Effect of CVN Striker Radius on Absorbed Energy and Lateral Expansion for Various Stainless Steels

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Abstract

A number of wrought and cast stainless steel alloys were used to evaluate the effect of Charpy V-notch striker radius (2 mm vs 8 mm). Standard 10 mm by 10 mm (and 5 mm by 10 mm for N06022) specimens were machined from 5 grades of wrought material (304, 309, 316, N08367 (more commonly known as AL-6XN® alloy), and N06022 (more commonly known as Alloy 22)) and one grade of cast material (CN-3MN, but in two heat treatments). Statistical analysis showed a small, but in some cases significant (p value of less than 0.05), difference in the data obtained from the two strikers.

Keywords

Charpy impact testing; impact testing; striker radius

Introduction

Different parts of the world prefer to use either 8 mm or 2 mm radius strikers on their Charpy impact machines. When international contracts span such boundaries, it is reasonable to question which striker radius will be used in the machine generating the data, or whether this distinction is even important. A small trial (with representative, donated stainless steel) was run by NIST to evaluate the effect of the striker radius.

Material

Material was received in two forms. The wrought material was in the form of plate 20 mm to 30 mm thick, and the cast material was in the form of keel blocks, about 25 mm square in cross section. Five grades of wrought material were received (304, 309, 316, N08367 (more commonly known as AL-6XN alloy), and N06022 (more commonly known as Alloy 22) and one grade of cast material was received (CN-3MN, a cast version of AL-6XN alloy). The cast material was heat treated two ways, properly (standard) and improperly.

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Specimens

Standard impact specimens (according to ASTM E 23) were machined from all materials. Full size (10 mm by 10 mm cross section) specimens were machined from all grades, except for Alloy 22 where half size (5 mm by 10 mm cross section) specimens were produced. Since Alloy 22 is known to be very tough, the small size was selected to stay within the E 23 criterion of not using more than 80 % of the capacity of the impact machine that we had selected for this test.

Test Procedure

We selected one of the reference-grade machines at NIST for these tests. The machine had a maximum capacity of 358 J. As the impact energy is a function of temperature, we selected test temperatures that were estimated to keep the energies below 80 % of the machine capacity, 76 K (-197° C, liquid nitrogen) for the 304, 309, 316, N08367, and Alloy 22, and 233 K (- 40° C) for the CN-3MN materials.

Results and Discussion

1. Absorbed Energy Data

Figure 1 shows a scatter plot of the absorbed energy data from the wrought material with the 8 mm striker data on the vertical scale and the 2 mm striker data on the horizontal scale. A reference line with a correlation of one has been added to emphasize the deviations from identical performance. Generally, the data fit previous trends with the two strikers producing similar data at low energies, and a bias toward higher values for the 8 mm striker at higher energies [Ref. 1-3]. The presence of the 309 data on the other side of the line appears to be an exception, but this is discussed in the next paragraph. Table 1 lists the means and standard deviations of each set of five wrought specimens, and Table A1 lists the raw data.

Figure 2 shows the same data but as mean absorbed energy (the average of the 8 mm and 2 mm data) on the horizontal scale and differences between the means of the 2 mm and 8 mm data from the two strikers on the vertical scale. This representation emphasizes the differences between the two strikers, and includes error bars (three standard deviations of the mean difference) to help estimate the significance of the difference. The 304 and 316 data are at very reasonable locations based on studies of other alloys. The 309 data are centered on the other side of the one-to-one line from the other alloys, but the error bars show that this is not significant. The N08367 data are about where they might be expected, but some of the energies were higher than estimated, and so exceeded 80 % of the machine capacity (and so may have a bias). Perhaps this alloy should be reevaluated using a half-size specimen. The Alloy 22 data are about at the expected energy for half-size specimens. Based on t statistics for unpaired data, the Alloy 22, 304, and 316 data are significantly (statistically) different at the 0.05 level (p values of 0.0006, 0.0131, and 0.0280 respectively), showing an effect of striker radius.

Figure 3 shows a scatter plot of the data from the cast material (CN-3MN) with the 8 mm data on the vertical scale and the 2 mm data on the horizontal scale. A reference line with a correlation of one has been added to emphasize the deviations from identical performance. Compared to the data for the wrought alloys, the results show fairly similar data at low energies, and a greater bias toward higher values for the 8 mm striker at higher energies. Table 2 lists the quantitative values of the means and standard deviations for the two sets of data, and Table A2 lists the raw data.

Figure 4 shows the same data for the cast material but as mean absorbed energy (the average of the 8 mm and 2 mm data) on the horizontal scale and differences between the means of the data from the two strikers on the vertical scale. This representation emphasizes the differences between the two strikers, and includes error bars (three standard deviations of the mean difference) to help estimate the significance of the difference. The differences between the 8 mm and 2 mm strikers in the standard and improper heat treatment data are fairly small and follow the trends seen in studies of other alloys. [Ref. 1-3]. Based on t statistics for unpaired data, only the standard heat treatment data are significantly different ($p = 0.0100$).

2. Lateral Expansion Data

Figure 5 shows a scatter plot of the lateral expansion data from the wrought material with the 8 mm data on the vertical scale and the 2 mm data on the horizontal scale. A reference line with a correlation of one has been added to emphasize the deviations from identical performance. Generally, the data fit previous trends with the two strikers producing similar data, with a slight trend toward higher values for the 2 mm striker at higher energies [Ref. 3-4]. Table 3 lists the means and standard deviations of each set of five specimens, and Table A1 lists the raw data.

Figure 6 shows the same data but as mean lateral expansion (the average of the 8 mm and 2 mm data) on the horizontal scale and differences between the means of the 2 mm and 8 mm data from the two strikers on the vertical scale. This representation emphasizes the differences between the two strikers, and includes error bars (three standard deviations of the mean difference) to help estimate the significance of the difference. The 304, 309, and 316 data are at very reasonable values based on studies of other alloys. The N08367 data are about where they might be expected, but some of the energies were higher than expected, and so exceeded 80 % of the machine capacity (and so may have a bias). Perhaps this alloy should be reevaluated using half-size specimens. The Alloy 22 data are about at the expected location for half-size specimens. Based on t statistics for unpaired data, the Alloy 22 and 316 data are significantly different (p values of 0.0009 and 0.0053, respectively).

Figure 7 shows a scatter plot of the data from the cast material (CN-3MN) with the 8 mm data on the vertical scale and the 2 mm data on the horizontal scale. A reference line with a correlation of one has been added to emphasize the deviations from identical performance. Generally, the data fit previous trends with the two strikers producing fairly similar data. Table 4 lists the quantitative values of the means and standard deviations, and Table A2 lists the raw data.

Figure 8 shows the same data for the cast material but as mean lateral expansion (the average of the 8 mm and 2 mm data) on the horizontal scale and differences between the means of the data from the two strikers on the vertical scale. This representation emphasizes the differences between the two strikers, and includes error bars (three standard deviations of the mean difference) to help estimate the significance of the difference. The striker radius is not a significant factor affecting lateral expansion for either heat treatment.

3. Comparison of Absorbed Energy (AE) to Lateral Expansion (LE) Data

The AE and LE data described in parts 1 and 2 are compared in this section. Figure 9 compares the AE data to the LE data for four of the wrought stainless steels (304, 309, 316, and N08367). Alloy 22 was excluded from the comparison because its 5-mm width changes its lateral expansion response from that of the others. We chose to fit to an exponential line, as the r^2 value (0.76) was slightly better than the linear line (0.68). However, the scatter is so large that either one is acceptable.

Notice that the scatter becomes larger for larger values of AE and LE, making it more difficult to compare criteria based on the two measurements. There was no difference between the two strikers.

Figure 10 compares the AE data to the LE data for the two treatments of the cast steel. Again, an exponential curve fits the data best ($r^2 = 0.96$). Combining the data for the wrought and cast specimens reduces the quality of the fit.

References

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Table 1 - Average (Mean) absorbed energy and standard deviation for five specimens of each alloy with each striker.

	Mean Energy (J)		Standard Dev (J)	
Alloy	8 mm Striker	2 mm Striker	8 mm Striker	2 mm Striker
6	305	284	43	39
22	97	89	1.8	2.7
304	197	179	5.3	11
309	165	179	30	28
316	281	243	30	10

Table 2 - Average (Mean) absorbed energy and standard deviation for five specimens of each cast alloy heat treatment condition with each striker.

	Mean Energy (J)		Standard Dev (J)	
Heat Treatment	8 mm Striker	2 mm Striker	8 mm Striker	2 mm Striker
Standard	232	192	23	14
Improper	42	28	29	15

Table 3 - Average (Mean) lateral expansion and standard deviation for five specimens of each alloy with each striker.

	Mean (mm)		Standard Dev (mm)	
Alloy	8 mm Striker	2 mm Striker	8 mm Striker	2 mm Striker
6	2.2	2.3	0.17	0.15
22	1.55	1.71	0.03	0.06
304	1.85	1.9	0.03	0.08
309	1.6	1.8	0.26	0.27
316	2.33	2.43	0.01	0.04

Table 4 - Average (Mean) lateral expansion and standard deviation for five specimens of each cast alloy heat treatment condition with each striker.

	Mean (mm)		Standard Dev (mm)	
Heat Treatment	8 mm Striker	2 mm Striker	8 mm Striker	2 mm Striker
Standard	2.2	2.1	0.10	0.19
Improper	0.84	0.60	0.54	0.31

Table A1 - Absorbed energy and lateral expansion - Raw Data - five specimens of each alloy with each striker.

Alloy	8 mm Striker		2 mm Striker	
	AE(J)	LE(mm)	AE(J)	LE(mm)
6	345	2.3	236	2.3
6	358	2.5	299	2.2
6	274	2.2	289	2.4
6	278	2.2	338	2.3
6	268	2.1	260	2.0
22	98	1.5	87	1.8
22	95	1.6	92	1.7
22	95	1.6	89	1.8
22	98	1.5	90	1.7
22	97	1.6	85	1.8
304	194	1.9	191	2.0
304	197	1.9	162	1.8
304	190	1.8	186	2.0
304	200	1.8	176	1.9
304	204	1.8	180	1.9
309	181	1.7	180	1.8
309	166	1.5	215	2.2
309	206	1.9	196	2.0
309	131	1.3	147	1.5
309	142	1.4	158	1.6
316	261	2.3	251	2.4
316	280	2.3	250	2.5
316	333	2.3	226	2.4
316	266	2.3	242	2.4
316	264	2.3	246	2.5

Table A2 - Absorbed energy and lateral expansion - Raw Data - five specimens of each cast alloy heat treatment condition with each striker

Heat Treatment	8 mm Striker		2 mm Striker	
	AE(J)	LE(mm)	AE(J)	LE(mm)
Standard	214	2.2	199	2.3
Standard	232	2.2	183	2.3
Standard	224	2.1	204	2.0
Standard	271	2.3	201	1.9
Standard	218	2.0	172	2.3
Improper	43	1.0	23	0.7
Improper	35	0.8	17	0.4
Improper	29	0.5	31	0.5
Improper	90	1.6	52	1.1
Improper	12	0.2	18	0.3

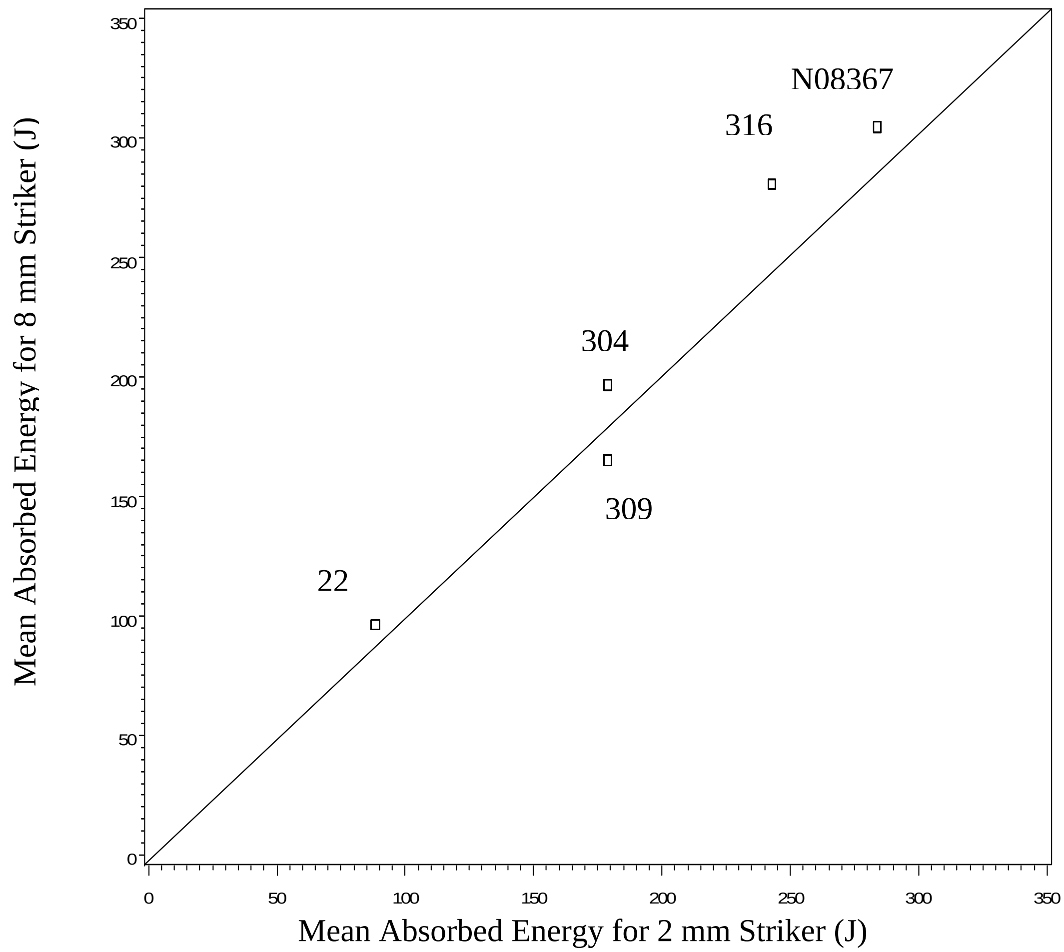

Figure 1. Absorbed energy means when tested by the two striker designs. Each point represents the sample mean for a single alloy when tested by the 8 and 2 mm strikers.

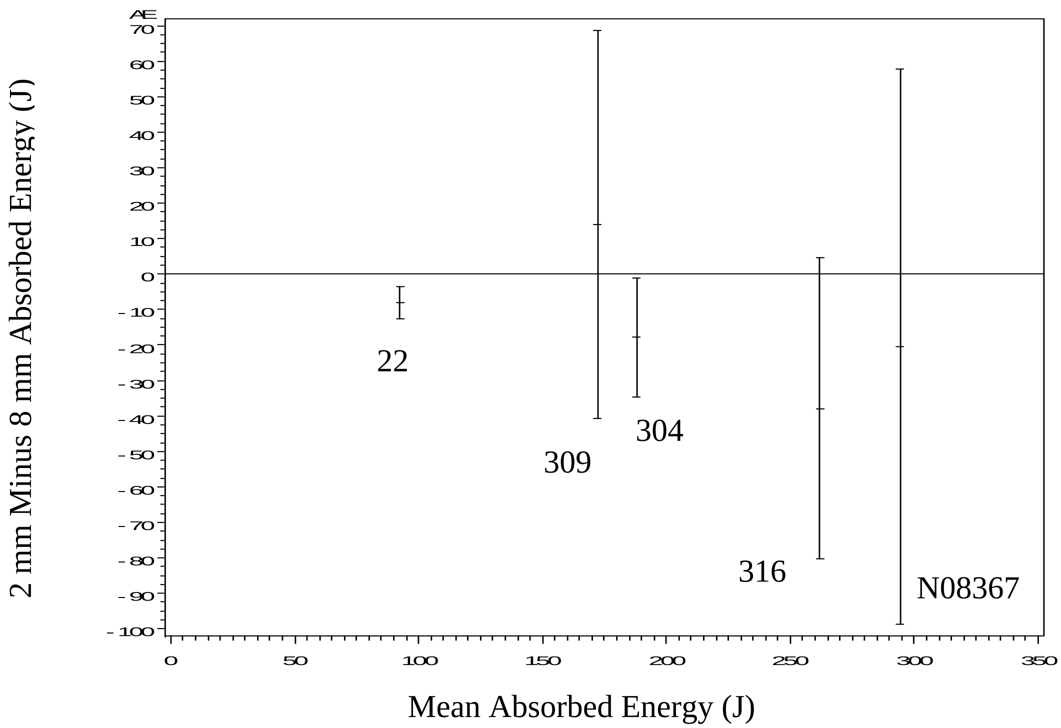

Figure 2. Graphical representation of the differences in the means for the data in Table 1.

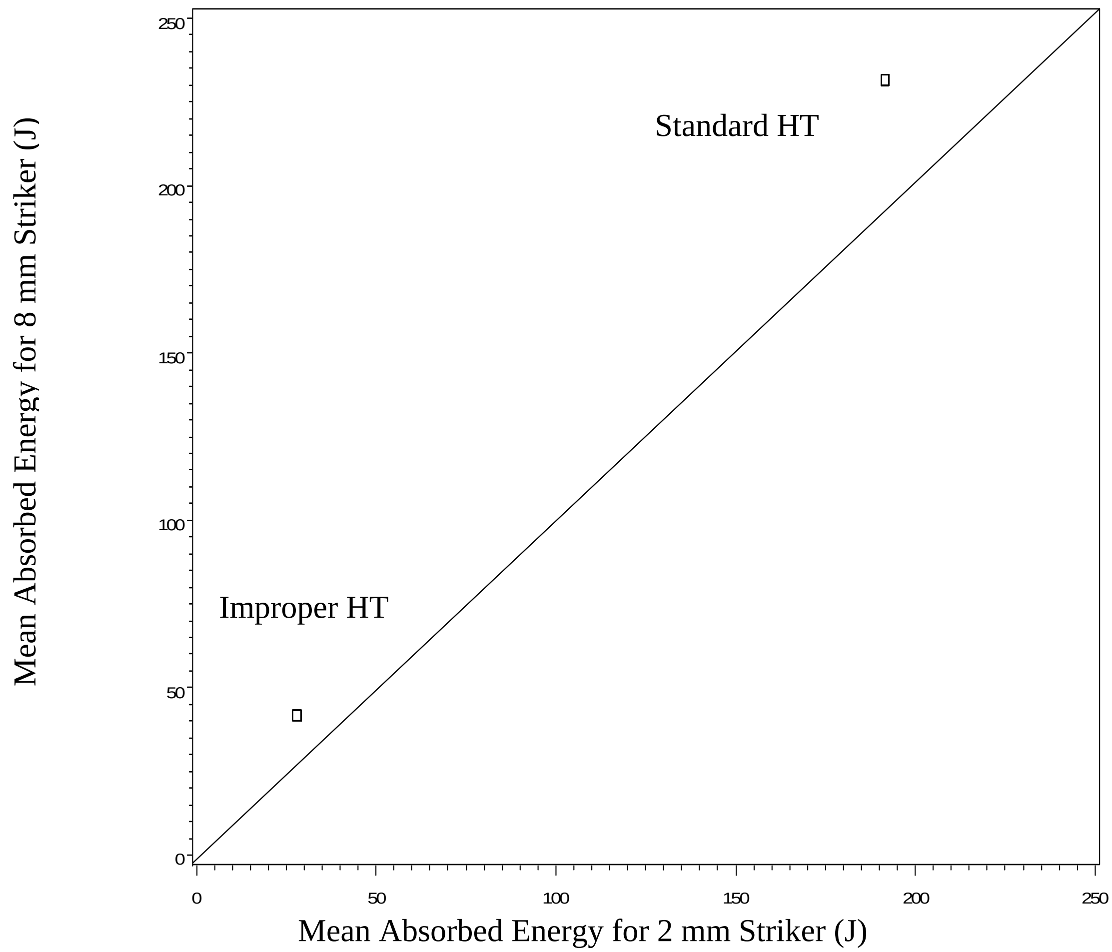

Figure 3. Absorbed energy means for cast alloys when tested by the two striker designs. Each point represents data from a single heat treatment condition when tested by each striker.

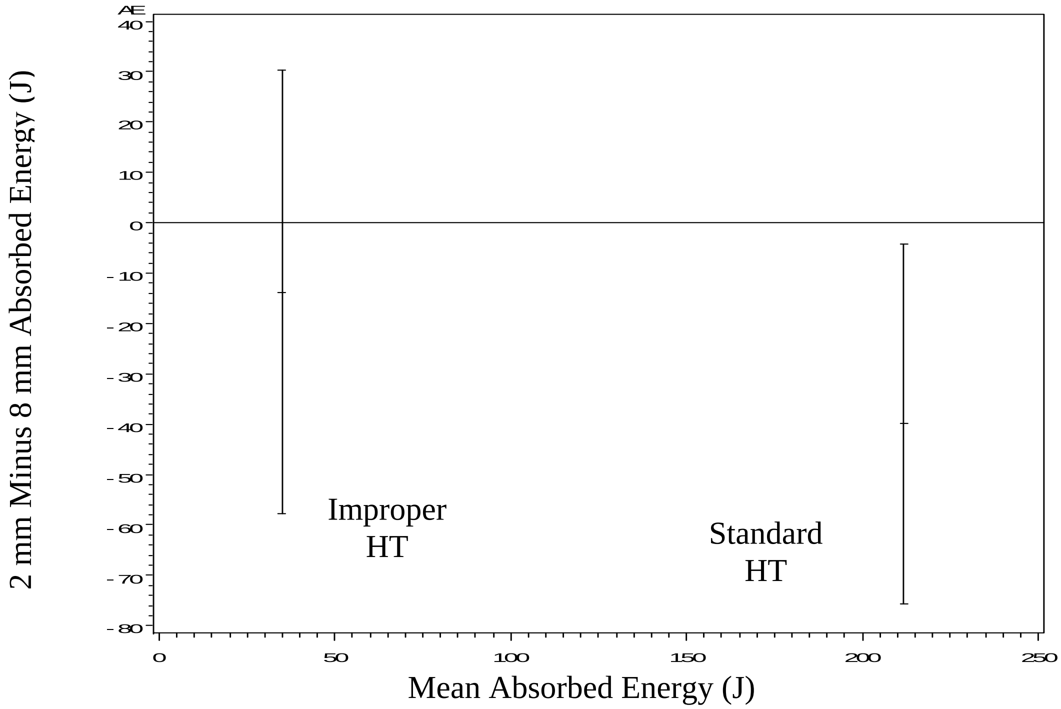

Figure 4. Graphical representation of the differences in the means for the data in Table 2.

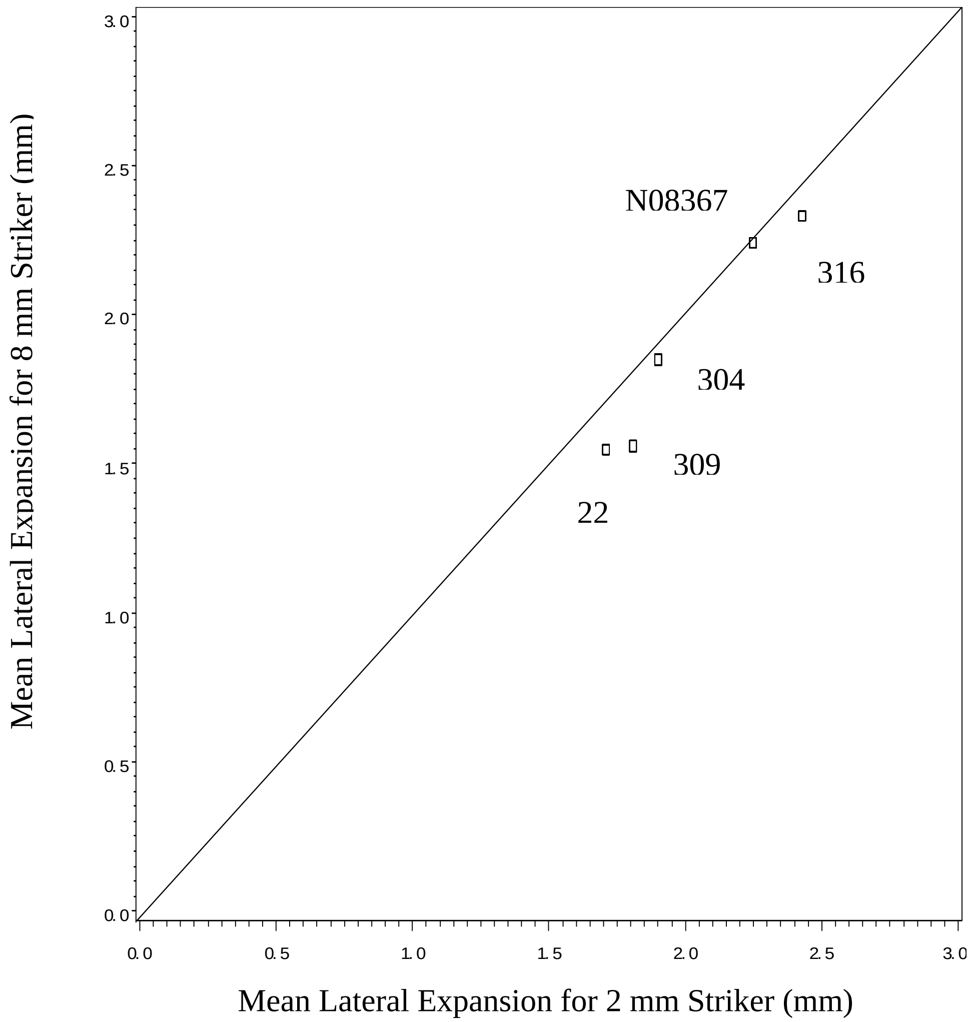

Figure 5. Lateral expansion means when tested by the two striker designs. Each point represents data from a single alloy when tested by the strikers.

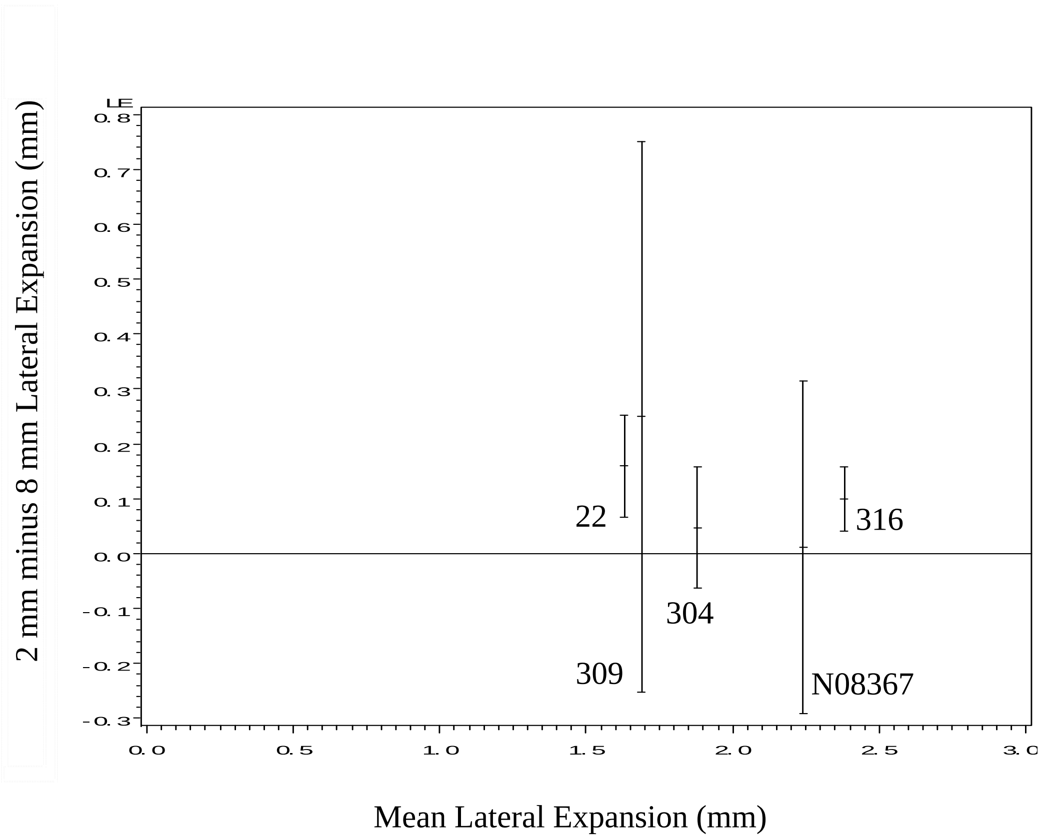

Figure 6. Graphical representation of the differences in the means for the data in Table 3.

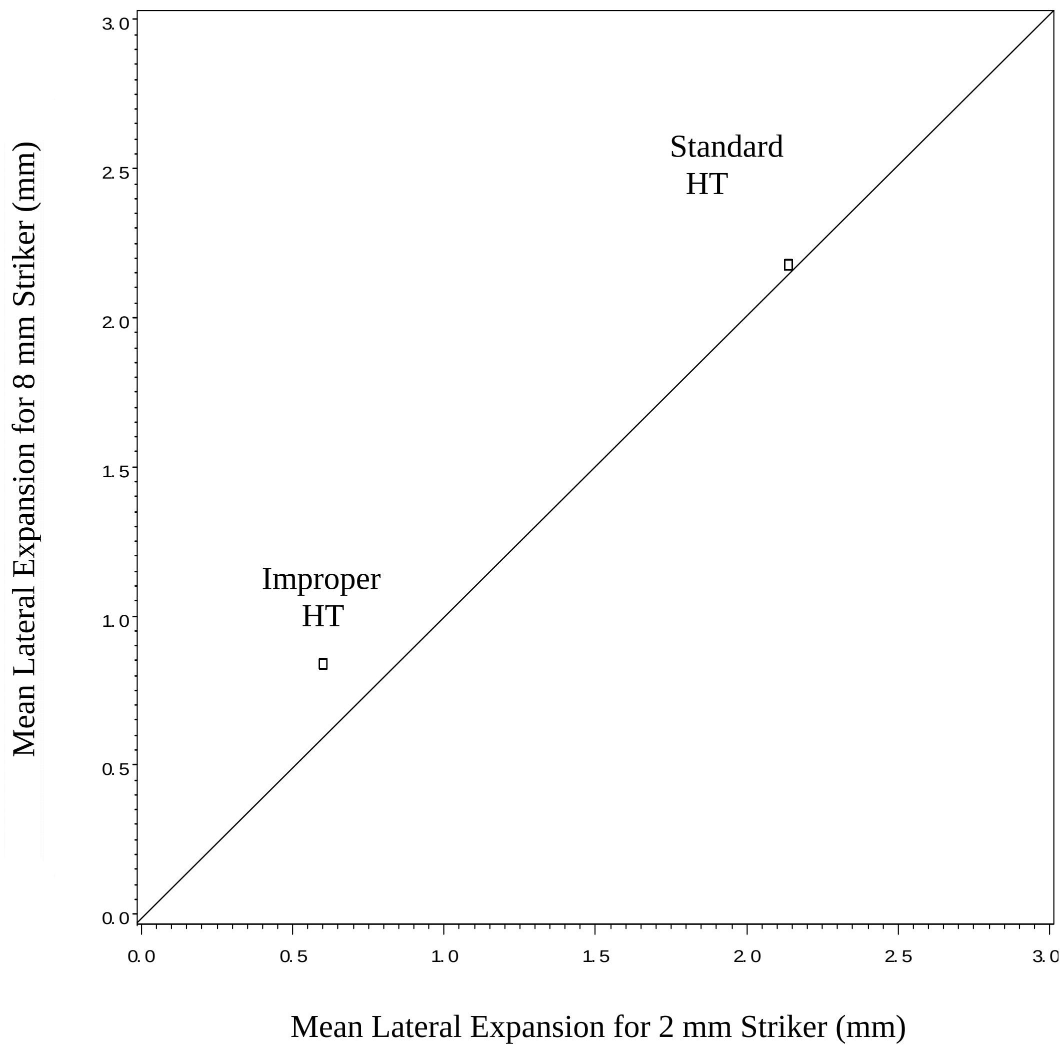

Figure 7. Lateral expansion means for cast alloys when tested by the two striker designs. Each point represents data from a single heat treatment condition when tested by each striker.

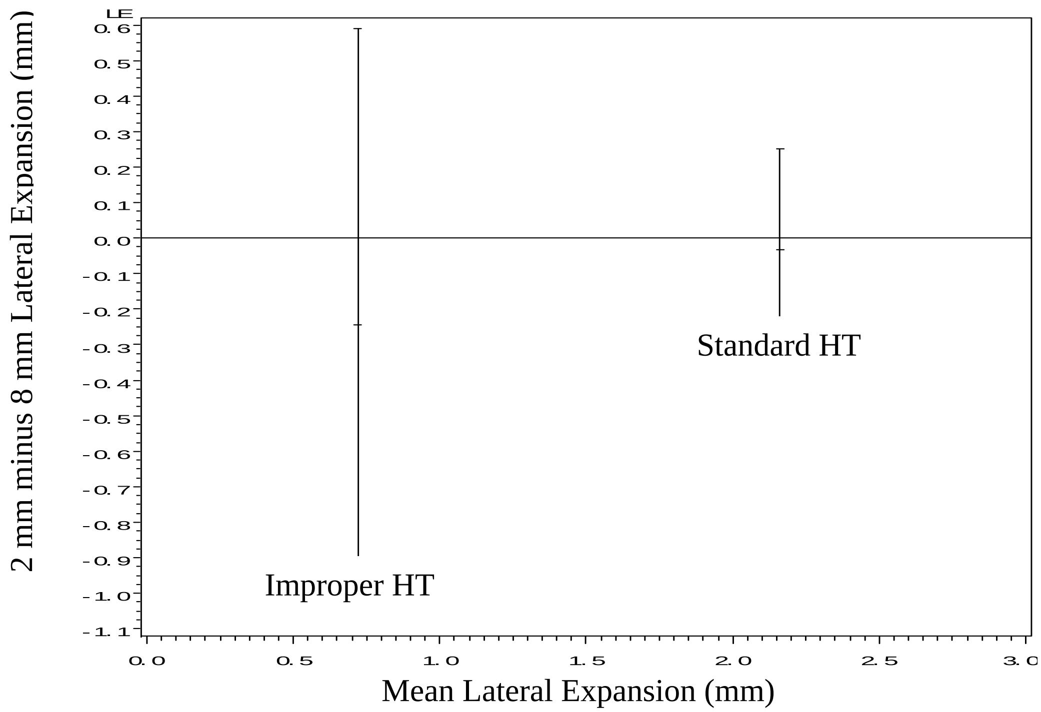

Figure 8. Graphical representation of the differences in the means for the data in Table 4.

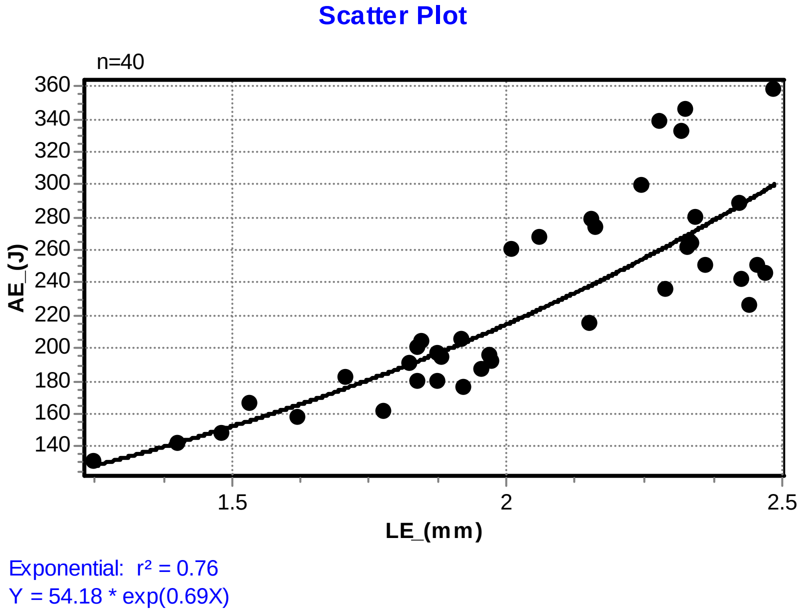

Figure 9. AE versus LE data for four wrought stainless steels (304, 309, 316, and N08367.

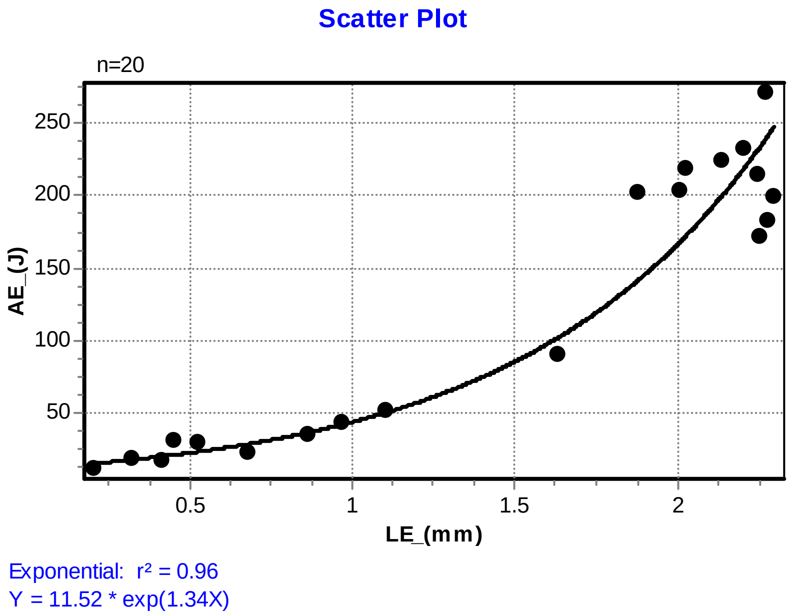

Figure 10. AE versus LE data for the two treatments of cast steel.