

3.2 YIELD STRENGTH (F_Y)

3.2.1 ORGANIZED DATA FROM THE 4-MILL GROUP

Tables 3.7 to 3.10 present the organized data on yield strength for all the slabs from mills 1, 3, 4, and 5 respectively. In each table, the yield strength at seven locations on each plate sampled is presented for each steel grade and each thickness group. The mean, low, and high values observed for each sampled plate are also shown in the last three columns of each table.

Table 3.7: Raw Data on Yield Strength from Mill 1.

Grade	Thickness Group	Yield Strength (ksi) from Mill 1									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	58.3	57.0	60.1	60.0	61.2	58.2	59.9	59.2	57.0	61.2
		62.8	60.5	63.5	61.5	61.5	59.9	60.0	61.4	59.9	63.5
		54.1	55.3	54.2	54.1	54.0	53.9	54.6	54.3	53.9	55.3
		65.4	60.5	62.9	62.8	61.4	57.5	61.4	61.7	57.5	65.4
		61.8	63.0	61.4	61.1	61.6	64.6	63.1	62.4	61.1	64.6
	62.9	67.9	62.6	62.6	63.3	63.6	64.8	64.0	62.6	67.9	
	T2	57.6	58.4	56.9	57.1	56.1	61.7	57.8	57.9	56.1	61.7
		70.4	56.9	60.2	61.5	61.9	60.4	60.7	61.7	56.9	70.4
	T3	54.4	52.5	55.9	53.0	53.2	56.5	54.8	54.3	52.5	56.5
		58.4	57.6	58.8	56.8	52.5	53.0	54.5	55.9	52.5	58.8
57.9		58.4	59.6	58.0	57.3	57.5	67.3	59.4	57.3	67.3	
A 588	T1	54.9	60.6	56.4	56.8	56.5	57.2	58.5	57.3	54.9	60.6
		63.8	65.0	62.7	62.6	63.2	59.7	58.0	62.1	58.0	65.0
		57.5	58.0	57.3	59.2	57.8	58.5	58.8	58.2	57.3	59.2
		53.2	52.6	52.4	52.8	53.2	54.3	52.8	53.0	52.4	54.3
		53.1	52.0	52.6	51.3	53.9	53.3	53.2	52.8	51.3	53.9
	T2	64.2	61.3	59.2	60.0	58.1	59.4	60.2	60.3	58.1	64.2
		53.9	54.7	55.2	55.2	55.4	51.0	54.9	54.3	51.0	55.4
	T3	66.5	68.6	62.4	65.7	62.2	65.5	68.3	65.6	62.2	68.6
		68.0	66.7	66.4	65.2	63.9	73.4	64.9	66.9	63.9	73.4

Table 3.8: Raw Data on Yield Strength from Mill 3.

Grade	Thickness Group	Yield Strength (ksi) from Mill 3									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	56.0	55.0	56.0	55.0	56.0	58.0	57.0	56.1	55.0	58.0
		58.0	54.0	55.0	55.0	56.0	55.0	57.0	55.7	54.0	58.0
	T2	57.0	55.0	56.0	58.0	56.0	57.0	56.0	56.4	55.0	58.0
		58.0	57.0	56.0	55.0	56.0	58.0	57.0	56.7	55.0	58.0
	T3	56.0	54.0	54.0	47.0	49.0	51.0	49.0	51.4	47.0	56.0
		58.0	57.0	56.0	55.0	56.0	58.0	57.0	56.7	55.0	58.0
		55.0	54.0	55.0	53.0	54.0	54.0	55.0	54.3	53.0	55.0
		55.0	54.0	55.0	53.0	54.0	54.0	55.0	54.3	53.0	55.0
		55.0	54.0	55.0	53.0	54.0	54.0	55.0	54.3	53.0	55.0
A 588	T1	58.0	58.0	58.0	58.0	58.0	59.0	59.0	58.3	58.0	59.0
		60.0	60.0	58.0	59.0	59.0	59.0	60.0	59.3	58.0	60.0
	T2	56.0	56.0	51.0	56.0	56.0	56.0	55.0	55.1	51.0	56.0
		57.0	56.0	55.0	55.0	56.0	57.0	57.0	56.1	55.0	57.0
		56.0	56.0	55.0	54.0	54.0	55.0	55.0	55.0	54.0	56.0
	T3	55.0	54.0	55.0	53.0	54.0	54.0	55.0	54.3	53.0	55.0
		54.0	51.0	50.0	52.0	52.0	54.0	55.0	52.6	50.0	55.0
	T4	52.0	50.0	51.0	51.0	51.0	50.0	51.0	50.9	50.0	52.0
		53.0	54.0	55.0	53.0	55.0	54.0	55.0	54.1	53.0	55.0
		54.0	55.0	54.0	54.0	55.0	54.0	55.0	54.4	54.0	55.0

Table 3.9: Raw Data on Yield Strength from Mill 4.

Grade	Thickness Group	Yield Strength (ksi) from Mill 4										
		LOCATION							Mean	Low	High	
		1	2	3	4	5	6	7				
A 572	T1	67.1	67.5	58.5	58.4	59.3	67.2	65.8	63.4	58.4	67.5	
		58.6	59.4	57.4	57.2	57.2	61.1	56.8	58.2	56.8	61.1	
		67.3	64.9	57.0	56.1	57.2	60.0	62.7	60.7	56.1	67.3	
		57.8	60.6	55.5	54.9	55.3	63.5	62.9	58.6	54.9	63.5	
	T2	57.2	56.1	55.1	58.3	55.1	57.7	56.9	56.6	55.1	58.3	
		57.7	55.8	54.7	55.6	55.9	58.8	57.7	56.6	54.7	58.8	
		56.3	54.9	53.2	58.2	58.4	58.9	58.4	56.9	53.2	58.9	
		53.9	53.1	51.1	54.3	55.6	55.3	52.8	53.7	51.1	55.6	
		66.5	69.5	58.9	53.2	53.2	59.5	62.2	60.4	53.2	69.5	
A 588	T1	61.9	65.0	58.1	56.4	60.0	63.9	61.4	61.0	56.4	65.0	
		57.1	56.0	50.6	54.1	56.4	54.2	59.6	55.4	50.6	59.6	
		62.5	60.7	54.4	54.6	59.1	60.5	66.4	59.7	54.4	66.4	
	T2	52.3	50.9	52.4	51.3	52.6	50.4	52.7	51.8	50.4	52.7	
		54.8	56.1	57.6	57.1	56.3	57.0	55.3	56.3	54.8	57.6	
		51.8	52.4	57.1	53.3	51.1	53.6	54.8	53.4	51.1	57.1	
		55.8	54.4	54.8	58.6	53.4	59.3	56.7	56.1	53.4	59.3	
		55.8	54.4	54.8	58.6	53.4	59.3	56.7	56.1	53.4	59.3	
Grade	Thickness Group	Yield Strength (ksi) from Mill 5										
		LOCATION							Mean	Low	High	
1	2	3	4	5	6	7						
A 572	T1	63.9	63.7	65.7	64.9	64.7	65.4	66.7	65.0	63.7	66.7	
		55.6	55.4	55.9	56.3	57.1	56.4	58.1	56.4	55.4	58.1	
	T2	55.3	55.4	55.7	55.9	56.1	56.1	55.3	55.7	55.3	56.1	
		58.6	58.9	59.9	59.4	60.4	57.4	60.4	59.3	57.4	60.4	
	T3	59.9	59.6	60.0	60.4	60.2	60.1	60.6	60.1	59.6	60.6	
		62.3	59.9	61.5	63.0	62.3	64.0	61.8	62.1	59.9	64.0	
	T4	64.2	63.6	65.6	65.3	64.3	66.0	62.8	64.5	62.8	66.0	
		56.2	56.7	57.8	57.0	58.2	56.9	58.1	57.3	56.2	58.2	
	A 588	T1	61.5	64.9	61.2	60.9	62.7	60.2	62.4	62.0	60.2	64.9
			59.1	60.3	63.6	62.9	62.9	61.3	62.1	61.7	59.1	63.6
			61.0	58.8	61.1	62.1	61.6	59.8	58.5	60.4	58.5	62.1
		T2	56.6	56.8	57.0	57.1	56.5	57.0	57.2	56.9	56.5	57.2
55.5			58.1	56.4	56.1	57.8	55.0	55.7	56.4	55.0	58.1	
59.0			61.7	63.4	61.4	61.1	62.4	59.0	61.1	59.0	63.4	
T3		57.6	58.3	59.1	58.0	57.2	56.9	58.0	57.9	56.9	59.1	
		56.3	58.2	57.6	57.9	57.2	58.2	59.3	57.8	56.3	59.3	

Table 3.10: Raw Data on Yield

Strength from Mill 5.

3.2.2 STATISTICAL ANALYSIS RESULTS FROM ALL MILLS

Tables 3.11 and 3.12 summarize the statistical analysis results for the 4-mill group (mills 1, 3, 4, and 5) and the 2-mill group (mills 2 and 6), respectively. Each table includes the mean and coefficient of variation values of the yield strength for each thickness group from the individual mills as well as overall statistics (i.e., including all the mills in the corresponding mill group).

Table 3.11: Statistical Analysis of Yield Strength for the 4-Mill Group.

Group	Yield Strength, F _y (ksi)														
	Mill 1			Mill 3			Mill 4			Mill 5			Overall		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	42	60.5	5.74	14	55.9	2.16	28	60.3	6.72	14	60.7	7.52	98	59.8	6.52
A572-T2	14	59.8	6.10	21	56.6	1.81	28	56.0	3.64	14	57.5	3.52	77	57.1	4.52
A572-T3	14	55.1	4.00	28	54.2	4.74	0	-	-	14	61.1	2.24	56	56.2	6.51
A572-T4	0	-	-	0	-	-	0	-	-	14	60.9	6.38	14	60.9	6.38
A588-T1	42	57.1	6.76	14	58.8	1.36	28	59.1	7.81	21	61.4	2.61	105	58.7	6.48
A588-T2	14	57.3	6.20	28	55.1	2.35	28	54.4	4.54	21	58.1	4.23	91	55.9	5.01
A588-T3	14	66.3	4.28	14	51.7	3.07	0	-	-	21	57.9	1.41	49	58.5	10.0
A588-T4	0	-	-	14	54.3	1.34	0	-	-	7	57.3	1.32	21	55.3	2.96
A572 All Groups	70	59.3	5.56	63	55.4	3.43	56	58.1	5.52	56	60.1	5.39	245	58.2	5.98
A588 All Groups	70	59.0	6.13	70	55.0	2.16	56	56.8	6.53	70	59.0	2.86	266	57.5	6.72
All Data	140	59.1	5.85	133	55.2	2.84	112	57.4	6.03	126	59.4	4.20	511	57.8	6.37

Table 3.12: Statistical Analysis of Yield Strength for the 2-Mill Group.

Group	Yield Strength, F_y (ksi)					
	Mill 2			Mill 6		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	282	58.6	6.08	857	61.0	7.78
A572-T2	8	60.5	3.78	626	56.5	5.88
A572-T3	-	-	-	271	54.3	5.37
A572-T4	-	-	-	260	54.5	5.83
A588-T1	44	63.6	5.59	59	62.1	6.37
A588-T2	-	-	-	73	55.0	4.71
A588-T3	-	-	-	71	54.1	4.41
A588-T4	-	-	-	16	54.7	3.52
A572 All Groups	290	58.7	6.03	2014	57.9	6.79
A588 All Groups	44	63.6	5.59	219	56.6	5.17
All Data	334	59.3	5.97	2233	57.7	6.66

From Table 3.11, it may be observed that, for the 4-mill group, the average yield strength ranged from 51.7 to 66.3 ksi. With respect to variability in yield strength values, the largest coefficients of variation values obtained for any single mill and for the 4-mill group were 7.81% and 10.0%, respectively. Considering all of the data, the coefficient of variation was 6.37%.

Similarly, from Table 3.12, it may be observed that both mills showed small variability in yield strength recorded with coefficient of variation values ranging from 3.52% to 7.78%. The average yield strength recorded for the two mills ranged from 54.1 to 63.6 ksi. Considering all of the data, the coefficient of variation was 6.66%.

Another important observation that may be made from Tables 3.11 and 3.12 is that the yield strength values obtained from the surveyed tests (with the 4-mill group) and the mill tests (with the 2-mill group) are quite similar. These values generally exceeded the minimum requirement of 50 ksi for both steel grades – only one plate (an A572-T3

plate from Mill 3 that can be examined in Table 3.8) from all of the data gathered showed three locations of the seven where this minimum value was not attained.

3.2.3 DISTRIBUTION OF SAMPLED YIELD STRENGTH VALUES

The percent of sampled test locations on the plates studied that had yield strength values greater than or equal to a specific strength level was studied. The specific yield strength levels considered are 50 and 55 ksi. The 50 ksi level was selected since it is the specification requirement value; the 55 ksi level was selected since it represents a value 10% above the specification requirement. The statistical analysis results are shown in Table 3.13. It should be noted that since most plates from Mills 2 and 6 had only one test location per plate, this analysis included only the data from the 4-mill group (Mills 1, 3, 4, and 5).

It may be observed from Table 3.13 that all groups except A572-T3 had 100% percent of sampled yield strength values greater than or equal to the required yield strength. In other words, in almost every case, all seven locations from each plate had yield strength equal to or greater than 50 ksi. However, it was found that for the A572 and A588 grades, the percentage of the sample (considering all thickness groups) that had yield strength values greater than 55 ksi decreased to 84.0% and 73.3%, respectively.

Table 3.13: Percent of All Test Locations that had Yield Strength Greater than or Equal to a Specific Strength Level (4-Mill Group).

Percent Greater than or Equal to Specific Yield Strength (%)					
Group	Number of Test Locations	50 ksi		55 ksi	
		Mean	COV, %	Mean	COV, %
A572-T1	98	100	0	91.8	24.9
A572-T2	77	100	0	89.6	24.8
A572-T3	56	94.6	16.0	60.7	57.3
A572-T4	14	100	0	100	0
A588-T1	105	100	0	79.0	44.2
A588-T2	91	100	0	69.2	50.4
A588-T3	49	100	0	73.5	61.9
A588-T4	21	100	0	61.9	53.3
A572 All Groups	245	98.7	7.4	84.0	33.4
A588 All Groups	266	100	0	73.3	48.8

3.3 TENSILE STRENGTH (F_U)

3.3.1 ORGANIZED DATA FROM THE 4-MILL GROUP

Tables 3.14 to 3.17 present the organized data on tensile strength for all the slabs from mills 1, 3, 4, and 5, respectively. In each table, the tensile strength at seven locations on each plate is presented for each steel grade and each thickness group. The mean, low, and high values observed for each sampled plate are also shown in the last three columns of each table.

Table 3.14: Raw Data on Tensile Strength from Mill 1.

Grade	Thickness Group	Tensile Strength (ksi) from Mill 1									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	82.2	80.3	84.7	83.8	85.9	80.5	82.5	82.8	80.3	85.9
		86.1	82.9	87.6	85.9	85.9	82.6	83.8	85.0	82.6	87.6
		79.9	77.9	79.8	79.2	79.4	79.2	78.8	79.2	77.9	79.9
		90.8	87.1	88.1	87.9	87.2	86.2	87.7	87.9	86.2	90.8
		89.5	92.4	89.8	92.0	89.2	92.3	88.5	90.5	88.5	92.4
	89.8	95.7	89.6	90.7	89.1	92.0	89.7	90.9	89.1	95.7	
	T2	86.9	90.1	86.6	88.0	87.5	87.5	88.7	87.9	86.6	90.1
		88.4	86.4	84.8	85.7	85.4	86.9	85.6	86.2	84.8	88.4
	T3	82.4	82.9	81.9	81.8	82.1	82.3	82.9	82.3	81.8	82.9
80.4		81.0	81.3	80.3	80.8	81.8	81.3	81.0	80.3	81.8	
A 588	T1	80.7	80.0	80.4	80.1	77.9	79.7	80.4	79.9	77.9	80.7
		78.3	80.0	80.0	80.2	80.1	80.0	80.1	79.8	78.3	80.2
		88.4	89.8	88.3	87.7	88.1	87.9	87.2	88.2	87.2	89.8
		83.8	82.8	82.1	82.5	81.8	82.5	80.8	82.3	80.8	83.8
		75.7	75.9	75.0	75.7	75.5	76.5	75.3	75.7	75.0	76.5
		76.1	75.6	76.1	75.7	76.2	76.4	76.2	76.0	75.6	76.4
	T2	81.2	79.8	79.8	80.6	80.8	81.7	83.0	81.0	79.8	83.0
		81.4	82.1	83.1	83.1	83.9	82.4	83.4	82.8	81.4	83.9
	T3	93.6	93.6	89.9	91.2	90.2	92.9	92.7	92.0	89.9	93.6
		94.2	91.8	93.4	92.8	92.9	94.4	93.4	93.3	91.8	94.4

Table 3.15: Raw Data on Tensile Strength from Mill 3.

Grade	Thickness Group	Tensile Strength (ksi) from Mill 3										
		LOCATION							Mean	Low	High	
		1	2	3	4	5	6	7				
A 572	T1	75.0	76.0	77.0	75.0	74.0	77.0	75.0	75.6	74.0	77.0	
		80.0	75.0	78.0	79.0	75.0	76.0	74.0	76.7	74.0	80.0	
	T2	78.0	76.0	78.0	78.0	79.0	80.0	79.0	78.3	76.0	80.0	
		80.0	79.0	79.0	79.0	79.0	81.0	80.0	79.6	79.0	81.0	
	T3	80.0	79.0	79.0	79.0	79.0	81.0	80.0	79.6	79.0	81.0	
		80.0	80.0	78.0	77.0	78.0	79.0	79.0	78.7	77.0	80.0	
		80.0	79.0	79.0	79.0	79.0	81.0	80.0	79.6	79.0	81.0	
		74.0	74.0	74.0	73.0	74.0	73.0	74.0	73.7	73.0	74.0	
		74.0	74.0	74.0	73.0	74.0	73.0	74.0	73.7	73.0	74.0	
A 588	T1	77.0	76.0	77.0	77.0	77.0	77.0	81.0	77.4	76.0	81.0	
		78.0	78.0	78.0	78.0	78.0	79.0	78.0	78.1	78.0	79.0	
	T2	75.0	75.0	69.0	75.0	75.0	75.0	74.0	74.0	74.0	75.0	
		76.0	75.0	75.0	77.0	75.0	77.0	76.0	75.9	75.0	77.0	
		75.0	76.0	74.0	74.0	74.0	74.0	75.0	74.6	74.0	76.0	
	T3	74.0	74.0	74.0	73.0	74.0	73.0	74.0	73.7	73.0	74.0	
		84.0	82.0	80.0	82.0	83.0	84.0	85.0	82.9	80.0	85.0	
		84.0	83.0	83.0	80.0	82.0	82.0	83.0	82.4	80.0	84.0	
		80.0	81.0	81.0	80.0	81.0	81.0	81.0	80.7	80.0	81.0	
		T4	81.0	80.0	81.0	81.0	82.0	80.0	81.0	80.9	80.0	82.0
			81.0	80.0	81.0	81.0	82.0	80.0	81.0	80.9	80.0	82.0

Table 3.16: Raw Data on Tensile Strength from Mill 4.

Grade	Thickness Group	Tensile Strength (ksi) from Mill 4									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	84.4	85.1	79.0	79.5	79.2	84.4	83.8	82.2	79.0	85.1
		71.4	78.4	77.7	78.3	77.6	78.5	78.5	77.2	71.4	78.5
		84.3	83.3	78.1	77.9	78.1	78.7	79.5	80.0	77.9	84.3
		78.4	79.9	78.5	78.4	78.4	81.4	81.4	79.5	78.4	81.4
	T2	82.1	83.2	82.5	83.7	82.2	83.1	83.4	82.9	82.1	83.7
		82.3	83.0	81.8	83.1	82.3	83.7	82.2	82.6	81.8	83.7
		81.0	81.4	81.4	81.4	81.2	82.0	82.6	81.6	81.0	82.6
		80.9	80.9	79.3	79.2	79.6	80.0	80.9	80.1	79.2	80.9
A 588	T1	77.2	81.2	73.5	73.5	73.7	75.7	77.2	76.0	73.5	81.2
		76.9	79.2	75.4	76.5	77.3	78.3	77.6	77.3	75.4	79.2
		74.0	73.3	72.9	75.5	75.4	74.4	75.5	74.4	72.9	75.5
	T2	78.7	78.0	75.0	75.3	76.8	77.7	80.3	77.4	75.0	80.3
		78.4	78.0	78.0	77.5	80.4	77.9	78.7	78.4	77.5	80.4
		80.1	80.7	79.4	79.7	79.7	80.4	79.4	79.9	79.4	80.7
		76.1	76.7	75.4	76.7	75.7	76.7	77.1	76.3	75.4	77.1
		78.8	79.6	79.2	79.4	79.0	79.8	79.6	79.3	78.8	79.8

Table 3.17: Raw Data on Tensile Strength from Mill 5.

Grade	Thickness Group	Tensile Strength (ksi) from Mill 5									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	86.3	85.9	86.3	87.0	87.1	86.0	87.9	86.6	85.9	87.9
		81.3	82.0	83.1	80.5	81.3	81.8	82.9	81.8	80.5	83.1
	T2	77.5	78.6	78.0	77.9	77.8	76.9	76.1	77.5	76.1	78.6
		84.1	85.1	87.4	87.2	88.9	85.5	86.7	86.4	84.1	88.9
	T3	89.4	89.4	86.9	87.5	86.9	89.3	89.3	88.4	86.9	89.4
		88.6	90.0	91.2	92.6	89.5	88.7	90.3	90.1	88.6	92.6
	T4	89.9	92.5	94.9	92.3	91.1	90.9	91.8	91.9	89.9	94.9
		85.0	85.6	86.4	86.2	87.1	86.5	86.3	86.2	85.0	87.1
A 588	T1	89.0	90.9	90.6	90.1	89.7	88.9	87.8	89.6	87.8	90.9
		87.8	86.8	90.2	90.1	90.4	91.1	90.3	89.5	86.8	91.1
		82.8	82.6	84.7	86.3	85.9	83.8	83.7	84.3	82.6	86.3
	T2	81.1	81.7	84.1	84.2	83.8	85.0	84.6	83.5	81.1	85.0
		85.3	84.4	81.9	82.8	82.4	83.1	83.0	83.3	81.9	85.3
		88.4	87.7	89.9	90.0	89.5	90.7	87.6	89.1	87.6	90.7
	T3	81.9	83.0	82.4	82.0	82.1	79.8	80.6	81.7	79.8	83.0
		80.2	81.0	82.3	80.0	79.9	83.4	81.0	81.1	79.9	83.4
		80.6	79.6	81.2	78.6	79.8	80.8	80.0	80.1	78.6	81.2
	T4	88.7	88.8	89.4	89.4	89.4	88.2	89.3	89.0	88.2	89.4

3.3.2 STATISTICAL ANALYSIS RESULTS FROM ALL MILLS

Tables 3.18 and 3.19 summarize the statistical analysis results for the 4-mill group (mills 1, 3, 4, and 5) and the 2-mill group (mills 2 and 6), respectively. Each table includes the mean and coefficient of variation values of the tensile strength for each thickness group from the individual mills as well as overall statistics (i.e., including all the mills in the corresponding mill group).

Table 3.18: Statistical Analysis of Tensile Strength for the 4-Mill Group.

Group	Tensile Strength, Fu (ksi)														
	Mill 1			Mill 3			Mill 4			Mill 5			Overall		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	42	86.1	5.30	14	76.1	2.41	28	79.7	3.67	14	84.2	3.10	98	82.6	6.23
A572-T2	14	87.0	1.67	21	79.1	1.40	28	81.8	1.55	14	82.0	5.81	77	82.1	4.24
A572-T3	14	81.7	1.03	28	76.4	3.76	0	-	-	14	89.3	1.75	56	80.9	7.09
A572-T4	0	-	-	0	-	-	0	-	-	14	89.0	3.60	14	89.0	3.60
A588-T1	42	80.3	5.38	14	77.8	1.53	28	76.3	2.83	21	87.8	3.27	105	80.4	6.44
A588-T2	14	81.9	1.63	28	74.5	1.98	28	78.5	1.93	21	85.3	3.56	91	79.4	5.68
A588-T3	14	92.6	1.49	14	82.6	1.75	0	-	-	21	81.0	1.54	49	84.8	6.18
A588-T4	0	-	-	14	80.8	0.72	0	-	-	7	89.0	0.53	21	83.5	4.81
A572 All Groups	70	85.4	4.23	63	77.3	2.84	56	80.8	2.79	56	86.1	3.77	245	82.4	5.76
A588 All Groups	70	83.1	4.16	70	78.1	1.64	56	77.4	2.41	70	85.1	2.81	266	81.1	6.02
All Data	140	84.2	4.20	133	77.7	2.28	112	79.1	2.61	126	85.6	3.28	511	81.7	5.90

Table 3.19: Statistical Analysis of Tensile Strength for the 2-Mill Group.

Group	Tensile Strength, F_u (ksi)					
	Mill 2			Mill 6		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	282	72.1	7.07	857	75.8	5.65
A572-T2	8	79.7	8.97	626	75.9	3.94
A572-T3	-	-	-	271	78.7	4.56
A572-T4	-	-	-	260	77.9	3.87
A588-T1	44	83.5	10.2	59	81.2	3.03
A588-T2	-	-	-	73	81.4	2.81
A588-T3	-	-	-	71	83.8	2.89
A588-T4	-	-	-	16	83.8	1.77
A572 All Groups	290	72.3	7.15	2014	76.5	4.80
A588 All Groups	44	83.5	10.2	219	82.3	2.84
All Data	334	73.8	7.77	2233	77.1	4.62

From Table 3.18, it may be observed that, for the 4-mill group, the average tensile strength ranged from 74.5 to 92.6 ksi. With respect to variability in tensile strength values, the largest coefficients of variation values obtained for any single mill and for the 4-mill group were 5.81% and 7.09%, respectively. Considering all of the data, the coefficient of variation was 5.90%.

Similarly, from Table 3.19, it may be observed that both mills showed small variability in tensile strength with coefficient of variation values ranging from 1.77% to 10.2%. The average tensile strength recorded for the two mills ranged from 72.1 to 83.8 ksi.

Another important observation that may be made from Tables 3.17 and 3.18 is that the tensile strength values obtained from the surveyed tests (with the 4-mill group) and the mill tests (with the 2-mill group) are quite similar. These values exceed the minimum requirements of 65 ksi for both steel grades.

3.3.3 DISTRIBUTION OF SAMPLED TENSILE STRENGTH VALUES

The percent of sampled test locations on the plates studied that had tensile strength values greater than or equal to a specific strength level was studied. The specific strength levels considered are 65 and 70 ksi. The 65 ksi level was selected since it is the specification requirement value; the 70 ksi level was selected as it is 5 ksi (approximately 8%) above the specification requirement. The statistical analysis results are shown in Table 3.20. Again, it should be noted that since most plates from Mills 2 and 6 had only one test location per plate, this analysis included only the data from the 4-mill group (Mills 1, 3, 4, and 5).

It may be observed from Table 3.20 that all groups had 100% percent of sampled tensile strength values greater than or equal to the required tensile strength. In other words, in all cases, all seven locations from each plate had tensile strength equal to or greater than 65 ksi. This is also true for the 70 ksi level with only exception: the A588-T2 plates had 98.9% of the samples with tensile strengths greater than 70 ksi. The results suggest that most plates had adequate tensile strength with low variability.

Table 3.20: Percent of All Test Locations that has Tensile Strength Greater than or Equal to Specific Strength Level (4-Mill Group).

Percent Greater than or Equal to Specific Tensile Strength (%)					
Group	Number of Test Locations	65 ksi		70 ksi	
		Mean	COV, %	Mean	COV, %
A572-T1	98	100	0	100	0
A572-T2	77	100	0	100	0
A572-T3	56	100	0	100	0
A572-T4	14	100	0	100	0
A588-T1	105	100	0	100	0
A588-T2	91	100	0	98.9	4.0
A588-T3	49	100	0	100	0
A588-T4	21	100	0	100	0
A572 All Groups	245	100	0	100	0
A588 All Groups	266	100	0	99.6	2.3

3.4 YIELD TO TENSILE RATIO

3.4.1 ORGANIZED DATA FROM THE 4-MILL GROUP

Tables 3.21 to 3.24 present the organized data on yield to tensile ratio for all the slabs from mills 1, 3, 4, and 5 respectively. In each table, the yield to tensile ratio at seven locations on each plate is presented for each steel grade and each thickness group. The mean, low, and high values observed for each sampled plate are also shown in the last three columns of each table.

Table 3.21: Raw Data on Yield to Tensile Ratio from Mill 1.

Grade	Thickness Group	Yield to Tensile Ratio from Mill 1									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	0.71	0.71	0.71	0.72	0.71	0.72	0.73	0.72	0.71	0.73
		0.73	0.73	0.72	0.72	0.72	0.73	0.72	0.72	0.72	0.73
		0.68	0.71	0.68	0.68	0.68	0.68	0.69	0.69	0.68	0.71
		0.72	0.69	0.71	0.71	0.70	0.67	0.70	0.70	0.67	0.72
		0.69	0.68	0.68	0.66	0.69	0.70	0.71	0.69	0.66	0.71
	0.70	0.71	0.70	0.69	0.71	0.69	0.72	0.70	0.69	0.72	
	T2	0.66	0.65	0.66	0.65	0.64	0.71	0.65	0.66	0.64	0.71
		0.80	0.66	0.71	0.72	0.72	0.70	0.71	0.72	0.66	0.80
	T3	0.66	0.63	0.68	0.65	0.65	0.69	0.66	0.66	0.63	0.69
0.73		0.71	0.72	0.71	0.65	0.65	0.67	0.69	0.65	0.73	
A 588	T1	0.72	0.73	0.74	0.72	0.74	0.72	0.84	0.74	0.72	0.84
		0.70	0.76	0.71	0.71	0.71	0.72	0.73	0.72	0.70	0.76
		0.72	0.72	0.71	0.71	0.72	0.68	0.67	0.70	0.67	0.72
		0.69	0.70	0.70	0.72	0.71	0.71	0.73	0.71	0.69	0.73
		0.70	0.69	0.70	0.70	0.70	0.71	0.70	0.70	0.69	0.71
	0.70	0.69	0.69	0.68	0.71	0.70	0.70	0.69	0.68	0.71	
	T2	0.79	0.77	0.74	0.74	0.72	0.73	0.73	0.75	0.72	0.79
		0.66	0.67	0.66	0.66	0.66	0.62	0.66	0.66	0.62	0.67
	T3	0.71	0.73	0.69	0.72	0.69	0.71	0.74	0.71	0.69	0.74
		0.72	0.73	0.71	0.70	0.69	0.78	0.69	0.72	0.69	0.78

Table 3.22: Raw Data on Yield to Tensile Ratio from Mill 3.

Grade	Thickness Group	Yield to Tensile Ratio from Mill 3										
		LOCATION							Mean	Low	High	
		1	2	3	4	5	6	7				
A 572	T1	0.75	0.72	0.73	0.73	0.76	0.75	0.76	0.74	0.72	0.76	
		0.73	0.72	0.71	0.70	0.75	0.72	0.77	0.73	0.70	0.77	
	T2	0.73	0.72	0.72	0.74	0.71	0.71	0.71	0.72	0.71	0.74	
		0.73	0.72	0.71	0.70	0.71	0.72	0.71	0.71	0.70	0.73	
	T3	0.70	0.68	0.69	0.61	0.63	0.65	0.62	0.65	0.61	0.70	
		0.73	0.72	0.71	0.70	0.71	0.72	0.71	0.71	0.70	0.73	
		0.74	0.73	0.74	0.73	0.73	0.74	0.74	0.74	0.73	0.74	
	A 588	T1	0.75	0.76	0.75	0.75	0.75	0.77	0.73	0.75	0.73	0.77
			0.77	0.77	0.74	0.76	0.76	0.75	0.77	0.76	0.74	0.77
T2		0.75	0.75	0.74	0.75	0.75	0.75	0.74	0.75	0.74	0.75	
		0.75	0.75	0.73	0.71	0.75	0.74	0.75	0.74	0.71	0.75	
		0.75	0.74	0.74	0.73	0.73	0.74	0.73	0.74	0.73	0.75	
T3		0.74	0.73	0.74	0.73	0.73	0.74	0.74	0.74	0.73	0.74	
		0.64	0.62	0.63	0.63	0.63	0.64	0.65	0.63	0.62	0.65	
		0.62	0.60	0.61	0.64	0.62	0.61	0.61	0.62	0.60	0.64	
T4		0.66	0.67	0.68	0.66	0.68	0.67	0.68	0.67	0.66	0.68	
	0.67	0.69	0.67	0.67	0.67	0.68	0.68	0.67	0.67	0.69		

Table 3.23: Raw Data on Yield to Tensile Ratio from Mill 4.

Grade	Thickness Group	Yield to Tensile Ratio from Mill 4									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	0.80	0.79	0.74	0.73	0.75	0.80	0.79	0.77	0.73	0.80
		0.82	0.76	0.74	0.73	0.74	0.78	0.72	0.76	0.72	0.82
		0.80	0.78	0.73	0.72	0.73	0.76	0.79	0.76	0.72	0.80
		0.74	0.76	0.71	0.70	0.71	0.78	0.77	0.74	0.70	0.78
	T2	0.70	0.67	0.67	0.70	0.67	0.69	0.68	0.68	0.67	0.70
		0.70	0.67	0.67	0.67	0.68	0.70	0.70	0.68	0.67	0.70
		0.70	0.67	0.65	0.71	0.72	0.72	0.71	0.70	0.65	0.72
A 588	T1	0.67	0.66	0.64	0.69	0.70	0.69	0.65	0.67	0.64	0.70
		0.86	0.86	0.80	0.72	0.72	0.79	0.81	0.79	0.72	0.86
		0.80	0.82	0.77	0.74	0.78	0.82	0.79	0.79	0.74	0.82
	T2	0.77	0.76	0.69	0.72	0.75	0.73	0.79	0.74	0.69	0.79
		0.79	0.78	0.73	0.73	0.77	0.78	0.83	0.77	0.73	0.83
		0.67	0.65	0.67	0.66	0.65	0.65	0.67	0.66	0.65	0.67
		0.68	0.70	0.73	0.72	0.71	0.71	0.70	0.70	0.68	0.73
		0.68	0.68	0.76	0.69	0.68	0.70	0.71	0.70	0.68	0.76
		0.71	0.68	0.69	0.74	0.68	0.74	0.71	0.71	0.68	0.74

Table 3.24: Raw Data on Yield to Tensile Ratio from Mill 5.

Grade	Thickness Group	Yield to Tensile Ratio from Mill 5									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	0.74	0.74	0.76	0.75	0.74	0.76	0.76	0.75	0.74	0.76
		0.68	0.68	0.67	0.70	0.70	0.69	0.70	0.69	0.67	0.70
	T2	0.71	0.70	0.71	0.72	0.72	0.73	0.73	0.72	0.70	0.73
		0.70	0.69	0.69	0.68	0.68	0.67	0.70	0.69	0.67	0.70
	T3	0.67	0.67	0.69	0.69	0.69	0.67	0.68	0.68	0.67	0.69
		0.70	0.67	0.67	0.68	0.70	0.72	0.68	0.69	0.67	0.72
	T4	0.71	0.69	0.69	0.71	0.71	0.73	0.68	0.70	0.68	0.73
		0.66	0.66	0.67	0.66	0.67	0.66	0.67	0.66	0.66	0.67
A 588	T1	0.69	0.71	0.68	0.68	0.70	0.68	0.71	0.69	0.68	0.71
		0.67	0.69	0.71	0.70	0.70	0.67	0.69	0.69	0.67	0.71
		0.74	0.71	0.72	0.72	0.72	0.71	0.70	0.72	0.70	0.74
	T2	0.70	0.70	0.68	0.68	0.67	0.67	0.68	0.68	0.67	0.70
		0.65	0.69	0.69	0.68	0.70	0.66	0.67	0.68	0.65	0.70
		0.67	0.70	0.71	0.68	0.68	0.69	0.67	0.69	0.67	0.71
	T3	0.70	0.70	0.72	0.71	0.70	0.71	0.72	0.71	0.70	0.72
		0.70	0.72	0.70	0.72	0.72	0.70	0.73	0.71	0.70	0.73
		0.72	0.74	0.73	0.73	0.73	0.70	0.72	0.73	0.70	0.74
	T4	0.65	0.64	0.65	0.64	0.65	0.63	0.65	0.64	0.63	0.65

3.4.2 STATISTICAL ANALYSIS RESULTS FROM ALL MILLS

Tables 3.25 and 3.26 summarize the statistical analysis results for the 4-mill group (mills 1, 3, 4, and 5) and the 2-mill group (mills 2 and 6), respectively. Each table includes the mean and coefficient of variation values of the yield to tensile ratio for each thickness group from the individual mills as well as overall statistics (i.e., including all the mills in the corresponding mill group).

Table 3.25: Statistical Analysis of Yield to Tensile Ratio for 4-Mill Group.

Group	Yield to Tensile Ratio (F _y /F _u)														
	Mill 1			Mill 3			Mill 4			Mill 5			Overall		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	42	0.70	2.48	14	0.73	2.92	28	0.76	4.07	14	0.72	4.64	98	0.73	4.89
A572-T2	14	0.69	6.29	21	0.72	1.53	28	0.68	2.04	14	0.70	2.67	77	0.70	3.90
A572-T3	14	0.68	4.59	28	0.71	5.53	0	-	-	14	0.68	2.28	56	0.69	5.14
A572-T4	0	-	-	0	-	-	0	-	-	14	0.68	3.28	14	0.68	3.28
A588-T1	42	0.71	3.74	14	0.76	1.52	28	0.79	5.44	21	0.70	2.59	105	0.73	5.76
A588-T2	14	0.70	7.23	28	0.74	1.26	28	0.68	3.75	21	0.68	2.07	91	0.71	4.94
A588-T3	14	0.72	3.34	14	0.63	2.16	0	-	-	21	0.70	11.49	49	0.68	9.55
A588-T4	0	-	-	14	0.67	1.15	0	-	-	7	0.64	0.92	21	0.66	2.30
A572 All Groups	70	0.69	3.94	63	0.72	4.01	56	0.72	3.33	56	0.70	3.37	245	0.71	4.59
A588 All Groups	70	0.71	4.57	70	0.71	1.48	56	0.74	4.80	70	0.69	6.65	266	0.71	6.18
All Data	140	0.70	4.27	133	0.71	2.97	112	0.73	4.14	126	0.69	5.42	511	0.71	5.48

Table 3.26: Statistical Analysis of Yield to Tensile Ratio for Two-Mill Group.

Group	Yield to Tensile Ratio (F_y/F_u)					
	Mill 2			Mill 6		
	No. of Tests	Mean	COV, %	No. of Tests	Mean	COV, %
A572-T1	282	0.81	4.11	857	0.80	4.47
A572-T2	8	0.76	6.02	626	0.74	4.38
A572-T3	-	-	-	271	0.69	3.39
A572-T4	-	-	-	260	0.70	3.63
A588-T1	44	0.77	6.42	59	0.76	4.78
A588-T2	-	-	-	73	0.68	3.49
A588-T3	-	-	-	71	0.64	2.83
A588-T4	-	-	-	16	0.65	2.51
A572 All Groups	290	0.81	4.17	2014	0.76	4.26
A588 All Groups	44	0.77	6.42	219	0.69	3.77
All Data	334	0.81	4.49	2233	0.75	4.22

It can be observed from Table 3.25 that, for the 4-mill group, the average yield to tensile ratio ranged from 0.63 to 0.79. With respect to variability in yield to tensile ratios, the largest coefficients of variation values obtained for any single mill and for the 4-mill group were 11.49% and 9.55%, respectively. Considering all of the data, the coefficient of variation was 5.48%.

Similarly, from Table 3.26, it may be observed that both mills showed small variability in yield to tensile ratio with coefficient of variation values ranging from 2.51% to 6.42%. The average yield to tensile ratio for the two mills ranged from 0.64 to 0.81.

An important observation that may be made from Tables 3.25 and 3.26 is that the yield to tensile ratio from all six mills was found to be lower than the maximum permissible ratio of 0.85, which while not necessarily a requirement for plate specifications under study, is a common requirement for other product forms of the same steel covered by A992. In both steel grades, the average yield to tensile ratio for all mills was seen to decrease with an increase in plate thickness, except for a few cases where this trend was not observed.

3.5 YIELD STRENGTH TO YIELD POINT RATIO

3.5.1 ORGANIZED DATA FROM MILL 4

Since mill 4 was the only mill that reported data on yield point, table 3.27 presents the organized data on yield strength to yield point ratio for mill 4. In the table, the yield strength to yield point at seven locations on each plate is presented for each steel grade and each thickness group. The mean, low, and high values observed for each sampled plate is also shown in the last three columns.

Table 3.27: Raw Data on Yield Strength to Yield Point Ratio from Mill 4.

Grade	Thickness Group	Yield Strength to Yield Point (ksi) from Mill 4									
		LOCATION							Mean	Low	High
		1	2	3	4	5	6	7			
A 572	T1	0.98	0.99	0.98	0.97	1.00	0.96	0.98	0.98	0.96	1.00
		1.00	1.00	1.00	1.00	1.00	1.07	0.97	1.01	0.97	1.07
		0.97	1.04	1.00	1.00	1.09	1.01	0.99	1.01	0.97	1.09
		0.98	1.00	0.99	1.00	0.99	1.03	0.98	0.99	0.98	1.03
	T2	1.02	1.00	1.03	1.01	0.99	1.01	1.03	1.01	0.99	1.03
		1.00	1.01	1.01	1.00	1.01	1.03	1.00	1.01	1.00	1.03
		1.07	1.00	1.02	1.22	1.08	1.11	1.16	1.09	1.00	1.22
		0.98	1.00	1.01	0.97	1.02	0.96	1.02	1.00	0.96	1.02
A 588	T1	1.07	1.01	1.07	0.98	0.97	0.99	0.97	1.01	0.97	1.07
		0.97	0.99	1.03	0.96	1.00	1.01	0.97	0.99	0.96	1.03
		0.98	1.00	0.98	1.01	1.04	0.99	0.99	1.00	0.98	1.04
		1.00	0.99	0.98	0.99	0.98	0.97	0.98	0.98	0.97	1.00
	T2	1.02	1.02	1.05	1.00	1.00	1.00	1.04	1.02	1.00	1.05
		1.00	1.00	1.02	0.99	1.00	0.99	1.00	1.00	0.99	1.02
		0.98	0.97	-	1.03	1.01	0.98	0.99	1.00	0.97	1.03
		1.00	1.00	1.02	1.11	1.02	1.13	1.00	1.04	1.00	1.13

3.5.2 STATISTICAL ANALYSIS RESULTS FOR MILL 4

The statistical analysis results for mill 4 are summarized in table 3.28. Since no other mill provided data on yield point, overall statistics for all mills for the yield strength to yield point ratio could not be determined as was done for other parameters discussed. Table 3.28 shows that the average yield strength to yield point ratio of a572-t1, a572-t2, a588-t1 and a588-t2 groups was close to unity; the ratio (averaged for each thickness group) is seen to range from 0.99 to 1.01. In other words, the yield point level is very close to the yield strength with an average discrepancy of only about 1%. Moreover, the variability of this ratio for mill 4 is also relatively small with coefficient of variation values ranging from 1.70% to 3.48%. Considering all of the data, the coefficient of variation was 2.45%.

Table 3.28: Statistical Analysis of Yield Strength to Yield Point Ratio for Mill 4.

Group	Yield Strength to Yield Point Ratio (F_v/Y_p)		
	Mill 4		
	No. of Tests	Mean	COV, %
A572-T1	28	0.99	2.80
A572-T2	28	1.01	1.20
A572-T3	0	-	-
A572-T4	0	-	-
A588-T1	28	1.00	3.48
A588-T2	28	1.01	1.70
A588-T3	0	-	-
A588-T4	0	-	-
A572 All Groups	56	1.00	2.14
A588 All Groups	56	1.00	2.73
All Data	112	1.00	2.45

3.6 CHARPY V-NOTCH TOUGHNESS (CVN)

Charpy V-notch test data were only available for the mills in the 4-mill group. Figure 3.7 shows the distribution of plates among the four mills (Mills 1, 3, 4, and 5) for which CVN test data were available. It should be noted that this distribution is different from the one in Figure 2.2 due to the deletion of erroneous CVN test data as discussed in Section 2.2.

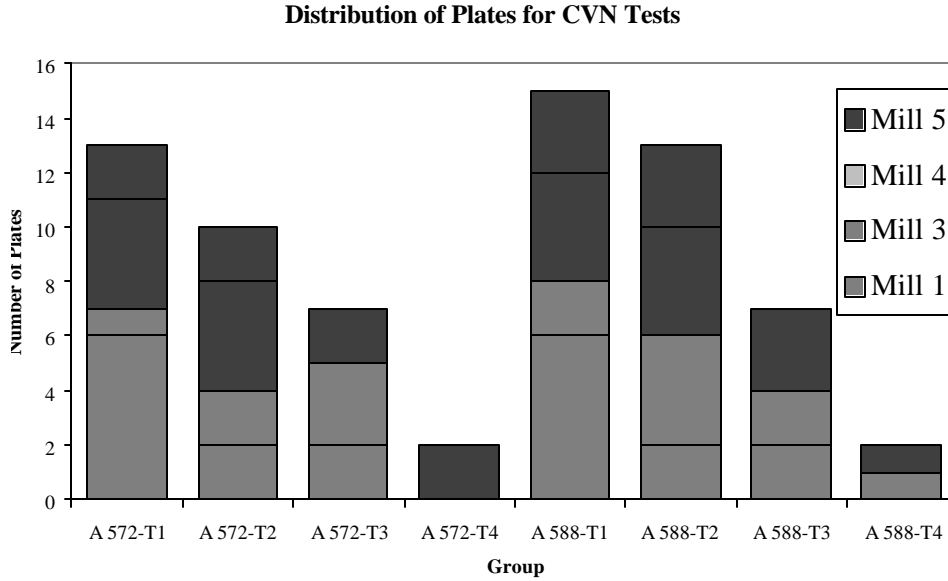


Figure 3.7:
Distribution of Plates
for CVN Tests (Mills 1,
3, 4, and 5).

3.6.1 ORGANIZED DATA FROM THE 4- MILL GROUP

Tables 3.29 to 3.32 present the three-test averages of absorbed energy from Mills 1, 3, 4, and 5, respectively. In each table, the three-test average of absorbed energy values at seven locations is presented for each steel grade and each thickness group. The mean, low, and high values for each sampled plate are also shown in the last three columns of each table.

Table 3.29: Three-Test Average of Absorbed Energy (ft-lbs) from Mill 1.

Grade	Thickness Group	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs) from Mill 1									
			LOCATION							Mean	Low	High
			1	2	3	4	5	6	7			
A 572	T1	0 F	48.3	58.3	21.7	21.0	17.0	41.7	67.0	39.3	17.0	67.0
			39.7	49.0	31.7	17.0	12.7	31.3	37.3	31.2	12.7	49.0
			46.7	91.7	32.3	69.3	70.7	93.3	87.3	70.2	32.3	93.3
			91.0	41.7	78.7	17.3	38.7	27.0	22.0	45.2	17.3	91.0
			40.7	9.3	30.0	5.7	11.3	6.7	10.7	16.3	5.7	40.7
		18.0	4.7	36.7	7.7	10.0	12.7	13.0	14.7	4.7	36.7	
		77.3	85.0	39.7	33.7	38.3	88.0	62.0	60.6	33.7	88.0	
		62.3	80.7	40.7	31.0	29.7	52.7	57.7	50.7	29.7	80.7	
		116.7	108.7	85.3	85.7	100.0	118.3	108.7	103.3	85.3	118.3	
		143.7	79.7	123.7	81.7	103.3	89.0	97.3	102.6	79.7	143.7	
		55.0	12.7	50.7	17.3	39.0	11.3	34.7	31.5	11.3	55.0	
		27.3	10.0	36.7	19.7	41.7	30.7	45.0	30.1	10.0	45.0	
	96.3	116.0	83.3	65.0	60.7	96.3	88.0	86.5	60.7	116.0		
	76.3	77.7	50.0	45.0	51.7	88.3	105.0	70.6	45.0	105.0		
	142.7	120.7	121.3	128.3	116.3	157.7	119.7	129.5	116.3	157.7		
	137.7	100.7	127.7	83.0	130.0	107.7	124.3	115.9	83.0	137.7		
	43.3	23.3	46.7	27.0	52.3	20.7	56.3	38.5	20.7	56.3		
	51.0	21.3	50.7	43.7	70.7	38.7	64.3	48.6	21.3	70.7		
	42.7	5.7	30.3	22.0	10.3	20.7	24.3	22.3	5.7	42.7		
	14.3	22.7	76.3	31.3	55.3	33.3	30.3	37.7	14.3	76.3		
	46.7	46.7	33.0	49.0	55.7	40.3	60.7	47.4	33.0	60.7		
	38.3	46.0	65.3	109.7	106.7	58.3	82.7	72.4	38.3	109.7		
	65.7	65.7	43.3	68.7	64.7	49.0	45.7	57.5	43.3	68.7		
	71.3	89.3	123.3	129.0	116.0	117.3	96.7	106.1	71.3	129.0		
	3.3	3.0	3.7	12.0	11.3	9.0	21.3	9.1	3.0	21.3		
	18.3	17.0	15.0	15.3	14.7	15.3	18.0	16.2	14.7	18.3		
	6.0	5.7	6.7	19.3	18.3	22.0	24.7	14.7	5.7	24.7		
	32.7	27.0	25.7	22.7	19.7	19.0	22.7	24.2	19.0	32.7		
	7.7	13.3	17.0	23.7	28.7	32.3	66.3	27.0	7.7	66.3		
	31.0	28.7	28.7	31.3	23.3	38.0	25.3	29.5	23.3	38.0		
	125.3	57.0	191.0	66.0	186.7	114.0	209.0	135.6	57.0	209.0		
	197.3	78.3	212.0	65.3	187.3	144.7	207.0	156.0	65.3	212.0		
	79.0	17.7	39.0	32.0	66.7	19.0	27.7	40.1	17.7	79.0		
	55.3	17.3	83.0	20.0	29.3	19.0	31.3	36.5	17.3	83.0		
	94.7	68.3	101.0	90.3	104.0	56.0	103.3	88.2	56.0	104.0		
	79.0	55.3	54.0	95.0	98.0	91.7	102.7	82.2	54.0	102.7		
196.0	111.3	214.0	151.3	204.3	140.0	207.0	174.9	111.3	214.0			
210.7	99.3	213.3	123.0	188.0	196.0	207.7	176.9	99.3	213.3			
79.3	40.3	70.0	62.0	70.7	67.0	103.0	70.3	40.3	103.0			
95.7	45.7	84.3	50.7	63.3	43.0	94.3	68.1	43.0	95.7			
237.7	130.0	160.7	129.7	195.3	161.0	218.3	176.1	129.7	237.7			
212.3	68.3	129.0	71.7	194.7	89.3	164.0	132.8	68.3	212.3			
224.3	164.3	218.7	188.3	186.7	158.7	206.7	192.5	158.7	224.3			
181.0	120.3	202.0	134.0	233.3	171.3	225.0	181.0	120.3	233.3			
76.7	50.0	111.3	113.0	101.3	94.3	93.3	91.4	50.0	113.0			
97.7	90.0	102.3	90.7	97.3	83.7	115.7	96.8	83.7	115.7			
255.3	217.7	257.3	176.7	261.3	163.3	269.7	228.8	163.3	269.7			
206.7	192.7	151.3	170.7	231.7	135.0	249.0	191.0	135.0	249.0			
42.7	75.0	56.3	78.0	21.3	77.0	49.0	57.0	21.3	78.0			
64.7	111.3	52.3	10.3	26.3	77.3	71.3	59.1	10.3	111.3			
161.3	183.3	93.0	189.3	115.3	73.0	205.0	145.8	73.0	205.0			
113.0	188.3	115.3	64.7	97.0	104.0	104.0	112.3	64.7	188.3			
174.7	207.7	164.3	156.0	158.7	166.0	127.3	165.0	127.3	207.7			
168.0	91.0	175.3	138.7	147.7	168.3	165.0	150.6	91.0	175.3			
13.7	13.3	10.7	15.3	12.3	14.3	17.3	13.9	10.7	17.3			
10.3	22.7	11.7	7.0	17.0	12.0	13.7	13.5	7.0	22.7			
24.7	21.3	16.7	18.3	32.3	22.3	20.3	22.3	16.7	32.3			
25.7	27.0	18.0	15.3	13.3	12.0	22.7	19.1	12.0	27.0			
33.3	52.7	35.7	45.7	46.7	24.7	30.0	38.4	24.7	52.7			
22.3	17.7	39.0	54.0	35.3	18.7	34.0	31.6	17.7	54.0			

Table 3.30: Three-Test Average of Absorbed Energy (ft-lbs) from Mill 3.

Grade	Thickness Group	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs) from Mill 3									
			LOCATION							Mean	Low	High
			1	2	3	4	5	6	7			
A 572	T1	0 F	58.3	65.0	90.3	80.3	70.7	67.3	65.0	71.0	58.3	90.3
		40 F	86.7	92.7	83.7	98.0	75.7	67.7	96.0	85.8	67.7	98.0
		70 F	109.7	107.3	110.0	114.0	116.7	110.7	109.7	111.1	107.3	116.7
	T2	0 F	76.7	75.0	70.3	51.0	51.3	85.3	89.3	71.3	51.0	89.3
		40 F	58.7	65.0	90.3	80.3	70.7	67.3	65.0	71.0	58.7	90.3
		70 F	95.0	87.0	92.3	99.7	88.3	129.7	122.0	102.0	87.0	129.7
	T3	0 F	86.7	92.7	83.7	98.0	75.7	67.7	96.0	85.8	67.7	98.0
			106.3	97.0	101.0	101.7	89.0	119.3	104.7	102.7	89.0	119.3
			109.7	107.3	110.0	114.0	116.7	110.7	109.7	111.1	107.3	116.7
		40 F	105.7	64.7	92.3	73.0	91.0	19.7	82.3	75.5	19.7	105.7
			31.3	33.7	109.0	62.0	118.7	96.0	102.3	79.0	31.3	118.7
			142.0	136.0	160.0	150.0	167.3	154.3	157.3	152.4	136.0	167.3
		70 F	109.3	35.3	146.7	87.0	120.0	64.3	132.0	99.2	35.3	146.7
			43.7	37.7	140.7	72.7	144.0	99.0	164.7	100.3	37.7	164.7
			152.3	158.7	193.3	194.7	190.7	188.0	179.0	179.5	152.3	194.7
	A 588	T1	166.0	123.3	120.3	83.0	160.7	121.3	131.0	129.4	83.0	166.0
			64.3	54.0	164.3	89.0	173.7	115.3	165.3	118.0	54.0	173.7
			184.0	177.7	180.7	187.3	189.3	178.7	182.7	182.9	177.7	189.3
T2		0 F	254.3	241.3	150.3	127.7	138.3	217.7	178.0	186.8	127.7	254.3
			228.7	154.7	146.3	122.0	124.0	156.0	150.7	154.6	122.0	228.7
			262.0	249.7	185.3	207.7	223.7	267.0	207.3	229.0	185.3	267.0
	40 F	261.7	237.7	211.0	186.3	220.0	145.7	161.3	203.4	145.7	261.7	
		256.0	266.3	240.3	256.3	245.3	232.3	233.7	247.2	232.3	266.3	
		254.0	247.7	201.3	196.7	226.3	219.0	226.0	224.4	196.7	254.0	
	T3	0 F	158.3	202.3	138.0	173.0	194.7	134.3	141.3	163.1	134.3	202.3
			135.0	134.7	190.7	216.0	132.3	136.7	127.7	153.3	127.7	216.0
			240.3	230.7	271.0	261.3	266.7	271.7	267.3	258.4	230.7	271.7
40 F		142.0	136.0	160.0	150.0	167.3	154.3	157.3	152.4	136.0	167.3	
		214.7	230.3	254.3	246.3	215.0	241.7	201.3	229.1	201.3	254.3	
		139.7	137.7	242.0	204.3	231.3	212.3	195.7	194.7	137.7	242.0	
70 F	262.0	259.3	272.3	269.3	270.7	268.0	263.7	266.5	259.3	272.3		
	152.3	158.7	193.3	194.7	190.7	188.0	179.0	179.5	152.3	194.7		
	216.7	233.3	223.0	213.3	212.3	240.7	252.7	227.4	212.3	252.7		
T4	0 F	177.3	155.3	241.0	238.3	227.0	246.0	233.7	217.0	155.3	246.0	
		262.3	252.0	257.3	255.0	253.7	254.7	254.0	255.6	252.0	262.3	
		184.0	177.7	180.7	187.3	189.3	178.7	182.7	182.9	177.7	189.3	
	40 F	72.3	78.0	102.7	43.0	83.3	10.3	59.3	64.1	10.3	102.7	
		89.0	42.3	110.0	24.7	107.7	61.3	88.7	74.8	24.7	110.0	
		83.0	67.3	109.0	35.0	103.7	101.7	85.7	83.6	35.0	109.0	
	70 F	116.7	33.7	122.7	45.3	137.0	100.0	107.3	94.7	33.7	137.0	
		145.0	127.7	129.7	166.0	132.0	108.7	122.0	133.0	108.7	166.0	
		165.0	130.7	140.0	135.3	136.0	61.0	155.3	131.9	61.0	165.0	
T4	0 F	64.7	71.0	98.3	43.0	69.0	23.3	59.3	61.2	23.3	98.3	
	40 F	130.7	67.3	109.0	35.0	103.7	101.7	85.7	90.4	35.0	130.7	
	70 F	145.0	127.7	129.7	166.0	132.0	108.7	122.0	133.0	108.7	166.0	

Table 3.31: Three-Test Average of Absorbed Energy (ft-lbs) from Mill 4.

Grade	Thickness Group	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs) from Mill 4																																										
			LOCATION							Mean	Low	High																																	
			1	2	3	4	5	6	7																																				
A 572	T1	0 F	107.3	105.0	147.0	128.0	174.3	125.3	129.3	130.9	105.0	174.3	125.3	151.0	120.3	131.7	90.7	136.0	139.3	127.8	90.7	151.0	126.7	125.7	129.0	135.0	129.3	131.0	137.0	130.5	125.7	137.0	158.0	154.3	133.3	122.0	175.0	150.0	166.7	151.3	122.0	175.0			
			117.0	121.7	152.7	117.3	160.7	119.7	122.7	130.2	117.0	160.7	140.7	142.0	139.0	130.3	148.7	142.7	126.0	138.5	126.0	148.7	122.3	134.3	158.0	147.3	147.7	134.0	137.3	140.1	122.3	158.0	172.3	148.7	155.3	147.7	183.7	154.0	169.0	161.5	147.7	183.7			
			107.0	124.0	169.3	144.7	177.0	134.3	145.7	143.1	107.0	177.0	143.7	121.0	149.7	153.7	140.3	139.0	136.7	140.6	121.0	153.7	119.7	127.3	169.0	156.7	159.7	133.0	133.3	142.7	119.7	169.0	175.7	153.7	182.3	179.7	210.0	149.3	166.3	173.9	149.3	210.0			
		T2	0 F	60.0	49.0	32.7	29.0	42.0	40.3	46.0	42.7	29.0	60.0	78.7	56.3	69.3	49.3	53.7	73.0	80.7	65.9	49.3	80.7	53.0	41.0	50.3	59.0	38.0	77.0	59.7	54.0	38.0	77.0	127.7	123.0	112.7	124.0	123.3	131.7	116.3	122.7	112.7	131.7		
				92.7	71.0	67.7	72.0	61.3	67.7	91.0	74.8	61.3	92.7	111.0	106.0	100.3	87.0	104.0	117.3	109.7	105.0	87.0	117.3	99.0	93.3	96.7	98.3	88.7	105.7	103.7	97.9	88.7	105.7	160.0	148.7	147.7	142.3	159.7	159.0	159.7	153.9	142.3	160.0		
				100.0	104.7	80.0	85.7	89.0	93.0	102.3	93.5	80.0	104.7	123.0	110.7	114.3	109.3	104.7	120.3	125.0	115.3	104.7	125.0	99.7	106.0	101.7	105.3	102.3	134.7	122.3	110.3	99.7	134.7	174.3	172.7	159.0	179.0	164.7	161.3	147.7	165.5	147.7	179.0		
			T1	0 F	99.0	99.0	121.7	123.3	120.0	142.7	144.7	121.5	99.0	144.7	94.7	102.7	152.3	128.3	106.0	132.7	153.7	124.3	94.7	153.7	161.7	104.7	161.0	115.3	155.7	160.0	143.7	143.1	104.7	161.7	146.0	141.0	195.3	155.7	141.3	144.0	145.0	152.6	141.0	195.3	
					94.3	135.7	164.0	162.7	132.3	113.3	163.3	138.0	94.3	164.0	101.0	115.7	179.0	171.0	120.7	150.7	168.3	143.8	101.0	179.0	180.3	129.0	175.0	146.3	172.7	187.7	180.7	167.4	129.0	187.7	153.3	147.7	202.0	215.7	208.0	141.7	143.0	173.0	141.7	215.7	
					92.0	122.7	144.7	134.7	159.7	158.3	114.7	132.4	92.0	159.7	100.7	136.0	169.0	171.3	124.3	163.7	136.7	143.1	100.7	171.3	159.0	158.3	197.0	166.7	161.0	172.7	171.3	169.4	158.3	197.0	153.3	152.7	204.3	216.0	214.0	138.3	150.3	175.6	138.3	216.0	
				T2	0 F	187.0	243.0	245.3	303.3	70.0	292.7	243.0	226.3	70.0	303.3	172.0	121.0	203.3	192.3	172.3	130.0	186.3	168.2	121.0	203.3	287.3	275.7	273.7	292.3	282.0	298.0	280.7	284.2	273.7	298.0	199.0	184.0	100.0	108.3	135.0	198.7	168.3	156.2	100.0	199.0
						115.7	299.0	294.7	290.0	219.7	285.3	287.7	256.0	115.7	299.0	247.0	230.7	231.3	255.7	231.7	247.0	236.0	239.9	230.7	255.7	289.7	290.0	286.3	286.3	294.7	297.7	288.7	290.5	286.3	297.7	229.0	218.0	221.0	161.7	220.7	232.7	243.7	218.1	161.7	243.7
						253.7	316.3	318.7	312.0	237.0	313.7	304.0	293.6	237.0	318.7	207.7	214.0	206.7	246.3	214.0	215.0	207.0	215.8	206.7	246.3	275.0	280.0	278.7	278.3	278.7	282.7	277.3	278.7	275.0	282.7	232.0	233.0	238.3	233.0	226.7	264.7	227.3	236.4	226.7	264.7

Table 3.32: Three-Test Average of Absorbed Energy (ft-lbs) from Mill 5.

Grade	Thickness Group	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs) from Mill 5																			
			LOCATION							Mean	Low	High										
			1	2	3	4	5	6	7													
A 572	T1	0 F	42.3	53.3	42.3	73.3	55.7	87.0	61.3	59.3	42.3	87.0	27.3	33.0	21.3	19.7	23.3	13.3	15.0	21.9	13.3	33.0
			69.7	51.3	72.7	90.7	77.0	111.3	76.0	78.4	51.3	111.3	32.0	31.3	23.7	29.3	34.3	42.0	46.0	34.1	23.7	46.0
		40 F	96.3	91.3	94.7	101.7	100.0	118.7	73.0	96.5	73.0	118.7	83.7	90.7	83.3	75.0	78.0	84.7	79.7	82.1	75.0	90.7
			111.0	103.3	108.0	113.3	108.3	148.0	118.3	115.8	103.3	148.0	26.7	30.7	23.0	21.7	31.7	24.3	21.7	25.7	21.7	31.7
		70 F	139.0	141.3	132.7	148.0	138.3	138.7	121.3	137.0	121.3	148.0	55.0	86.7	59.3	47.0	77.3	74.3	52.0	64.5	47.0	86.7
			149.7	167.7	170.0	149.3	186.7	210.0	192.7	175.1	149.3	210.0	118.0	125.7	86.7	107.0	127.7	118.3	98.7	111.7	86.7	127.7
	T2	0 F	66.3	85.3	90.0	68.3	34.3	43.7	84.0	67.4	34.3	90.0	10.7	6.7	13.3	20.7	20.7	16.0	21.3	15.6	6.7	21.3
			67.3	97.3	80.7	78.0	107.3	70.7	64.0	80.8	64.0	107.3	21.3	19.7	21.7	22.3	18.3	19.7	18.3	20.2	18.3	22.3
		40 F	103.3	102.7	110.3	115.0	144.0	112.7	109.7	114.0	102.7	144.0	19.0	28.3	24.3	40.7	30.0	12.3	28.3	26.1	12.3	40.7
			11.0	11.0	8.3	8.3	8.7	8.3	9.7	9.3	8.3	11.0	18.3	14.3	20.0	11.3	18.3	14.7	29.7	18.1	11.3	29.7
		70 F	14.3	10.7	12.3	12.7	12.7	22.0	15.3	14.3	10.7	22.0	30.0	29.3	40.3	27.0	26.3	42.7	34.0	32.8	26.3	42.7
			14.3	16.0	16.0	17.3	17.3	21.3	18.3	17.2	14.3	21.3	55.7	42.3	41.7	37.7	75.7	37.7	56.7	49.6	37.7	75.7
	T3	0 F	69.7	39.3	33.0	26.3	54.7	49.3	82.0	50.6	26.3	82.0	33.0	10.7	28.7	26.3	19.7	25.0	23.7	23.9	10.7	33.0
			136.7	109.3	137.7	110.7	84.7	79.0	41.7	100.0	41.7	137.7	84.7	99.7	74.3	39.7	82.7	83.7	129.7	84.9	39.7	129.7
		40 F	74.7	23.0	90.7	72.3	66.0	36.7	28.7	56.0	23.0	90.7	259.3	155.7	100.0	107.7	118.7	140.7	151.3	147.6	100.0	259.3
			120.3	110.0	86.0	69.3	107.7	90.3	162.3	106.6	69.3	162.3	128.7	89.3	95.0	123.3	89.7	57.7	82.3	95.1	57.7	128.7
		70 F	229.3	186.0	153.3	160.3	154.7	192.0	196.0	181.7	153.3	229.3	106.7	60.3	92.7	72.3	98.3	94.7	75.3	85.8	60.3	106.7
			61.0	75.0	72.3	107.7	79.7	52.3	50.7	71.2	50.7	107.7	152.3	161.7	90.7	116.7	119.0	119.7	113.0	124.7	90.7	161.7
	T4	0 F	111.0	121.7	140.0	136.0	165.0	146.0	147.7	138.2	111.0	165.0	97.3	82.7	100.7	103.3	123.3	117.7	104.0	104.1	82.7	123.3
			161.3	166.0	123.0	137.0	148.0	143.0	127.3	143.7	123.0	166.0	149.3	143.7	166.7	166.3	187.7	159.7	145.3	159.8	143.7	187.7
		40 F	106.7	110.3	137.7	145.7	133.3	142.7	142.3	131.2	106.7	145.7	81.7	35.0	22.0	26.3	13.7	21.3	32.7	33.2	13.7	81.7
			67.7	66.0	102.7	91.3	111.0	62.3	84.3	83.6	62.3	111.0	130.7	124.3	116.3	142.7	116.3	105.3	129.7	123.6	105.3	142.7
		70 F	55.7	65.7	53.3	59.7	31.3	38.0	62.7	52.3	31.3	65.7	123.0	85.7	120.0	119.7	114.3	129.0	103.3	113.6	85.7	129.0
			149.3	145.0	140.0	151.3	155.3	154.3	153.0	149.8	140.0	155.3	109.0	89.0	36.3	31.3	36.0	82.0	76.0	65.7	31.3	109.0
T5	0 F	112.0	109.7	125.7	124.3	136.0	115.3	113.0	119.4	109.7	136.0	159.0	154.0	135.0	135.0	142.3	162.0	165.0	150.3	135.0	165.0	
		29.7	19.3	21.0	22.3	27.0	28.7	22.7	24.4	19.3	29.7	40 F	51.0	39.0	43.7	47.0	55.7	57.0	56.3	50.0	39.0	57.0
	40 F	86.0	91.0	92.3	105.3	82.3	95.3	75.0	89.6	75.0	105.3	70 F	86.0	91.0	92.3	105.3	82.3	95.3	75.0	89.6	75.0	105.3

3.6.2 STATISTICAL ANALYSIS RESULTS FROM ALL MILLS

Tables 3.33 to 3.36 summarize the statistical analysis results for Mills 1, 3, 4, and 5, respectively. Each table includes the minimum, maximum, mean, and coefficient of variation values of the absorbed energy for each steel grade, each thickness group, and for three test temperatures. In addition, due to the fact that the coefficients of variation on absorbed energy are significantly large (e.g., 72.5% for A572-T1 at 0°F), it is important to determine whether this large variability stems from the variability in the specimens within a plate or from the variability between plates.

A one-way analysis of variance (ANOVA) was performed in order to determine the variability of absorbed energy within a plate and the variability between plates. The formulas used in the analysis are presented as follows:

$$SST = \left(\sum_{j=1}^k \sum_{i=1}^m E_{i,j}^2 \right) - \frac{\left(\sum_{j=1}^k \sum_{i=1}^m E_{i,j} \right)^2}{k \cdot m} \quad (3.1)$$

$$SSA = \frac{\sum_{j=1}^k \left(\sum_{i=1}^m E_{i,j} \right)^2}{k} - \frac{\left(\sum_{j=1}^k \sum_{i=1}^m E_{i,j} \right)^2}{k \cdot m} \quad (3.2)$$

$$SSW = SST - SSA \quad (3.3)$$

$$F = \frac{MSA}{MSW}; \quad \text{where } MSA = \frac{SSA}{k-1}, \quad MSW = \frac{SSW}{k(m-1)} \quad (3.4)$$

where,

$E_{i,j}$ = Absorbed Energy at location i of slab j ,

m = Number of locations on a single slab ($m = 7$, here),

i = Index for location on a slab; possible values are 1 to m ,

k = Number of slabs (in each thickness group),

SST = Total sum of squares,

SSA = Sum of squares between plates,

SSW = Sum of squares within a plate,

MSA = Variance between plates,

MSW = Variance within a plate,

$F = F\text{-ratio}$.

The F -ratio is used to compare the variability between plates to the variability within a plate. If this ratio is greater than one, it indicates that variability between plates is larger than the variability within a plate. However, since the F -ratio cannot be used to compare tests with different degrees of freedom (Frank et al., 1992), a p value (determined from the F -ratio and the number of degrees of freedom) is used instead in order to compare the variability for the eight groups of steel plates (corresponding to the two grades of steel and four thickness groups). This p value also helps make direct conclusions regarding whether or not the variability within a plate (based on the seven locations there) is significant at a specified level of significance. The level of significance used in this study is 5%. For instance, if the p value is less than 5% or 0.05, it means that the variability among the seven locations within a plate is not significant or that the large variability mainly stems from variability between plates.

Table 3.33: Statistical Analysis of Absorbed Energy for Mill 1.

Group	No. of Test Locations	Absorbed Energy (ft-lbs)				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		0 F							
		Min	Max	Mean	COV, %				
A572-T1	42	4.7	93.3	36.2	72.5	2980.1	369.3	8.07	0.000
A572-T2	14	5.7	76.3	30.0	61.5	828.0	299.6	2.76	0.123
A572-T3	14	3.0	21.3	12.7	46.7	178.6	23.1	7.74	0.012
A588-T1	42	17.3	212.0	89.8	65.1	16584.9	1582.4	10.5	0.000
A588-T2	14	10.3	111.3	58.1	46.5	14.7	787.2	0.019	0.890
A588-T3	14	7.0	22.7	13.7	27.4	0.5	15.1	0.034	0.887
Group	No. of Test Locations	40 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		Min	Max	Mean	COV, %				
		A572-T1	42	10.0	143.7				
A572-T2	14	33.0	109.7	59.9	40.0	2187.5	439.9	4.97	0.045
A572-T3	14	5.7	32.7	19.4	41.9	317.5	45.3	7.01	0.021
A588-T1	42	40.3	237.7	133.2	46.2	19132.5	1650.7	11.6	0.000
A588-T2	14	64.7	205.0	129.0	36.2	3911.1	2041.4	1.92	0.191
A588-T3	14	12.0	32.3	20.7	27.1	34.6	31.3	1.10	0.315
Group	No. of Test Locations	70 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		Min	Max	Mean	COV, %				
		A572-T1	42	20.7	157.7				
A572-T2	14	43.3	129.0	81.8	36.5	8273.3	278.9	29.7	0.000
A572-T3	14	7.7	66.3	28.2	48.2	21.5	198.7	0.11	0.746
A588-T1	42	50.0	269.7	163.6	37.1	22137.1	1119.4	19.8	0.000
A588-T2	14	91.0	207.7	157.8	17.0	723.8	716.2	1.01	0.335
A588-T3	14	17.7	54.0	35.0	33.7	162.3	136.7	1.19	0.297

Table 3.34: Statistical Analysis of Absorbed Energy for Mill 3.

Group	No. of Test Locations	Absorbed Energy (ft-lbs)				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		0 F							
		Min	Max	Mean	COV, %				
A572-T1	7	58.3	90.3	71.0	15.3	-	117.8	-	-
A572-T2	14	51.0	90.3	71.2	17.8	0.2	172.9	0.001	0.970
A572-T3	21	19.7	167.3	102.3	43.6	13204.5	740.9	17.8	0.000
A588-T1	14	122.0	254.3	170.7	26.7	3626.8	1942.6	1.87	0.197
A588-T2	28	127.7	271.7	181.8	27.9	18423.5	593.7	31.0	0.000
A588-T3	14	10.3	110.0	69.5	44.3	398.2	994.9	0.40	0.539
A588-T4	7	23.3	98.3	61.2	38.4	-	552.7	-	-
Group	No. of Test Locations	40 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		40 F							
		Min	Max	Mean	COV, %				
A572-T1	7	67.7	98.0	85.8	12.9	-	122.8	-	-
A572-T2	14	67.7	129.7	93.9	17.2	922.9	205.2	4.50	0.055
A572-T3	21	35.3	194.7	126.4	42.0	14837.8	1482.0	10.0	0.001
A588-T1	14	145.7	267.0	216.2	17.4	2288.6	1343.0	1.70	0.217
A588-T2	28	137.7	272.3	217.5	19.0	10487.1	602.9	17.4	0.000
A588-T3	14	33.7	137.0	89.1	36.6	427.2	1117.4	0.38	0.549
A588-T4	7	35.0	130.7	90.4	34.7	-	982.3	-	-
Group	No. of Test Locations	70 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		70 F							
		Min	Max	Mean	COV, %				
A572-T1	7	107.3	116.7	111.1	2.8	-	9.8	-	-
A572-T2	14	89.0	119.3	106.9	7.5	248.6	48.1	5.17	0.042
A572-T3	21	54.0	189.3	143.4	29.9	8408.1	1115.5	7.54	0.004
A588-T1	14	196.7	266.3	235.8	8.8	1813.4	311.3	5.82	0.033
A588-T2	28	155.3	262.3	220.7	14.6	6308.9	384.0	16.4	0.000
A588-T3	14	61.0	166.0	132.5	19.6	4.2	729.5	0.01	0.922
A588-T4	7	108.7	166.0	133.0	13.7	-	331.1	-	-

Table 3.35: Statistical Analysis of Absorbed Energy for Mill 4.

Group	No. of Test Locations	Absorbed Energy (ft-lbs)				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		0 F							
		Min	Max	Mean	COV, %				
A572-T1	28	90.7	175.0	135.1	14.4	830.4	322.8	2.57	0.077
A572-T2	28	29.0	131.7	71.3	46.3	8830.7	119.9	73.7	0.000
A588-T1	28	94.7	195.3	135.4	17.8	1569.8	460.3	3.41	0.033
A588-T2	28	70.0	303.3	208.7	32.8	24302.1	2250.8	10.8	0.000
Group	No. of Test Locations	40 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		40 F							
		Min	Max	Mean	COV, %				
A572-T1	28	117.0	183.7	142.6	12.1	1245.9	179.7	6.93	0.001
A572-T2	28	61.3	160.0	107.9	28.3	7742.5	82.4	94.0	0.000
A588-T1	28	94.3	215.7	155.5	20.0	2087.8	825.8	2.53	0.081
A588-T2	28	115.7	299.0	251.1	17.4	6508.0	1344.2	4.84	0.009
Group	No. of Test Locations	70 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		70 F							
		Min	Max	Mean	COV, %				
A572-T1	28	107.0	210.0	150.1	15.3	6729.6	369.2	18.2	0.000
A572-T2	28	80.0	179.0	121.2	24.0	1770.6	107.6	16.5	0.000
A588-T1	28	92.0	216.0	155.1	19.5	2997.5	658.9	4.55	0.011
A588-T2	28	206.7	318.7	256.1	14.4	9163.5	375.6	24.4	0.000

Table 3.36: Statistical Analysis of Absorbed Energy for ill 5.

Group	No. of Test Locations	Absorbed Energy (ft-lbs)				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		0 F							
		Min	Max	Mean	COV, %				
A572-T1	14	13.3	87.0	40.6	56.3	4915.6	156.2	31.48	0.000
A572-T2	14	21.7	148.0	70.7	67.8	28410.0	120.6	235.56	0.000
A572-T3	14	6.7	90.0	41.5	74.2	9394.8	246.7	38.08	0.000
A572-T4	14	8.3	29.7	13.7	44.6	268.7	18.2	14.76	0.002
A588-T1	21	10.7	137.7	58.1	67.3	10430.5	541.2	19.27	0.000
A588-T2	21	41.7	126.3	83.4	27.4	866.2	483.9	1.79	0.195
A588-T3	21	13.7	142.7	80.2	52.1	14358.1	340.5	42.17	0.000
A588-T4	7	19.3	29.7	24.4	16.5	-	16.2	-	-
Group	No. of Test Locations	40 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		40 F							
		Min	Max	Mean	COV, %				
A572-T1	14	23.7	111.3	56.2	47.6	6864.3	202.7	33.9	0.000
A572-T2	14	47.0	148.0	100.8	39.1	18409.0	145.4	127	0.000
A572-T3	14	18.3	107.3	50.5	66.0	12841.1	130.6	98.3	0.000
A572-T4	14	10.7	42.7	23.5	46.1	1201.0	27.8	43.2	0.000
A588-T1	21	23.0	259.3	96.2	55.3	15356.4	1434.6	10.7	0.001
A588-T2	21	82.7	165.0	122.3	18.8	2058.0	361.6	5.69	0.012
A588-T3	21	31.3	155.3	105.2	40.6	16977.5	137.2	124	0.000
A588-T4	7	39.0	57.0	50.0	14.0	-	48.7	-	-
Group	No. of Test Locations	70 F				MSA (ft ² -lbs ²)	MSW (ft ² -lbs ²)	F-Ratio	p-value
		70 F							
		Min	Max	Mean	COV, %				
A572-T1	14	73.0	118.7	89.3	13.9	723.8	105.8	6.84	0.023
A572-T2	14	86.7	210.0	143.4	26.3	14081.1	367.1	38.4	0.000
A572-T3	14	12.3	144.0	70.0	67.0	26986.8	138.1	195	0.000
A572-T4	14	14.3	75.7	33.4	57.9	3669.8	99.7	36.8	0.000
A588-T1	21	57.7	229.3	127.8	36.9	15465.7	751.5	20.6	0.000
A588-T2	21	106.7	187.7	144.9	13.3	1436.6	253.5	5.67	0.012
A588-T3	21	31.3	165.0	111.8	36.3	12849.5	402.0	32.0	0.000
A588-T4	7	75.0	105.3	89.6	10.9	-	94.8	-	-

Table 3.33 shows that, for Mill 1, there were three groups (A572-T2, A588-T2, and A588-T3) at 0°F and 70°F where the p value was greater than 0.05. Test locations impact the variability in absorbed energy in these three groups. In other words, the large variability mainly stems from the variability within a plate. In contrast, there were only two thickness groups at 40°F (A588-T2 and A588-T3) that suggest larger within-plate variability arising from test location differences.

By interpreting results for other mills in a manner similar to that discussed for Mill 1, it is found, as seen from Table 3.34, that Mill 3 had three thickness groups (A572-T2, A588-T1, and A588-T3) that showed significant within-plate variability for 0°F and 40°F. At 70 °F, there was only one thickness group (A588-T3) that suggests significant within-plate variability.

It can be observed from Table 3.35 that Mill 4 had relatively low p values with only one thickness group displaying the significance of within-plate variability at 0°F and 40°F. The between-plate variability dominated the overall variability for every thickness group at 70°F.

Finally, for Mill 5, Table 3.36 shows that the between-plate variability dominated the overall variability in almost every group studied at all test temperatures. With only one exception (A588-T2, 0°F), no p value exceeded 0.05, which indicates that within-plate variability was not significant for Mill 5.

Although the four mills studied do not show similar variability trends, an overall analysis summarized in Table 3.37 that combines the data from all the mills (in the 4-mill group) clearly shows that the variability between plates dominates the overall variability for both grades of steel and for all thickness groups at the three test temperatures. In summary, it is seen that for every thickness group, within-plate variability arising from samples at different test locations was not significant with respect to the overall variability. The variability in absorbed energy mainly stems from the variability between plates.