MATERION

TECH BRIEF

HARDNESS CONVERSIONS FOR COPPER ALLOYS

Several tests exist to measure a material's hardness with variations of the indenter shape, indenter material, force and penetration speed. Conversions are required to compare hardness values obtained in one test method with another and to further correlate with tensile strength.

HARDNESS TESTS

Hardness is a measure of a material's resistance to local plastic deformation caused by penetration from an indenter applied with a specified force and time. The impression (or effect of the impression) left by the indenter on the surface is used to determine the material's hardness. This Tech Brief provides hardness conversion data for high strength copper alloys, Alloy 25 and ToughMet® 3 alloy, to help facilitate material testing and selection.

The effect of the indenter is measured in two primary ways. Rockwell hardness tests measure the depth of the impression. Brinell and Vickers tests measure the size of the indentation. Rockwell tests are generally the most convenient methods as they do not require optical inspection of the indentation and provide a direct hardness reading moments after the test is complete. The Rockwell test has the added benefit of providing a preload to the indenter, making the test less sensitive to the surface condition of the material sample. Both Brinell and Vickers tests require a measurement of the indentation geometry. When a round indenter is used, as in a Brinell test, the indentation's diameter is used to calculate hardness. In a Vickers test, a pyramidal indenter is used and the impression's vertex distance is measured. Vickers tests should be used when assessing hardness on small, thin materials. Brinell and Vickers tests are more versatile since the indentation load can be varied, allowing the size to be easily controlled. However, manual measurement of the indentation can be laborious if many tests are required.

The proper selection of the hardness test will depend on the size and thickness of the material as well as the material's strength. If the load is too heavy or the material is too thin, an anvil effect can occur, in which a mark from the indentation is visible on the material's surface in contact with the supporting anvil. When this happens, high hardness readings are inaccurately measured because the plastically deformed region around the indentation extends through the specimen thickness to the hard support anvil. Macro-hardness scales like Rockwell and Brinell are more suited for thicker strip or bulk products as their indentation loads greater than 1000 grams. A Brinell test samples a large area, so is useful to obtain an accurate average hardness in materials with small scale hardness variations.

More information about hardness testing can be found in the Materion *Tech Brief* AT0012, "Hardness Testing of Copper Alloy Products" and the Materion *Technical Tidbits* TT0025 and TT026, "Hardness Testing" and "Hardness Testing Pitfalls."

HARDNESS SCALE CONVERSIONS

Materion has established conversions between micro Vickers (HV-500g), Vickers (HV-1kg), Brinell, Rockwell A, B, C, 30T and 30N scales. These are presented in Table 2 for copper beryllium and Table 3 for copper nickel tin. Alloy 25 (C17200) and ToughMet 3 alloy (C72900) were used for the copper beryllium and copper nickel tin hardness tests, respectively. The materials were obtained in a variety of product forms and heat treated to produce annealed (A temper), hard (H temper), underaged HT, and peak aged HT material. These heat treatments yielded a comprehensive range of strengths and hardness values. To establish the conversions shown in tables 2 and 3, 2^{nd} order polynomial curves were fitted to each data set using HV (500 g) as the basis for comparison. The experimental hardness data and regression curves for each test are displayed in Figure 1 for copper beryllium and Figure 2 for copper nickel tin.

ASTM E 140 provides hardness conversion data for non-austenitic steels, which covers the range of hardness values found in high strength copper alloys. As shown in Figures 3 and 4, these published conversions match well to the hardness conversions determined experimentally for copper beryllium and copper nickel tin alloys. The conversion tables published for cartridge brass and "soft" coppers in ASTM E 140 are for materials generally softer than copper beryllium and ToughMet 3 alloy and should not be applied to these high strength copper materials.

TENSILE STRENGTH CONVERSIONS

A full range of hardness and tensile strength conversions was created for both the TS tempers of ToughMet 3 alloy and Alloy 25. ToughMet 3 is sold from the mill in varying strength targets. This data was used to create the hardness to tensile conversions. Most of the heat-treated alloy 25 is sold at its peak properties but is also sold as cold worked or annealed leaving the customer to heat treat to their own specific requirements. The conversions for Alloy 25 were produced by aging in salt pots at temperatures between 500 and 800°F. The samples were soaked at temperature for durations between 3 and 300 minutes. After aging, tensile and Vickers hardness tests were performed on the materials to determine hardness-strength correlations.

Tables 2 and 3 have the conversions for Alloy 25 and the TS tempers of ToughMet 3 alloy respectively. For a given hardness, the actual tensile strength should not vary more than 15 ksi from the predicted value given by the hardness-UTS correlations. Hardness tests are a quick, inexpensive, and non-destructive method for gauging material strength but are not always satisfactory substitutes for tension tests. These published hardness conversions should be used for information purposes only, and any discrepancies in the material's strength should be resolved by tensile testing.

HARDNESS MEASUREMENT ERROR

There are several sources of hardness measurement error, which cause variation in tensile strength conversions. As shown in Table 1, most measurement errors involve the test machine, operator, test environment, sample prep, and calibration, although most can be avoided by following the standard operating procedures. In addition, microstructural variation can affect micro-hardness test results since this quasi-mechanical property is a measure of *local* resistance to plastic deformation. Features such as hard particles or phases can also produce misleading results if the indentations are made in their vicinity.

TABLE 1. COMMON HARDNESS TESTING MISTAKES

Pre-Test	Incorrect load/indenter combination for test scale
	Incorrect load/indenter/scale combination for sample
	Incorrect load/indenter/scale combination for hardness of test piece
	Failure to properly calibrate equipment before testing
	Inadequately fixtured test piece
	Improperly prepared metallographic mount of small sample
During Test	Failure to isolate equipment from dirt and vibration
	Inadequate spacing between indentations
	Inadequate number of measurements
	Conducting test on the wrong surface/area of part
	Conducting test through plating or other surface coating
	Failure to account for effect of rough or work hardened surface
Post-Test	Failure to properly correct measurements for surface curvature
	Incorrect use of conversion charts
	Failure to account for variability of test itself

Age hardening procedures and cold working will affect the directionality, and uniformity of properties across a material's cross section. They are closely linked to microstructure and may also affect hardness test results. The tensile data used in this paper was produced from samples pulled parallel to the work direction and the hardness data is from indentations on surfaces transverse to the work direction.

Hardness to tensile strength conversions cannot be used as a substitute for tensile tests. However, there are circumstances where hardness testing is the only possible method to evaluate whether a material meets a design requirement, so it is encouraged to exercise good engineering judgement when interpreting the results.

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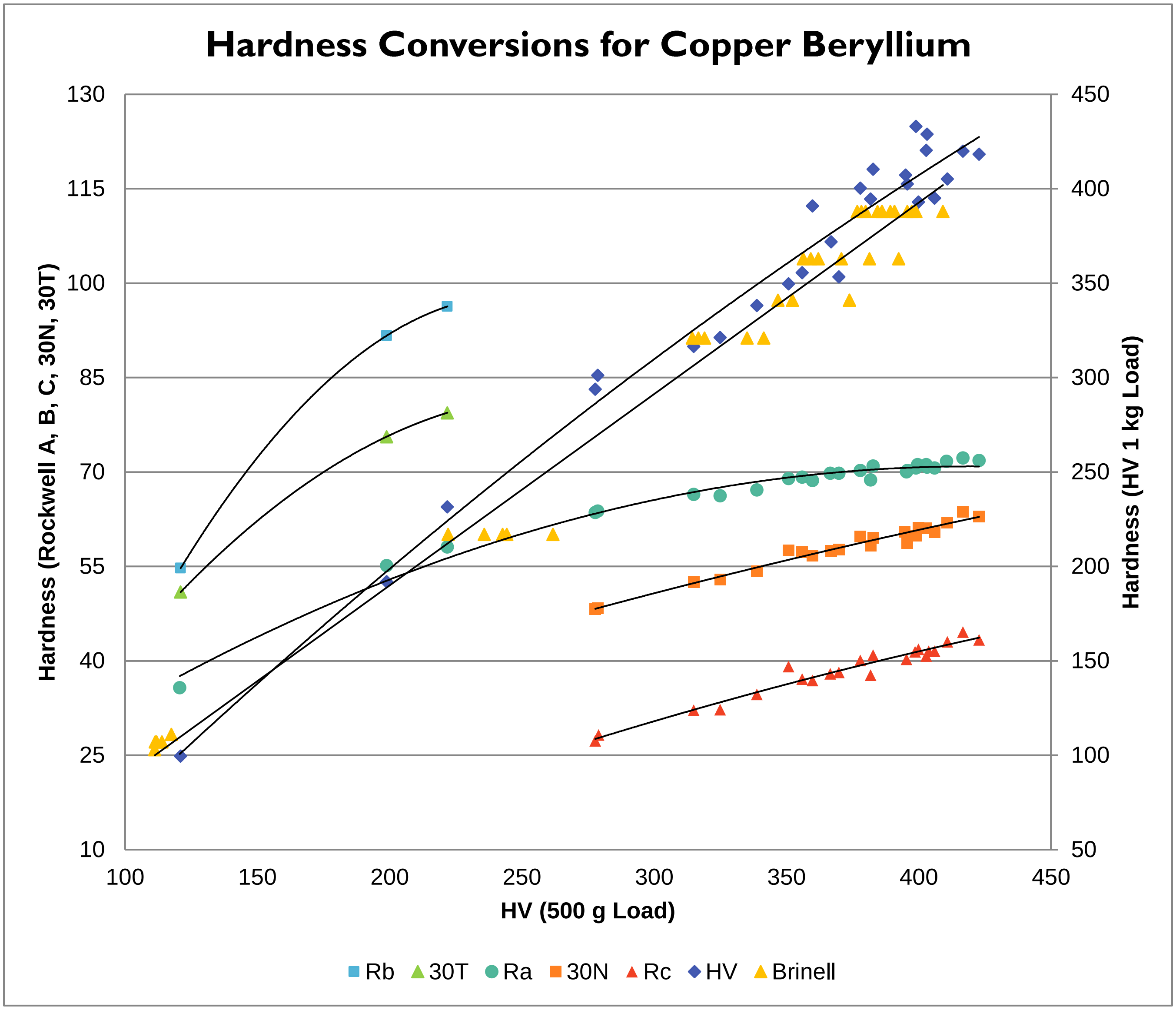
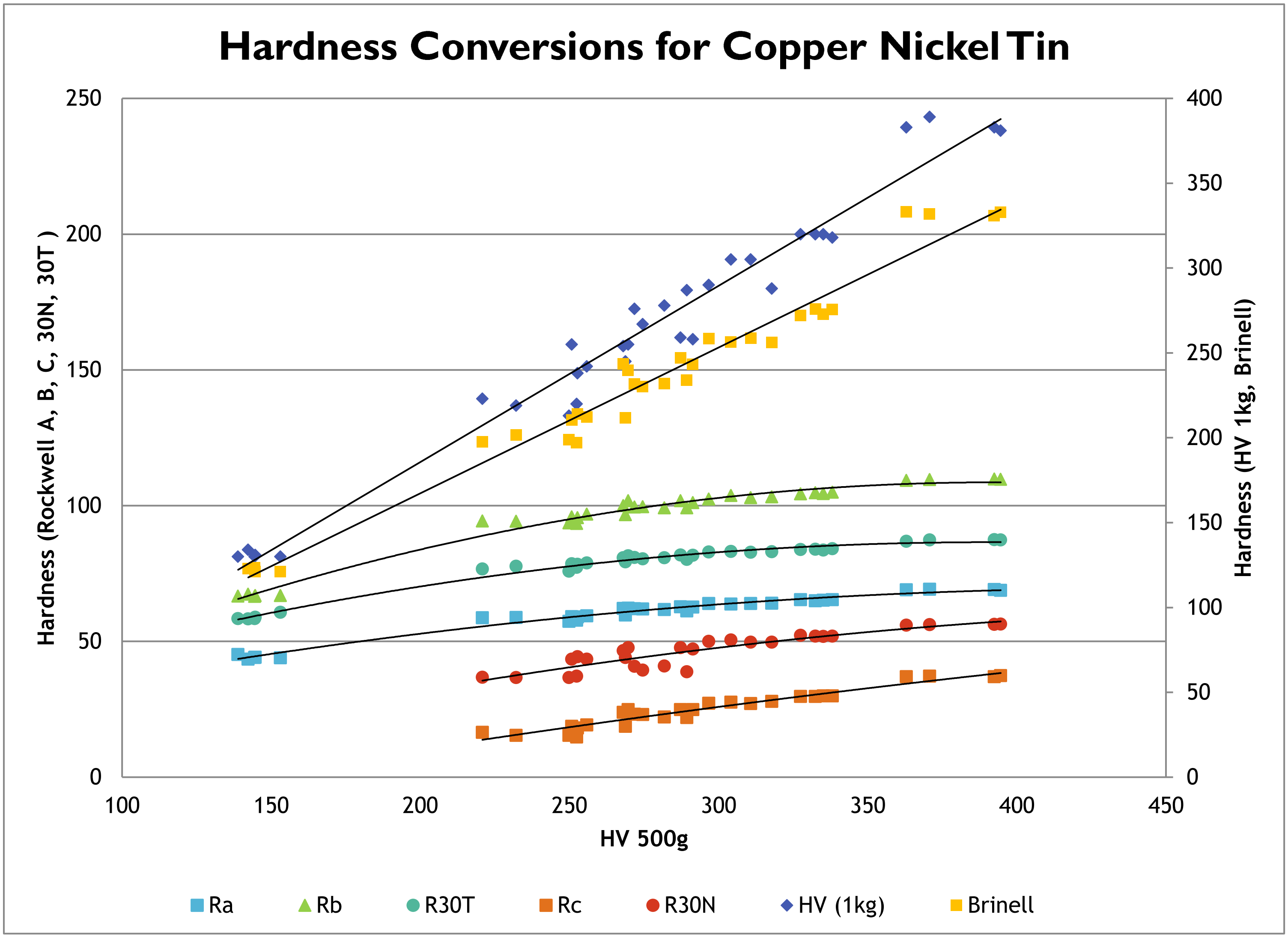
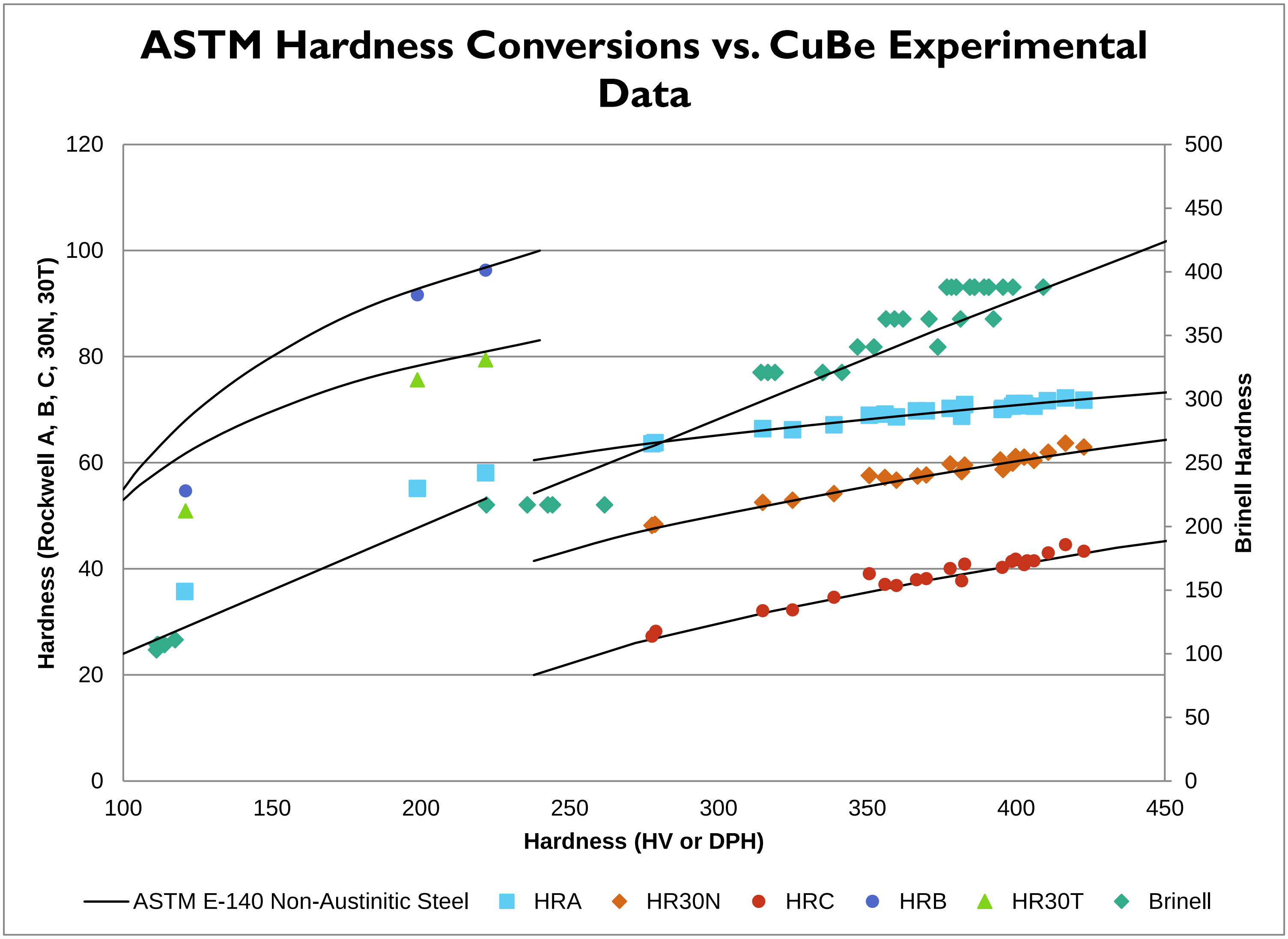


Graph 1: Copper Beryllium hardness conversion data for Vickers,Rockwell, and Brinell scales with 2nd order fitted curves.



Graph 2: Copper nickel tin hardness conversion data for Vickers, Rockwell, and Brinell scales along with 2nd order polynomial fitted curves.



Graph 3: Copper beryllium experimental hardness data compared to conversions published for non-austenitic steel in ASTM E-140.

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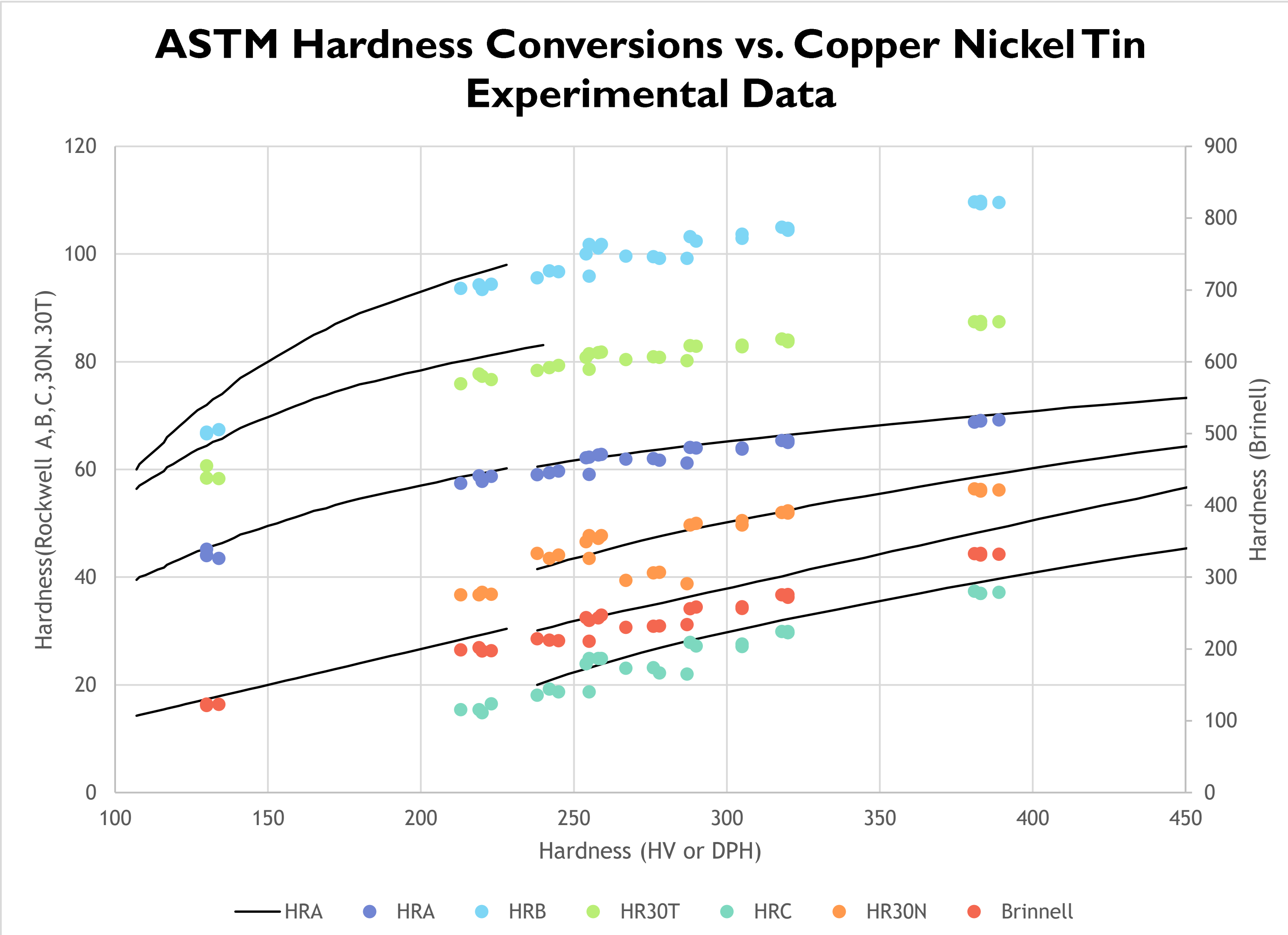

Graph 4: Copper nickel tin experimental hardness data compared to conversions published in the non-austenitic steel table in ASTM E-140.

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Table 2.—Hardness Conversions for Copper Beryllium

HV (500g)	HV (1kg)	Rockwell A	Rockwell C	Rockwell 30N	Rockwell 30T	Rockwell B	Brinell	UTS (ksi)
450	451.0*	70.5*	46.1*	65.1*	-	-	-	221
445	446.7*	70.6*	45.6*	64.7*	-	-	-	219
440	442.5*	70.7*	45.2*	64.3*	-	-	-	217
435	438.2*	70.8*	44.7*	63.9*	-	-	-	215
430	433.9*	70.8*	44.3*	63.4*	-	-	-	213
425	429.5	70.9	43.8	63.0	-	-	418.0	211
420	425.1	70.9	43.4	62.6	-	-	412.9	209
415	420.7	70.9	42.9	62.1	-	-	407.8	207
410	416.2	70.8	42.4	61.7	-	-	402.8	205
405	411.7	70.8	41.9	61.2	-	-	397.7	203
400	407.2	70.7	41.5	60.8	-	-	392.6	200
395	402.7	70.7	41.0	60.3	-	-	387.6	198
390	398.1	70.6	40.5	59.9	-	-	382.5	196
385	393.4	70.4	40.0	59.4	-	-	377.4	193
380	388.8	70.3	39.4	58.9	-	-	372.4	191
375	384.1	70.1	38.9	58.4	-	-	367.3	189
370	379.3	70.0	38.4	58.0	-	-	362.2	186
365	374.6	69.8	37.9	57.5	-	-	357.1	184
360	369.8	69.6	37.3	57.0	-	-	352.1	181
355	364.9	69.3	36.8	56.5	-	-	347.0	179
350	360.1	69.1	36.2	56.0	-	-	341.9	176
345	355.2	68.8	35.7	55.5	-	-	336.9	174
340	350.2	68.5	35.1	55.0	-	-	331.8	171
335	345.3	68.2	34.6	54.4	-	-	326.7	169
330	340.3	67.9	34.0	53.9	-	-	321.7	166
325	335.2	67.5	33.4	53.4	-	-	316.6	163
320	330.2	67.2	32.8	52.9	-	-	311.5	161
315	325.1	66.8	32.2	52.3	-	-	306.5	158
310	319.9	66.4	31.6	51.8	-	-	301.4	155
305	314.8	66.0	31.0	51.3	-	-	296.3	152
300	309.5	65.5	30.4	50.7	-	-	291.3	150
295	304.3	65.1	29.8	50.1	-	-	286.2	147
290	299.0	64.6	29.2	49.6	-	-	281.1	144

* Extrapolated

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Table 2.—Hardness Conversions for Copper Beryllium (continued)

HV (500g)	HV (1kg)	Rockwell A	Rockwell C	Rockwell 30N	Rockwell 30T	Rockwell B	Brinell	UTS (ksi)
285	293.7	64.1	28.6	49.0	-	-	276.1	141
280	288.4	63.6	27.9	48.5	-	-	271.0	138
275	283.0	63.1	27.3	47.9	-	-	265.9	135
270	277.6	62.5	26.7	47.3	-	-	260.9	132
265	272.2	62.0	26.0	46.7	-	-	255.8	129
260	266.7	61.4	25.4	46.1	-	-	250.7	126
255	261.2	60.8	24.7	45.6	-	-	245.7	123
250	255.6	60.2	24.0	45.0	-	-	240.6	120
245	250.0	59.5	23.3	44.4	-	-	235.5	117
240	244.4	58.8	22.7	43.8	-	-	230.5	114
235	238.8	58.2	-	-	80.7	97.6	225.4	111
230	233.1	57.5	-	-	80.2	97.2	220.3	108
225	227.4	56.8	-	-	79.7	96.7	215.3	104
220	221.6	56.0	-	-	79.0	96.0	210.2	101
215	215.9	55.3	-	-	78.3	95.2	205.1	98
210	210.0	54.5	-	-	77.5	94.3	200.1	94
205	204.2	53.7	-	-	76.7	93.2	195.0	91
200	198.3	52.9	-	-	75.7	92.0	189.9	88
195	192.4	52.1	-	-	74.7	90.6	184.9	84
190	186.4	51.2	-	-	73.6	89.1	179.8	81
185	180.4	50.3	-	-	72.5	87.5	174.7	-
180	174.4	49.5	-	-	71.2	85.7	169.7	-
175	168.4	48.6	-	-	69.9	83.8	164.6	-
170	162.3	47.6	-	-	68.5	81.8	159.5	-
165	156.2	46.7	-	-	67.1	79.6	154.5	-
160	150.0	45.7	-	-	65.5	77.3	149.4	-
155	143.8	44.8	-	-	63.9	74.9	144.3	-
150	137.6	43.8	-	-	62.2	72.3	139.3	-
145	131.3	42.7	-	-	60.4	69.6	134.2	-
140	125.0	41.7	-	-	58.6	66.8	129.1	-
135	118.7	40.7	-	-	56.7	63.8	124.1	-
130	112.4	39.6	-	-	54.7	60.7	119	-
125	106.0	38.5	-	-	52.6	57.5	113.9	-
120	99.5	37.4	-	-	50.4	54.1	108.9	-

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Table 3: Hardness Conversions for ToughMet 3 TS tempers

HV (500 g)	HV (1kg)	Rockwell A	Rockwell C	Rockwell 30N	Rockwell 30T	Rockwell B	Brinell	UTS (ksi)
380	373	68.4	36.6	56.2	87.1	-	322	168
375	368	68.2	36.1	55.8	86.8	-	317	166
370	362	68.0	35.6	55.3	86.5	-	313	164
365	357	67.8	35.0	54.9	86.2	-	309	163
360	352	67.5	34.5	54.4	86.0	-	304	161
355	347	67.3	34.0	53.9	85.7	-	300	159
350	342	67.0	33.4	53.4	85.4	-	296	157
345	336	66.7	32.9	52.9	85.1	-	292	155
340	331	66.4	32.3	52.4	84.8	-	287	154
335	326	66.1	31.7	51.9	84.5	-	283	152
330	321	65.8	31.1	51.3	84.2	-	279	150
325	316	65.5	30.5	50.7	83.8	-	275	148
320	310	65.1	29.9	50.2	83.5	-	270	146
315	305	64.8	29.3	49.6	83.2	-	266	144
310	300	64.4	28.7	48.9	82.8	-	262	142
305	295	64.0	28.1	48.3	82.5	-	258	140
300	290	63.6	27.5	47.7	82.2	-	253	138
295	284	63.2	26.8	47.0	81.8	-	249	135
290	279	62.8	26.2	46.3	81.5	-	245	133
285	274	62.4	25.5	45.7	81.1	-	240	131
280	269	61.9	24.8	45.0	80.7	-	236	129
275	263	61.4	24.2	44.2	80.4	-	232	127
270	258	61.0	-	43.5	80.0	98.6	228	115
265	253	60.5	-	42.8	79.6	97.7	223	113
260	248	60.0	-	42.0	79.2	96.9	219	112
255	243	59.5	-	41.2	78.8	96.0	215	110
250	237	58.9	-	40.5	78.4	95.0	211	108
245	232	58.4	-	39.7	78.0	94.1	206	106
240	227	57.8	-	38.8	77.6	93.1	202	104
235	222	57.3	-	38.0	77.2	92.0	198	102
230	217	56.7	-	37.2	76.8	91.0	193	100

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