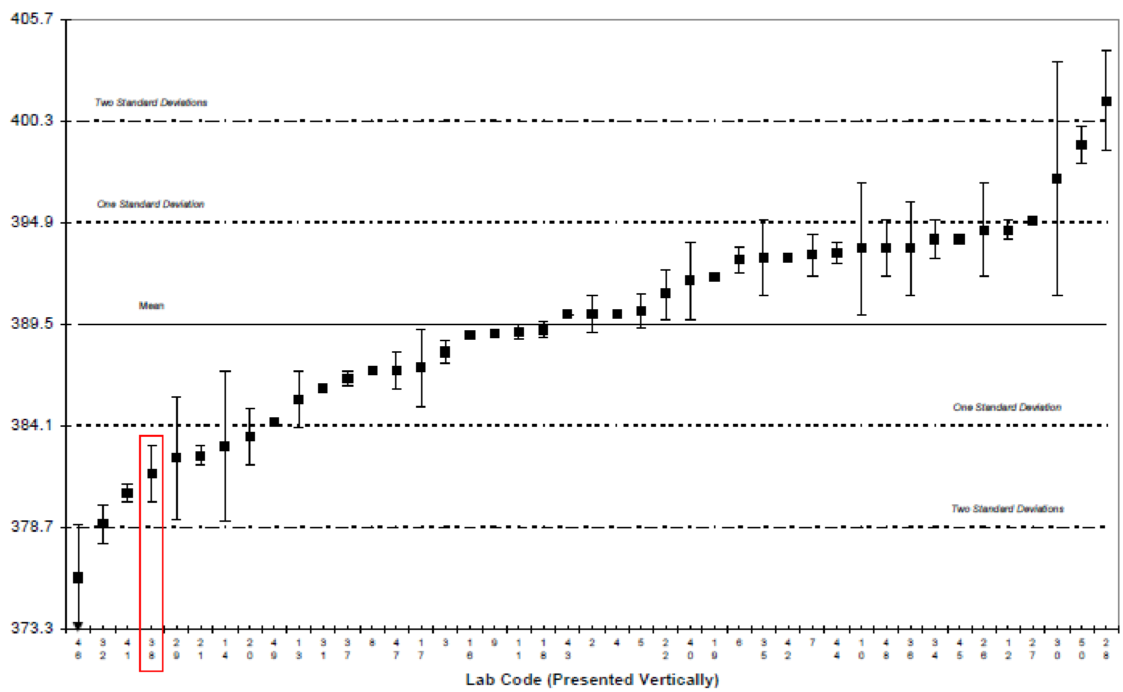

Figure 17 - ASTM PTP September 2010, Material A: values of R_m for program-supplied specimens.

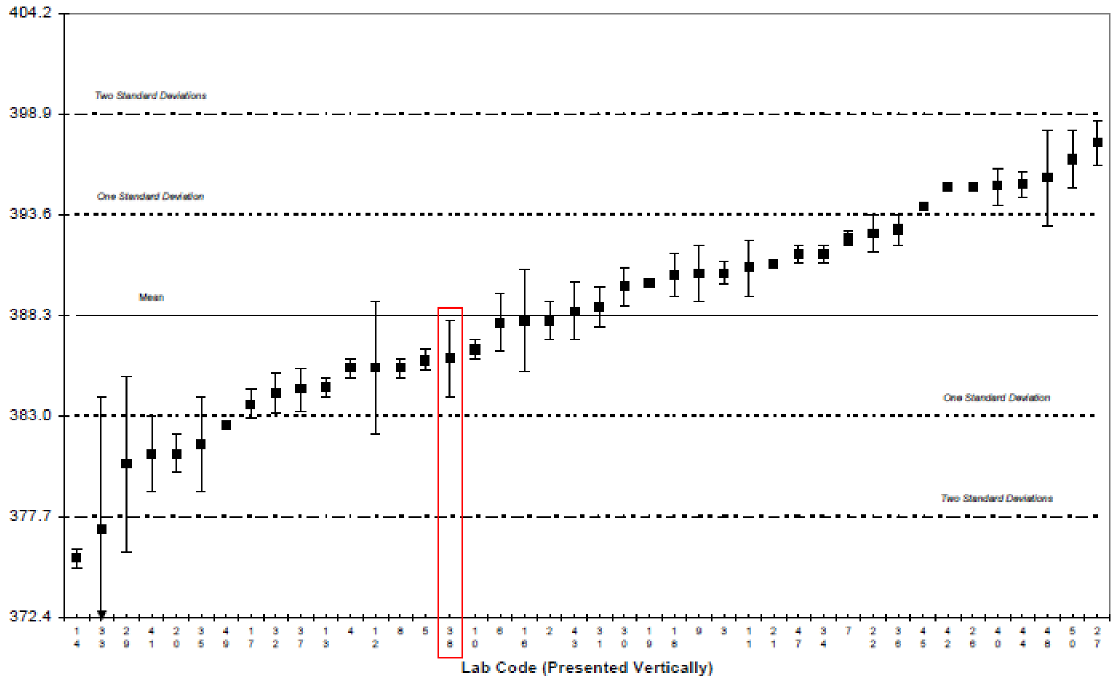

Figure 18 - ASTM PTP September 2010, Material A: values of R_m for lab-prepared specimens.

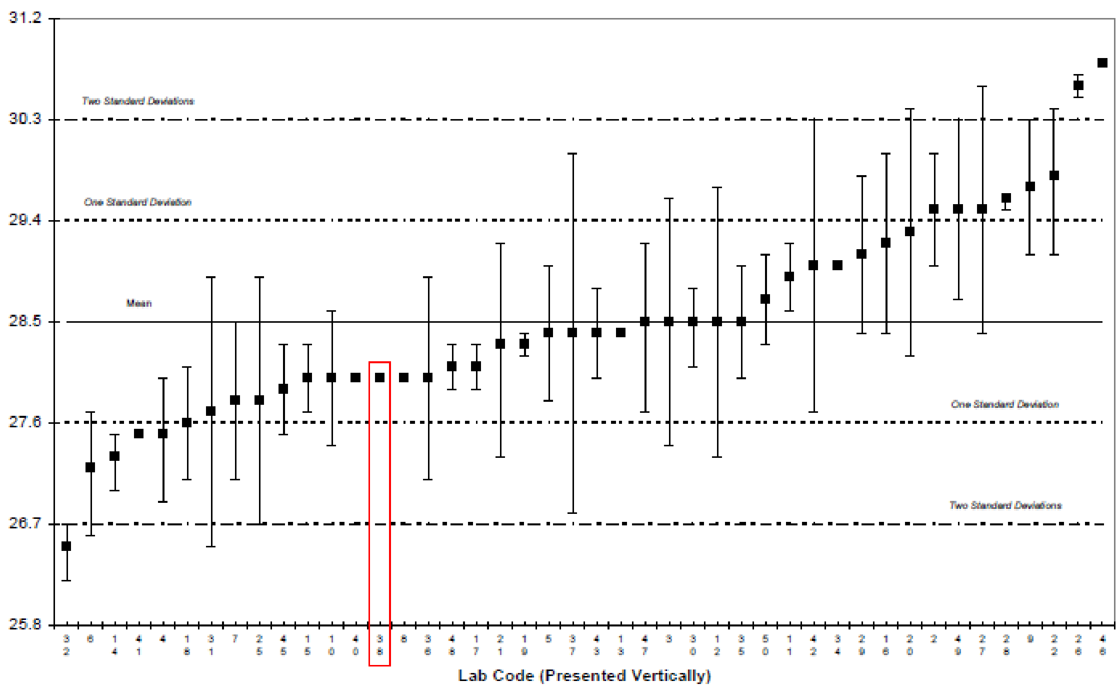

Figure 19 - ASTM PTP September 2010, Material A: values of elongation (% increase) for program-supplied specimens.

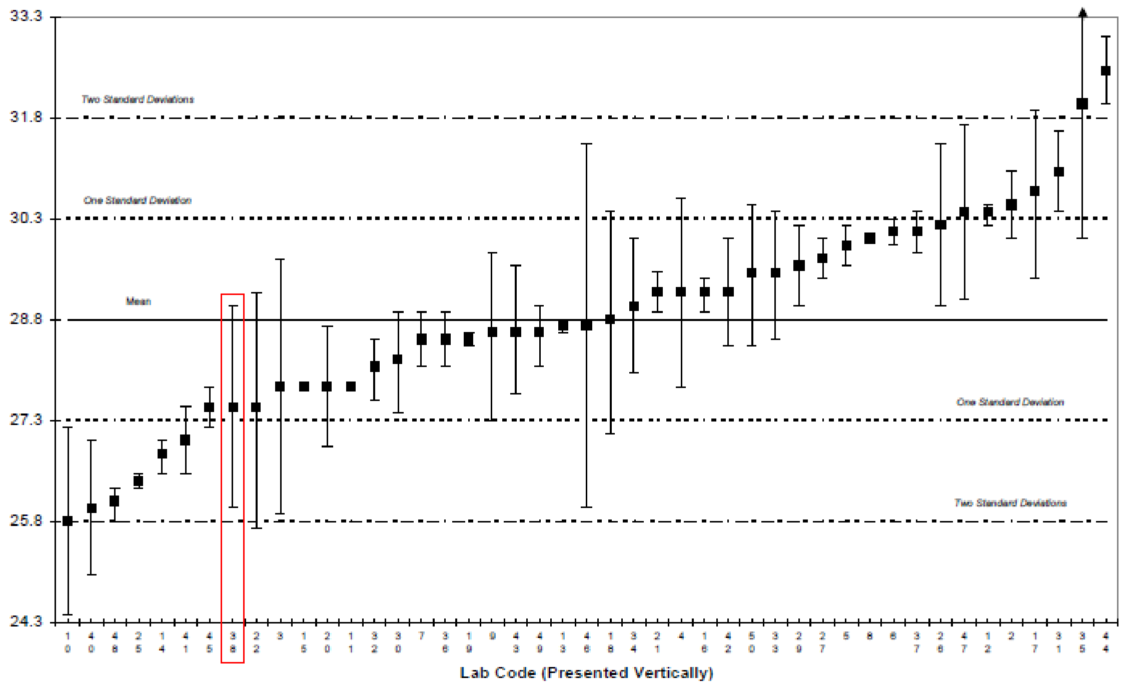

Figure 20 - ASTM PTP September 2010, Material A: values of elongation (% increase) for lab-prepared specimens.

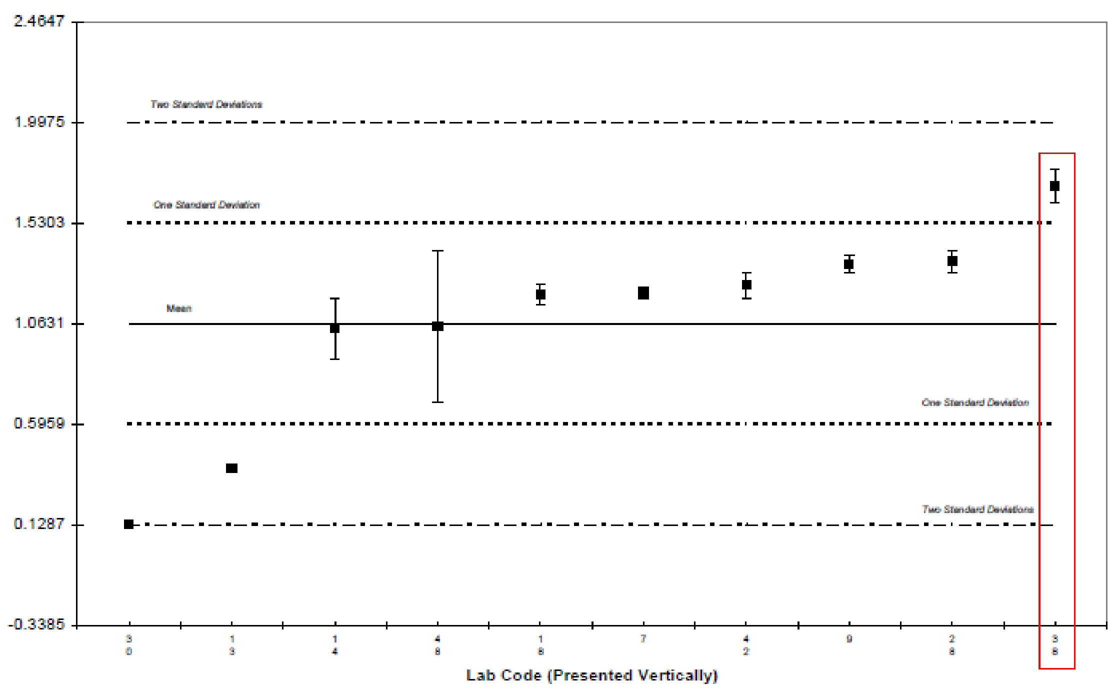

Figure 21 - ASTM PTP September 2010, Material A: values of yield-point elongation for program-supplied specimens.

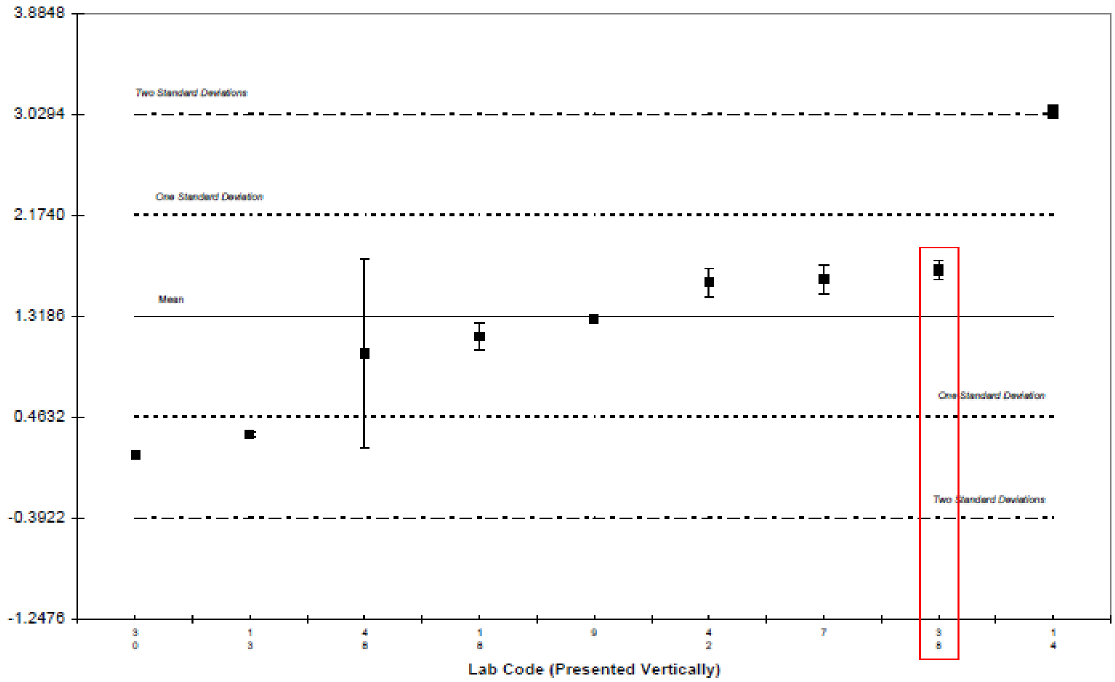

Figure 22 - ASTM PTP September 2010, Material A: values of yield-point elongation for lab-prepared specimens.

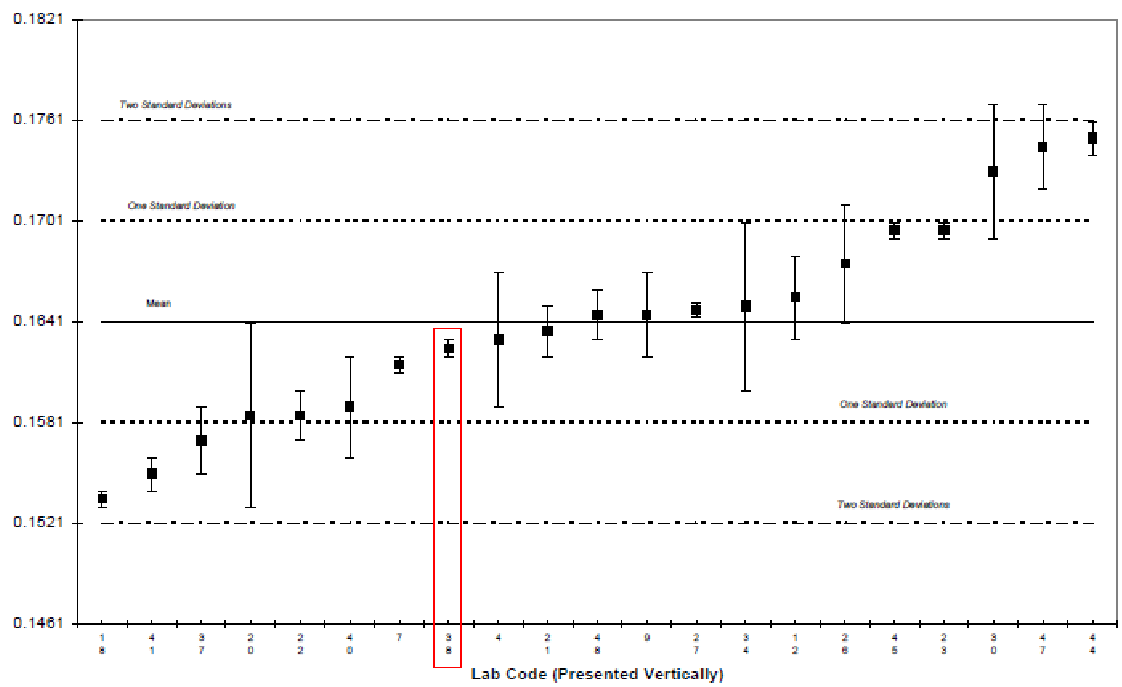

Figure 23 - ASTM PTP September 2010, Material A: values of strain-hardening exponent for program-supplied specimens.

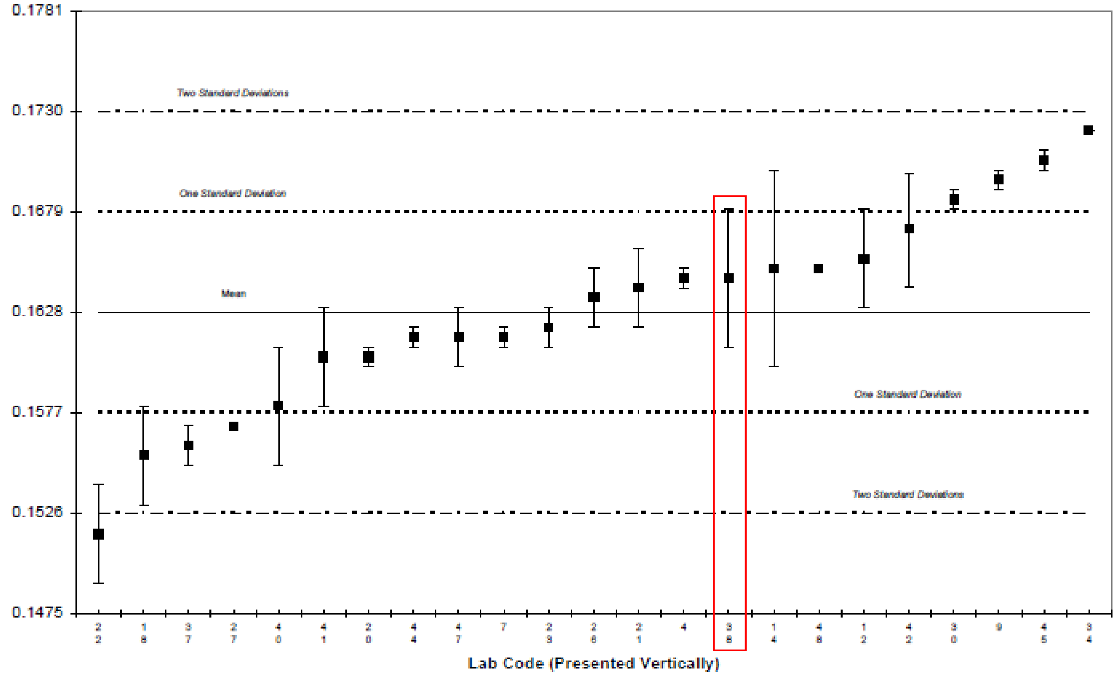

Figure 24 - ASTM PTP September 2010, Material A: values of strain-hardening exponent for lab-prepared specimens.

2.4.2 Tensile results - Material C

Using data and analyses provided by ASTM International in [2], tensile results returned by NIST (lab code: 038) for material C are summarized in Table 6, along with:

- number of analyzed results (*Count*);
- average of all analyzed results ($\overline{X}_{ALL}$);
- standard deviation of analyzed results ($\overline{\sigma}_{ALL}$);
- Z-score of NIST results.

Table 6 - Comparison between NIST tensile results (material C) and overall statistical analyses performed by ASTM.

Property	*Specimens*	*Count*	$\overline{X}_{ALL}$	$\overline{\sigma}_{ALL}$	$\overline{X}_{NIST}$	*Z-score*
$P_{EUL0.5}$ (N)	PS	60	3661.8	63.4	3677.5	0.2
$R_{EUL0.5}$ (MPa)	PS	58	250.1	4.3	243.0	-1.6
	LP	56	249.4	4.6	247.0	-0.5
$P_{p0.2}$ (N)	PS	84	3613.8	76.0	3600.5	-0.2
$R_{p0.2}$ (MPa)	PS	84	246.4	5.7	238.0	-1.5
	LP	82	246.2	6.4	242.0	-0.7
P_{max} (N)	PS	86	5172.0	48.6	5087.5	-1.7
R_m (MPa)	PS	88	351.5	5.0	336.5	-3.0
	LP	86	350.8	4.8	346.0	-1.0
A (%)	PS	94	39.0	1.3	41.5	1.9
	LP	86	39.1	1.5	**Outside ± 3σ range**	
YPE (%)	PS	18	0.3895	0.1716	0.550	0.9
	LP	16	0.4889	0.2410	0.435	-0.2
n	PS	44	0.1900	0.0039	0.192	0.5
	LP	46	0.1885	0.0042	0.192	0.8
r	PS	22	1.2939	0.0640	**Outside ± 3σ range**	
	LP	26	1.2539	0.0659	**Outside ± 3σ range**	

The average Z-score for all NIST tensile measurements on material C is -0.44, indicating an underestimation with respect to the data population of the participating laboratories, however well within $\pm 1\sigma$. Using only results obtained on program-supplied specimens, the average Z-score is -0.5; for lab-prepared samples, the value is -0.32.

Considering only force or strength-related parameters, the mean Z-score for all material C specimens tested is -1.11. Referring to the most recent calibration of the load cell (see NOTE in Section 1.3 on page 6), using the correction factor 0.99276 would slightly increase the absolute value of the Z-score.

The comparison diagrams provided by ASTM in [2], with NIST results highlighted using a red rectangle, are reproduced in:

- Figure 25 (yield strength force – 0.5 % Extension Under Load, program-supplied specimens)
- Figure 26 (yield strength– 0.5 % Extension Under Load, program-supplied specimens)
- Figure 27 (yield strength– 0.5 % Extension Under Load, lab-prepared specimens)
- Figure 28 (yield strength force – 0.2 % offset, program-supplied specimens)
- Figure 29 (yield strength– 0.2 % offset, program-supplied specimens)
- Figure 30 (yield strength– 0.2 % offset, lab-prepared specimens)
- Figure 31 (tensile strength force, program-supplied specimens)
- Figure 32 (tensile strength, program-supplied specimens)
- Figure 33 (tensile strength, lab-prepared specimens)
- Figure 34 (elongation – percent increase, program-supplied specimens)
- Figure 35 (yield point elongation, program-supplied specimens)
- Figure 36 (yield point elongation, lab-prepared specimens)
- Figure 37 (strain-hardening exponent, program-supplied specimens)
- Figure 38 (strain-hardening exponent, lab-prepared specimens).

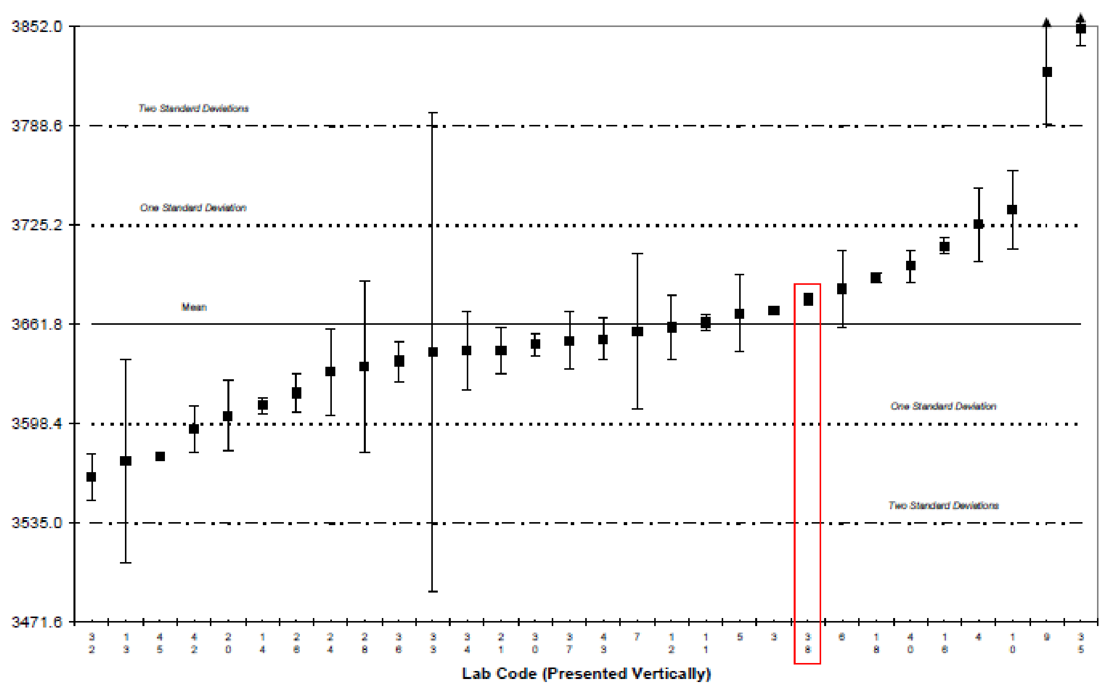

Figure 25 - ASTM PTP September 2010, Material C: values of $P_{EUL0.5}$ for program-supplied specimens.

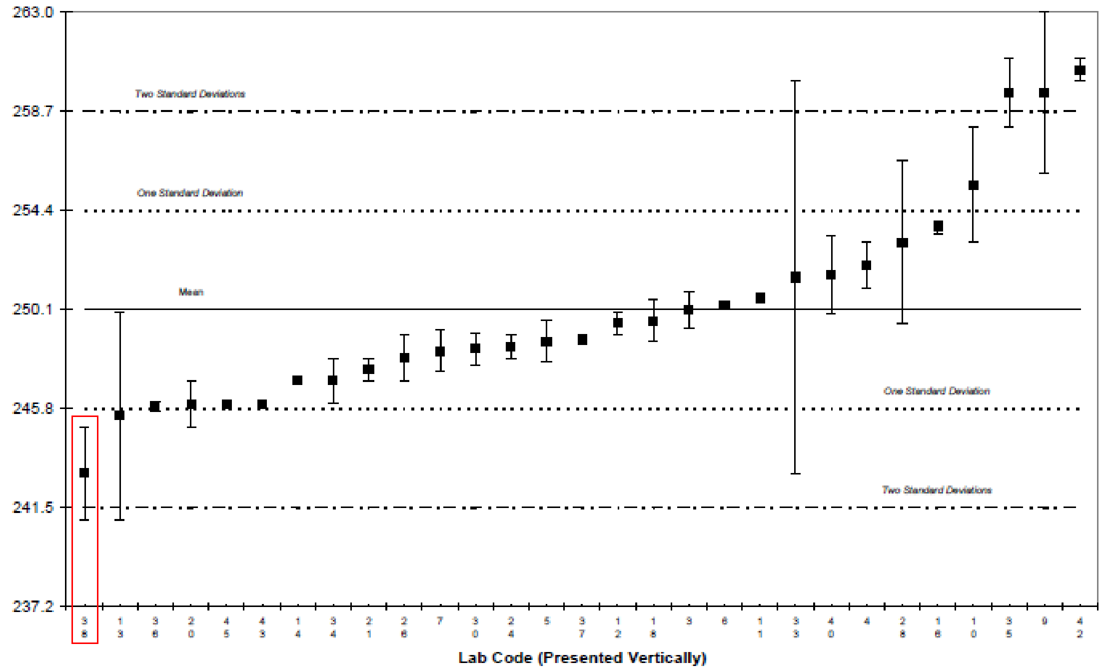

Figure 26 - ASTM PTP September 2010, Material C: values of $R_{EUL0.5}$ for program-supplied specimens.

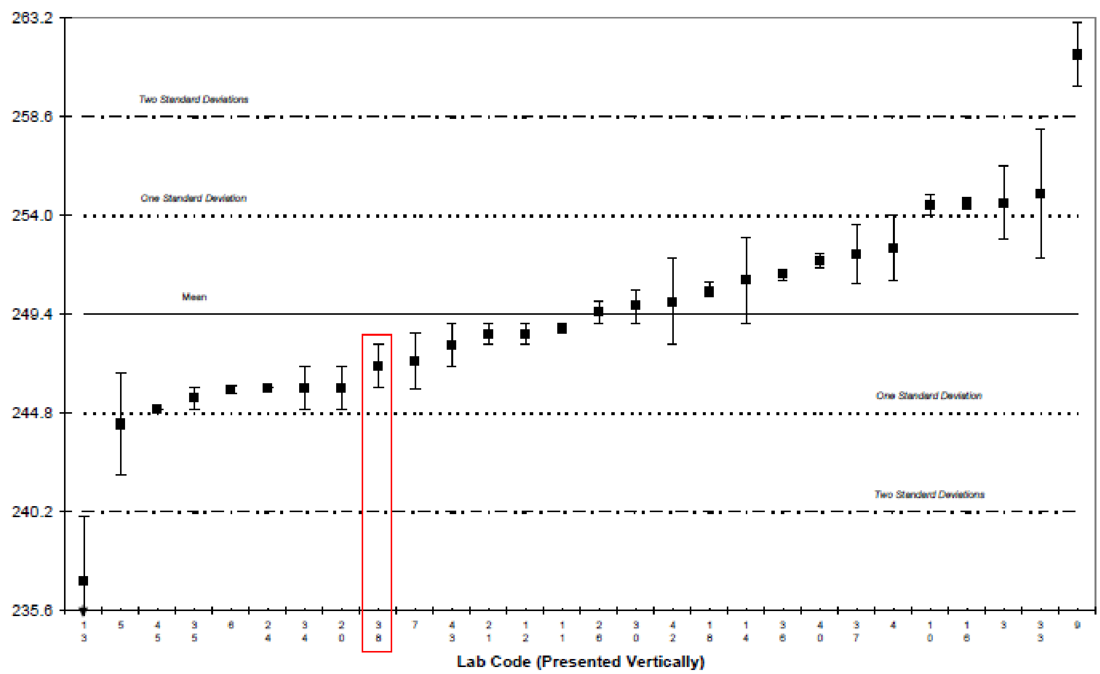

Figure 27 - ASTM PTP September 2010, Material C: values of $R_{EUL0.5}$ for lab-prepared specimens.

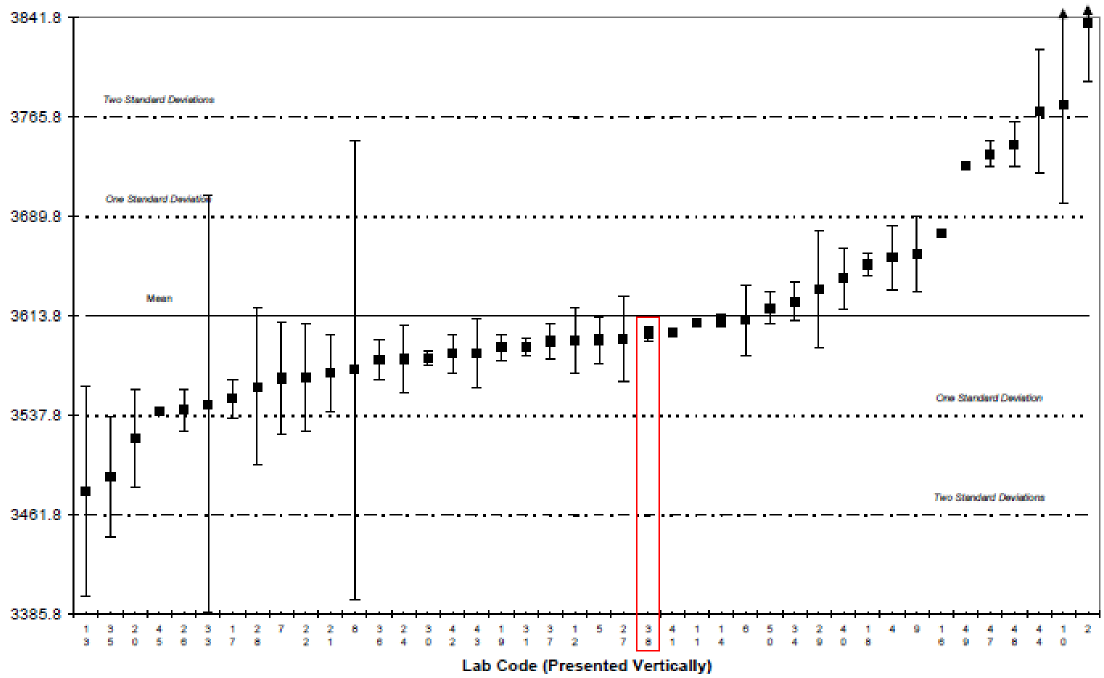

Figure 28 - ASTM PTP September 2010, Material C: values of $P_{p0.2}$ for program-supplied specimens.

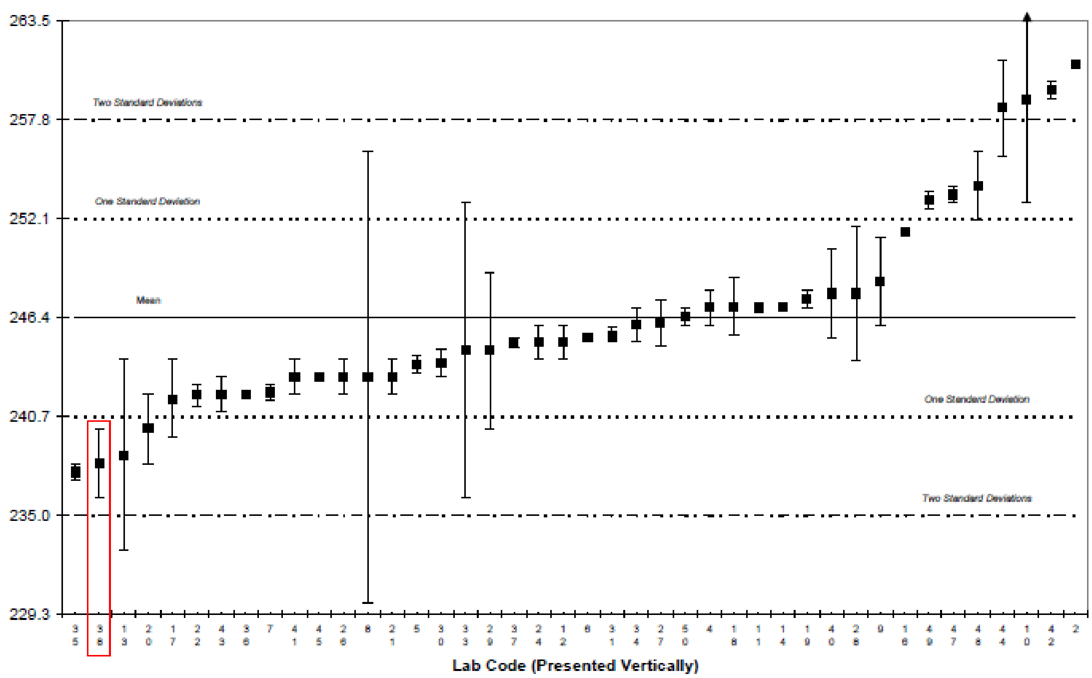

Figure 29 - ASTM PTP September 2010, Material C: values of $R_{p0.2}$ for program-supplied specimens.

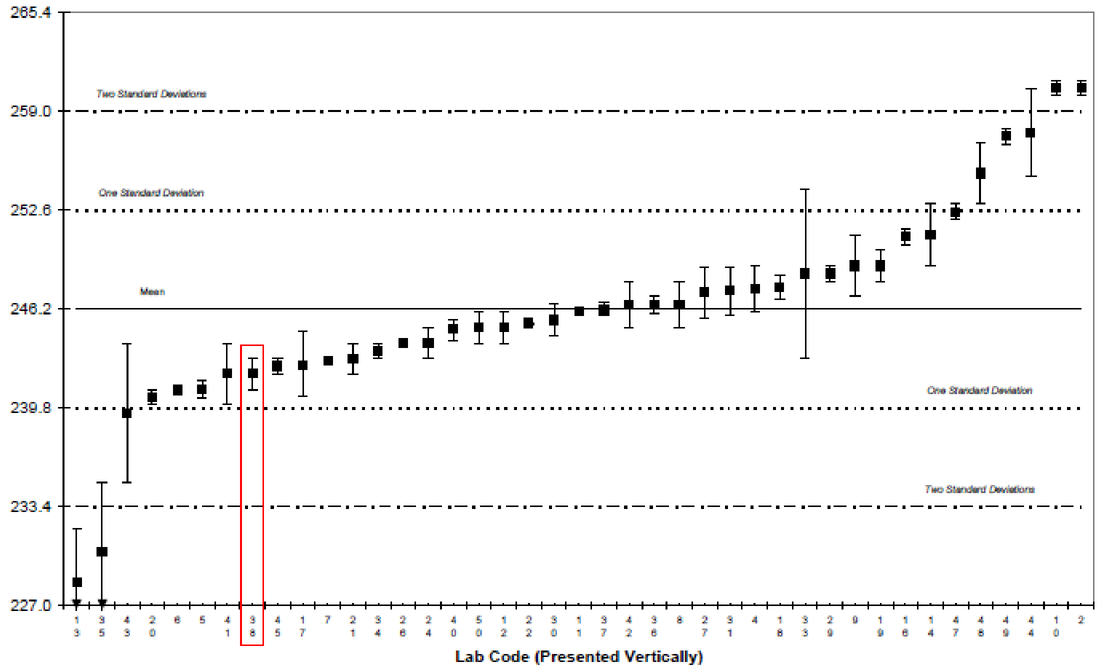

Figure 30 - ASTM PTP September 2010, Material C: values of $R_{p0.2}$ for lab-prepared specimens.

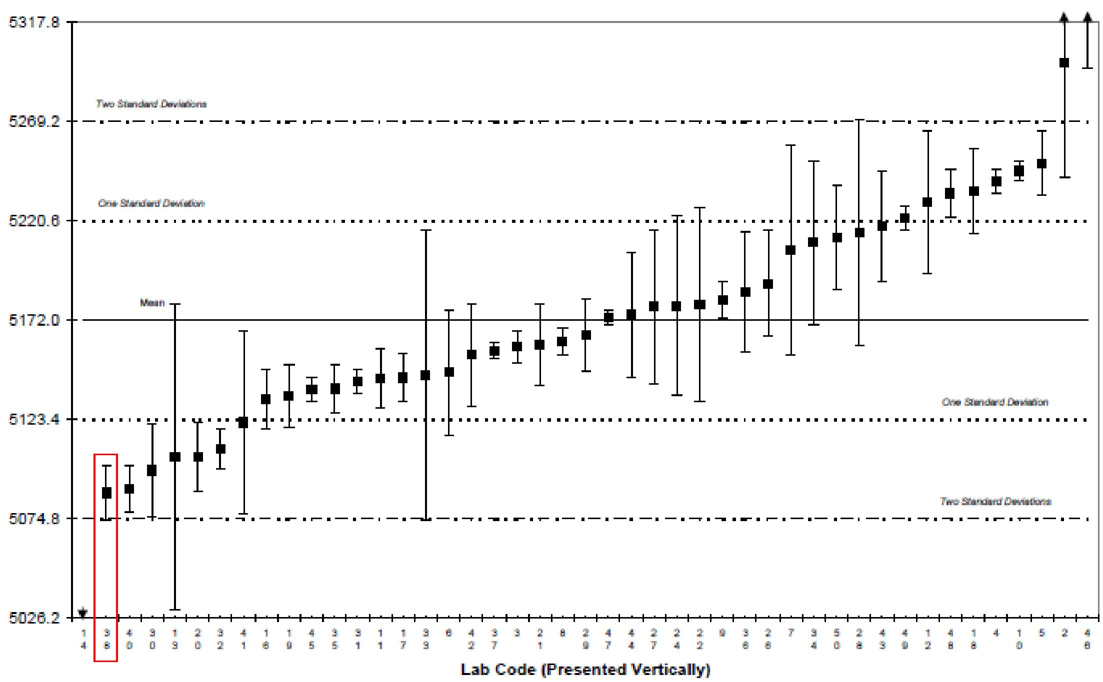

Figure 31 - ASTM PTP September 2010, Material C: values of P_{max} for program-supplied specimens.

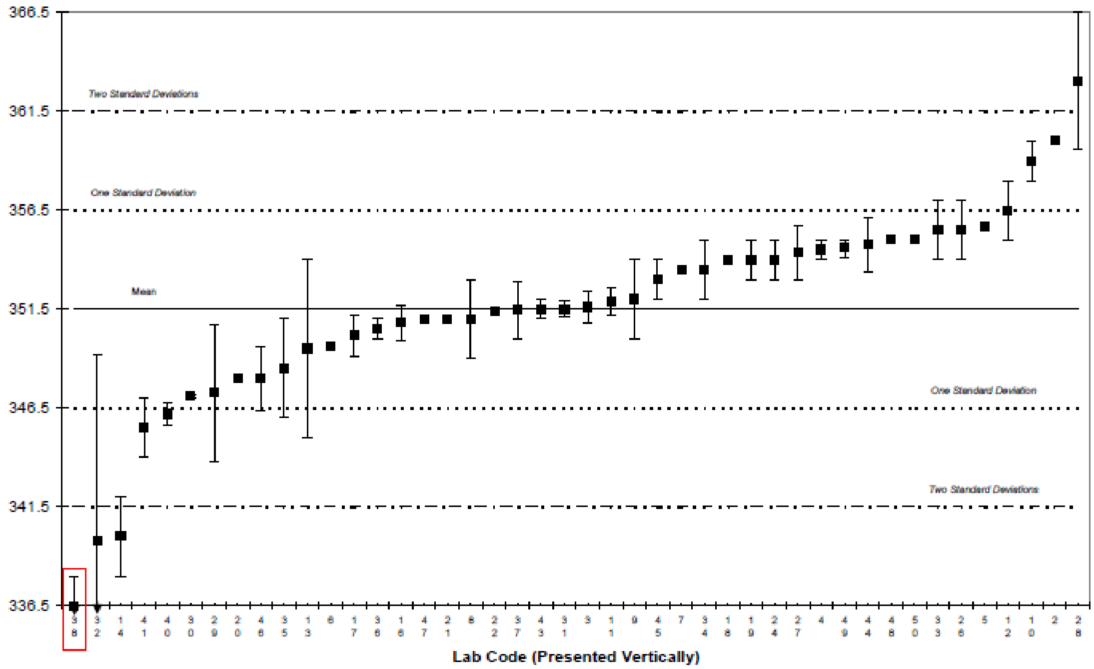

Figure 32 - ASTM PTP September 2010, Material C: values of R_m for program-supplied specimens.

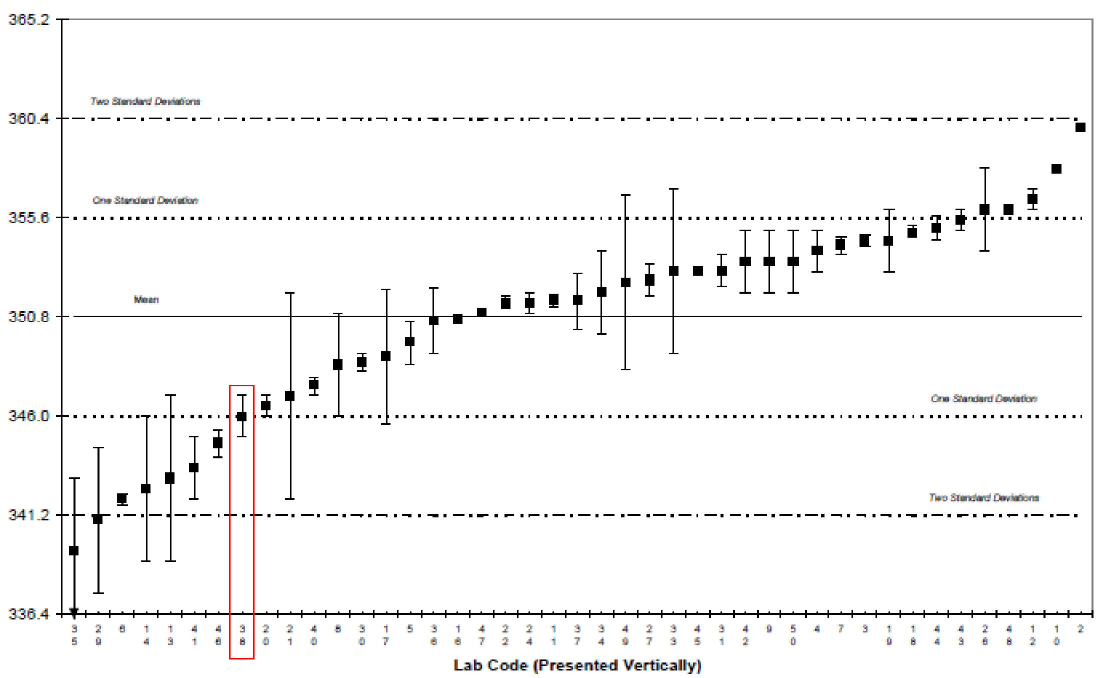

Figure 33 - ASTM PTP September 2010, Material C: values of R_m for lab-prepared specimens.

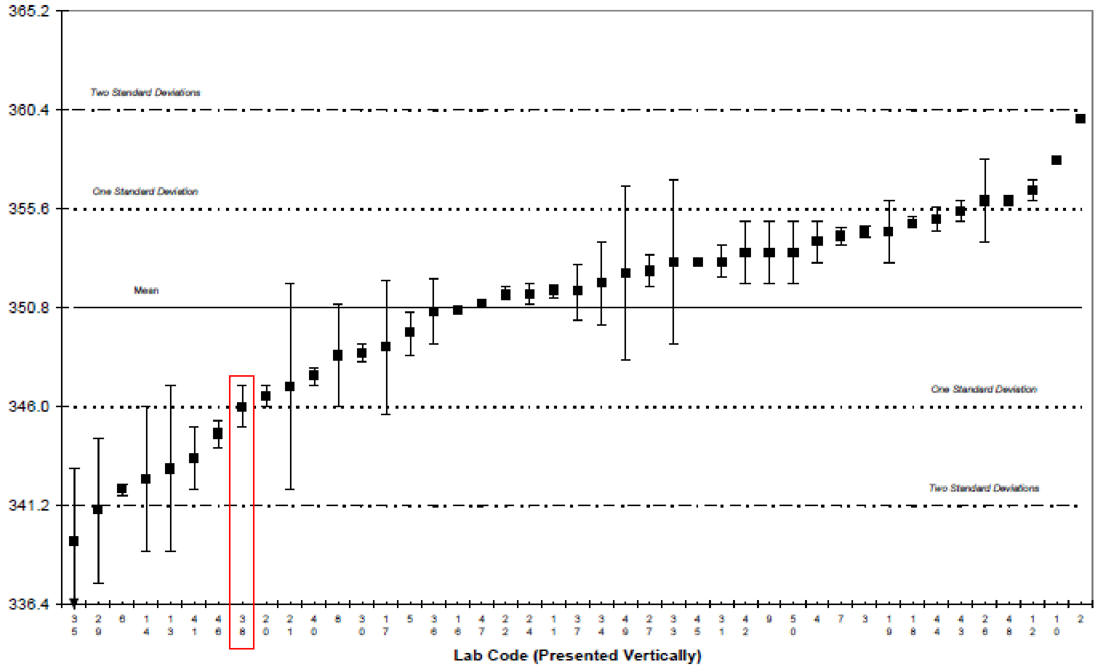

Figure 34 - ASTM PTP September 2010, Material C: values of elongation (% increase) for program-supplied specimens.

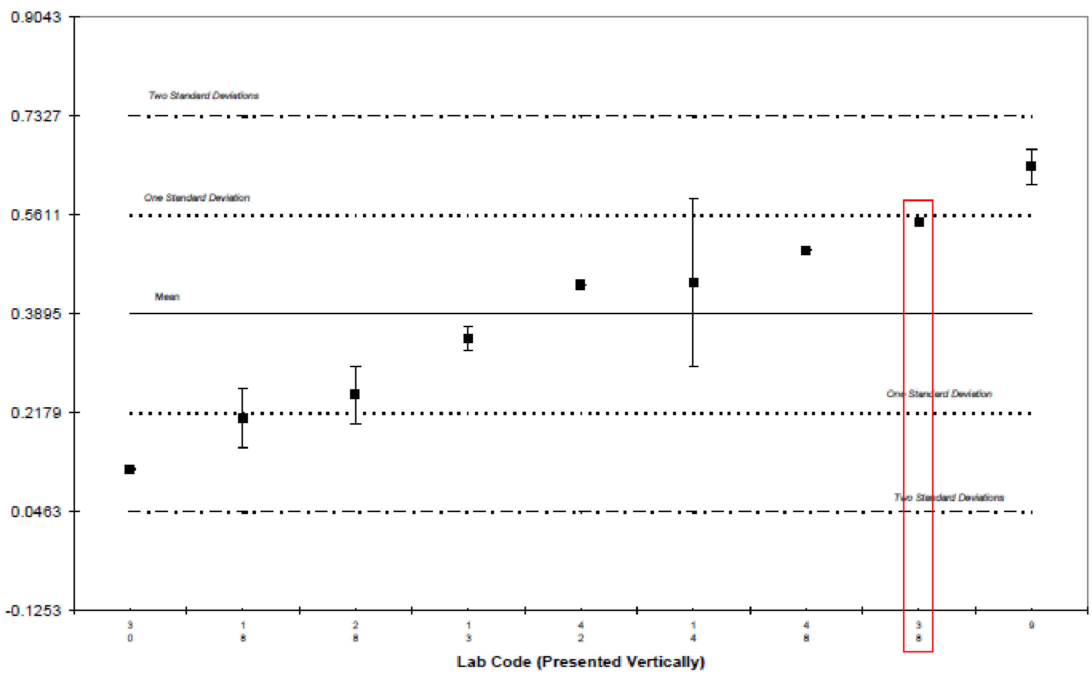

Figure 35 - ASTM PTP September 2010, Material C: values of yield-point elongation for program-supplied specimens.

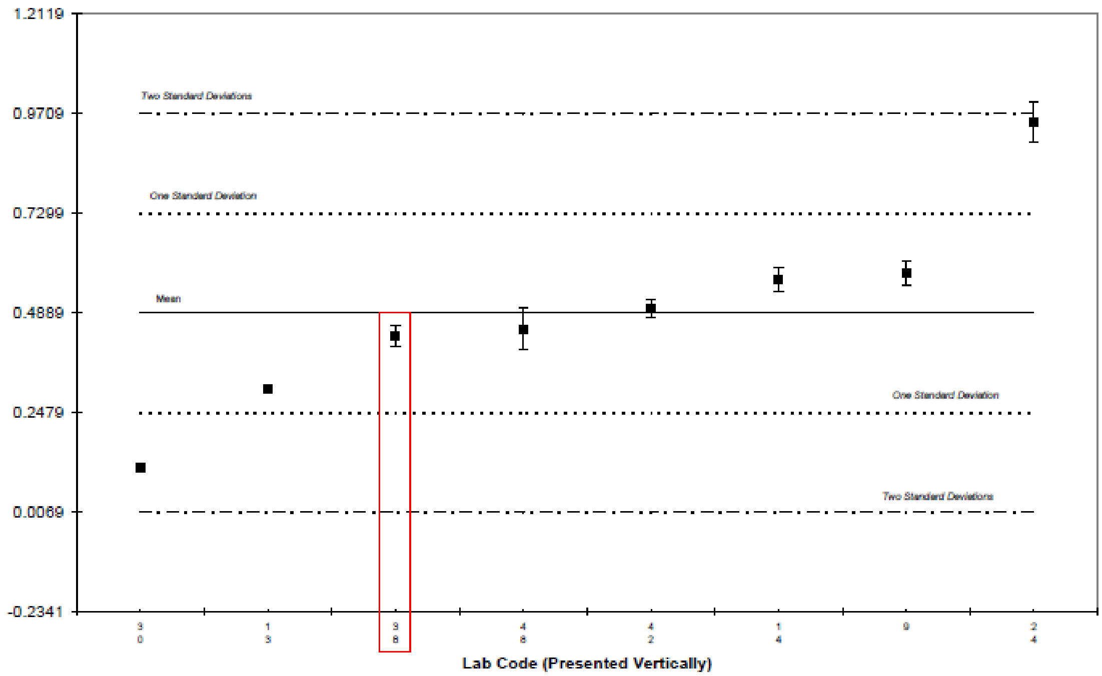

Figure 36 - ASTM PTP September 2010, Material C: values of yield-point elongation for lab-prepared specimens.

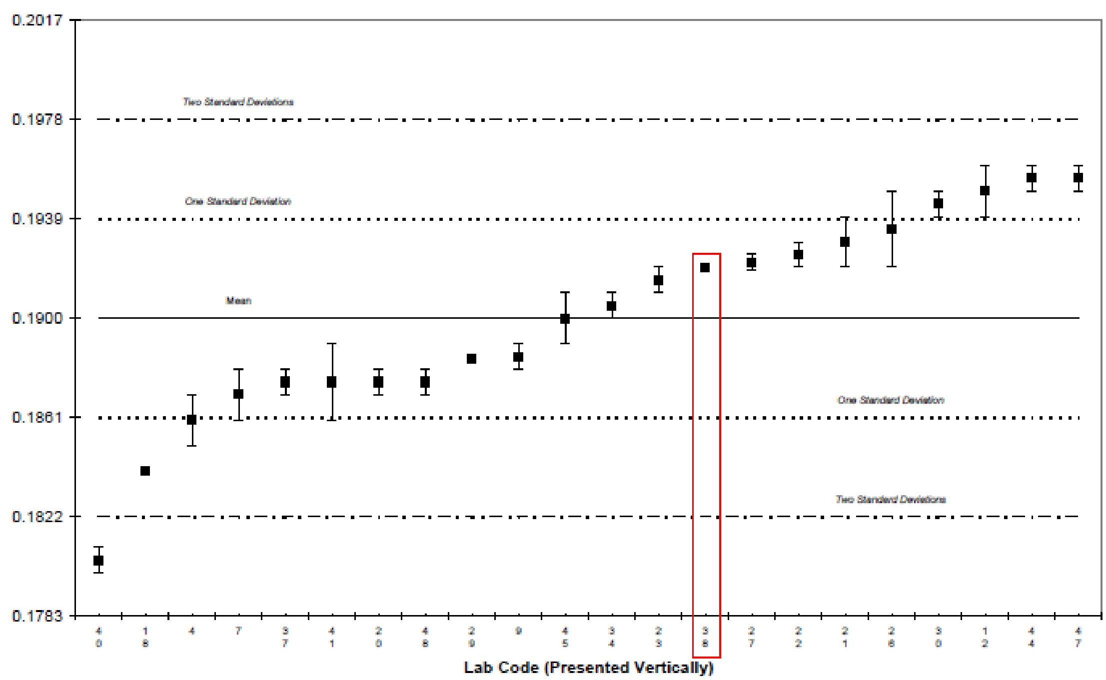

Figure 37 - ASTM PTP September 2010, Material C: values of strain-hardening exponent for program-supplied specimens.

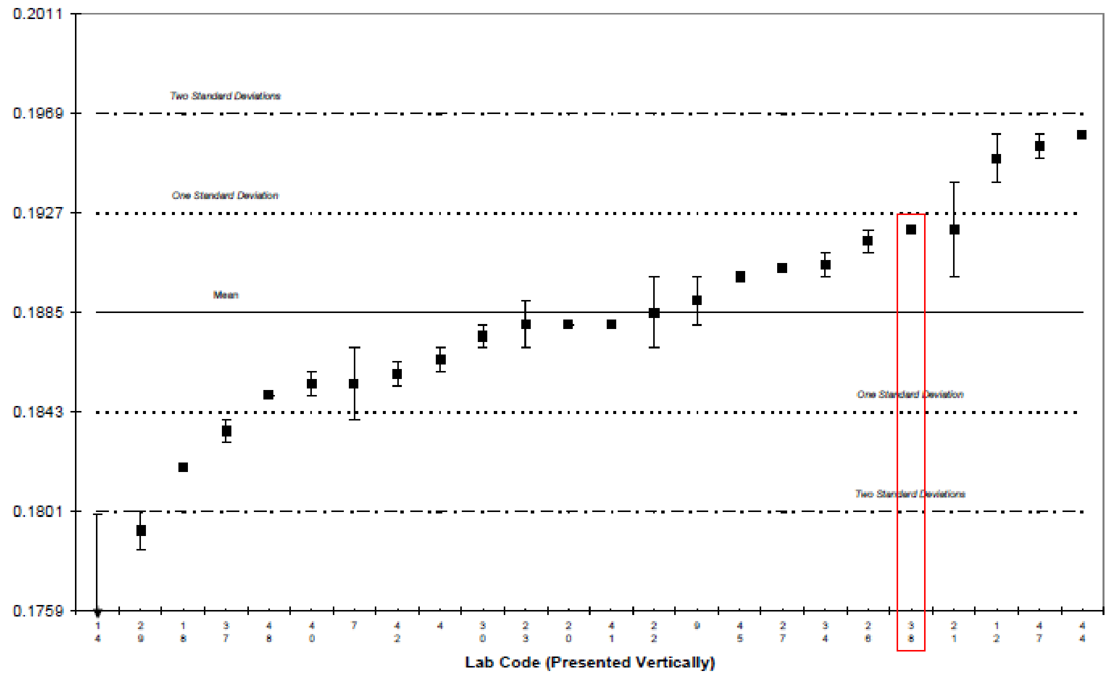

Figure 38 - ASTM PTP September 2010, Material C: values of strain-hardening exponent for lab-prepared specimens.

2.4.3 Hardness results - Materials A and C

PTP participants were required to perform hardness measurements on the two tensile specimens (one per material) machined by the labs and later returned to ASTM in untested condition. Although the Rockwell B scale was recommended for sheet steels, the use of other hardness scales was allowed, provided equivalent HRB results would be supplied using the on-line reporting form.

Rockwell B hardness measurements performed by NIST on materials A and C (five measurements per material), using a New Age INDENTRON NI300RB hardness tester, are reported in Table 7 and compared to mean values and standard deviations from the ASTM analyses in [2].

Table 7 - NIST hardness measurements on materials A and C.

	ASTM PTP		NIST measurements							
Material	$\overline{HRB}$	σ	HRB_1	HRB_2	HRB_3	HRB_4	HRB_5	$\overline{HRB}$	σ	**Z-score**
A	63.8	1.8	58.0	60.4	62.6	61.5	61.1	60.7	1.72	-1.6
C	56.7	3.1	50.1	51.0	51.3	47.3	50.6	50.1	1.61	-2.1

The Z-score of NIST data is significantly negative, indicating an underestimation of the mean hardness with respect ASTM PTP population.

Figure 39 and Figure 40 show all the hardness results of the PTP, with NIST data highlighted using a red rectangle.

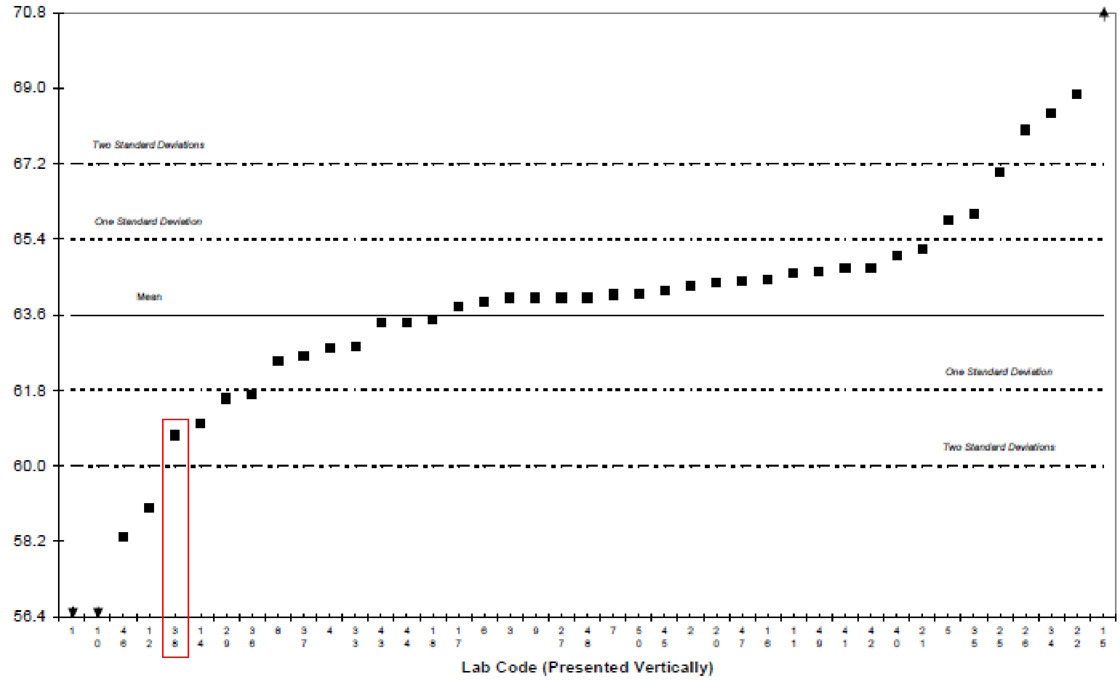

Figure 39 - ASTM PTP hardness data - material A.

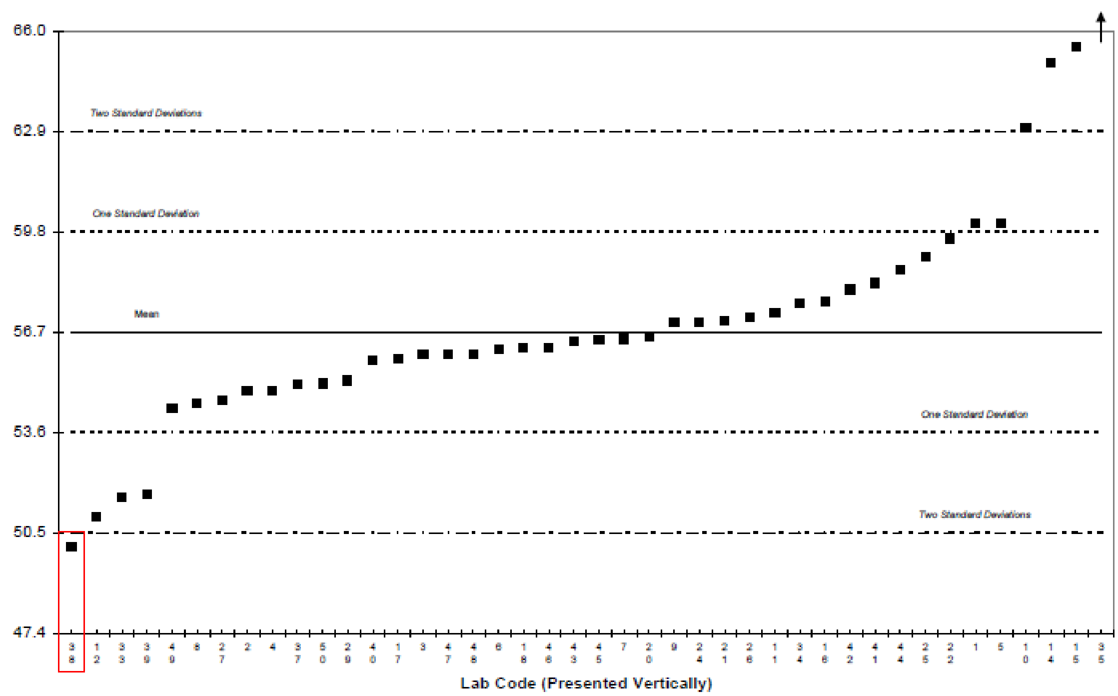

Figure 40 - ASTM PTP hardness data - material C.

Note that a second series of HRB measurements, performed on 1/13/11 on two previously tested tensile specimens of steels A and C, provided mean hardness values of 59.9 for material A and 54.4 for material C. These results, both lower than the first series of measurements, would correspond to even lower values of the Z-score.

2.5 General remarks

With reference to the tensile test results obtained by NIST for material A (Table 5), we observe that the mean values for 12 out of 17 parameters fall within $\pm 1\sigma$, 3 fall between $\pm 1\sigma$ and $\pm 2\sigma$, and 2 fall outside $\pm 3\sigma$. For material C (Table 6), 9 mean values fall within $\pm 1\sigma$, 4 fall between $\pm 1\sigma$ and $\pm 2\sigma$, 1 falls between $\pm 2\sigma$ and $\pm 3\sigma$, and 3 fall outside $\pm 3\sigma$.

As far as hardness values are concerned, NIST results fall between $\pm 1\sigma$ and $\pm 2\sigma$ for material A and once between $\pm 2\sigma$ and $\pm 3\sigma$ for material C.

For both materials and specimen types (program-supplied and lab-prepared), calculated values of plastic strain ratio r fall outside $\pm 3\sigma$, and were therefore classified by ASTM as outliers. This should not be considered surprising, since r is normally not measured from "conventional" tensile tests. According to ASTM E517-00, plastic strain ratio is measured either from a specimen stretched not beyond maximum force (*manual procedure*) or from a specimen instrumented with both axial and transversal extensometers (*automatic procedure*). Using values of final specimen width, w_f, corresponding to the limits of the gage length on a fractured specimen (as we did for our tests), inevitably yields a rough approximation of the actual plastic strain ratio.

For the materials under investigation, the parameter YPE (Yield Point Elongation) is also not clearly defined; a large scatter in the reported results is therefore to be expected.

As previously remarked, a generalized tendency for NIST was observed to provide lower tensile and hardness results (negative Z-score values) with respect to the population of laboratories that participated in the September 2010 cycle of the ASTM Proficiency Testing Program.

3. Conclusions

The results obtained from tensile tests performed on the IRMM reference material (Nimonic 75) can be considered satisfactory. All the measured parameters fall within $\pm 1\sigma$ of the certified values, with the only exception of the 0.5 % proof stress ($R_{p0.5}$), for which the NIST average (327 MPa) lies just above IRMM higher 95 % confidence limit (325 MPa).

NIST contribution to the September 2010 cycle of the ASTM Proficiency Testing Program shows a general tendency to underestimate tensile and hardness results returned by the participating laboratories. However, for most of the main tensile parameters, NIST data are within one standard deviation for both materials investigated. Our hardness results appear to be low.

References

[1] David Read and Nicholas Barbosa, "Coming Full Circle: The Application of Microtechnology Techniques to Evaluate Bulk Materials", 2010 MRS Fall Meeting, Boston MS, November 29-December 3, 2010.

[2] ASTM Committee E28 Proficiency Testing Program, Mechanical Properties of Steel, September 2010.