Research Note

A Statistical Analysis of the Mechanical Properties of the Beam 14 in Lines 630 and 650 of Iran National Steel Industrial Group

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Abstract

Structural steel sections are mainly used in beams and columns of building frames. Iran National Steel Industrial Group is among the oldest and largest producers of beams in Iran. It has two beam production lines, namely Line 630 and Line 650. In this study, the mechanical properties of manufactured beams in these production lines were compared. Based on the t-test results, the elongation is significantly higher in Line 650 products while tensile strength is higher in Line 630. However, the two lines do not show any significant differences in the yield stress. Mann-Whitney test was also used to determine if one of the mechanical properties significantly differs in the two lines products. Based on the test, the tensile strength, elongation and yield stress were significantly different in the two production lines. According to the Levene and Fisher test, Line 650 products were more homogeneous in terms of the tensile strength and yield stress while Line 630 products were more homogeneous with regard to elongation. Moreover, the length of the production line and the cooling time seem to affect the mechanical properties. In addition, an inverse relationship between tensile strength and beam elongation was observed in this study.

Keywords: Beam; Mechanical properties; Student's t tests; Mann-Whitney test; Levene test.

1. Introduction

The steel industry is one of the most influential industries in the industrial development of any country. It is the second largest industry after oil and gas industries with the estimated world's trade volume of $ 900 billion. Steel is used in many important industries such as energy, construction, transportation, automotive, infrastructure, machinery and packaging. A major product in the steel industry is the beam. Normal beams are manufactured with a height between 80 and 600 mm and are used in pillars, trusses, lintels, roofs, and Honeycomb bridges. Iran National Steel Industrial Group (INSIG), the first casting and rolling mill in Ahvaz, has an ingot casting capacity of 400,000 tons per year and a 1,000,000 ton capacity of producing rolled steel per year. There are two beam production lines in INSIG, namely Line 630 and Line 650. The latter was established in 1970 and became operational in 1972 while the former was founded in 1977 and exploited in 1983. The main activity of these lines includes the production of IPE and IPN beams in sizes 14, 16, 18 and 20. Of course, in Line 630 only beams in sizes 14 and 16 are manufactured. The lines are also capable of producing studs and T-beams. The production capacity of Lines 630 and 650 is 385000 tons per year. In this study, the beams mechanical properties such as yield stress, tensile strength and elongation in the both 630 and 650 lines of INSIG were compared using statistical techniques. The techniques were used in this study can help engineers and researchers with different disciplines to improve and enhance production lines. A number of well-known companies that continually benefit from these techniques include BMW, AUDI, Samsung, Sony, Henkel, airlines such as Boeing and Airbus, and especially organizations such as NASA, all of which are among the leading pioneers in their business and industry in terms of innovation. Unfortunately, statistical procedures for designing experiments are not known in most Iranian factories and few if any factories or research institutes in the country have ever opted for using these methods. Given the fact that the raw materials (ingots) are the same in the two lines, any significant difference between the two can be attributed to the effective role of other potential factors. Not surprisingly, any comparative analysis between the two lines would be valid as long as the item to be compared is manufactured in

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both lines; therefore, beams 14 were chosen from each line for the purpose of comparison. Data used in this section are collected between May 14, 2015 and May 22, 2015. The ingots used in the two production lines during this period were of the same quality. The data were generated in the laboratories of INSIG and included the mechanical and physicochemical properties of the beam 14 samples from each production line in the above-mentioned period. In this study, the mechanical properties of the products from the two production lines were compared both in terms of mean, median and also homogeneity. In this study, The Student t-test was applied to compare the two independent groups and Mann-Whitney test to compare the two independent groups. Also, the Levene test and F-test were used for the comparison of dispersion. In the materials and methods Section, statistical tests were used in this study are briefly presented. To perform statistical analysis, Minitab 16 and SPSS 18 were used. The result of our analysis are presented in Section 3. In the final Section, the discussion and conclusion, the obtained results are analyzed.

2. Materials and Methods

It is of interest to determine if the mechanical properties of beam, for example tensile strength, in one Line tends to contain larger values than the other Line. One of the aims of this research is to apply statistical test for determining whether measures of central tendency such as mean or median in two 630 and 650 Lines differ or not. In the special case where the data within each group are known to be normally distributed, and the differences between the groups are additive, the t-test may be used. These are very strong assumptions that rarely occur in the industry. For example, the mean of one group may be greatly influenced due to the existence of one or more outliers in that group, hence rendering the t-test is unreliable [1].

In many cases, where the data are skewed or there are outliers among the data, or the difference between the groups is not additive but multiplicative, the Mann-Whitney test is used to compare two independent groups. Mann-Whitney is based on the rank of the data and is not dependent on the probability distribution of the data. Therefore, it is a nonparametric test. The fundamental difference between the Student's t test and Mann-Whitney is that in the former the means of two populations are compared while in the latter the medians of the two groups are compared. See Wilcoxon [2] and Mann- Whitney [3] for more information.

In many cases, especially in industry, our interest is to compare the homogeneity in two or more populations. For example, when there are poor products due to their heterogeneity, the first step toward reforming the status quo would be comparing the homogeneity of the products produced by various machines to find the faulty devices. There are several tests to determine whether the variances of two populations differ or not. Seven equality tests of variances were compared by Lim and Loh [4]. Bartlett test, F-test and Levene test are the most well-known tests for equality of variances. Bartlett test is used when the data are normally distributed in the comparing populations. The test is sensitive to the non-normality of the data, and therefore its application is limited. For more details see Bartlett [5] and Snedecor and Cochran [6] F-test is equivalent to the Bartlett test in comparing two variances. F-test is known to be extremely sensitive to non-normality, so Levene test is better for testing the equality of two variances. In Levene test, the distance of the observations from the median is used instead of that from the mean and consequently, is not sensitive to outliers and can also be used for small sample volumes. In order to use the Levene test, the data should have a continuous distribution and do not need to be necessarily normal. Therefore, the Levene test is a nonparametric test. More details can be found in Rees [7] and Lim and Loh [4].

3. Comparison of the mechanical properties of the beam 14 in Lines 630 and 650

3. 1. Compare the average mechanical properties using t-test

In this section, the mechanical properties of beam 14 in Lines 630 and 650 are compared using t-test. The results of the comparisons are presented in Tables 1, 2 and 3 for elongation, tensile strength and yield stress, respectively. T-test is done with two different assumptions: (a) equal variances were assumed and (b) equal variances were not assumed. Due to the p- value in Levene's test for equality of variances in these tables, the assumption of equal variances was rejected. In the t-test for equality of means, the null hypothesis is the equality of the average of the two groups. Due to the p- value ($p<0.01$) of this part in Tables 1 and 2, there is a significant difference between the mechanical properties of products in Lines 630 and 650. Based on the results of Table 1, elongation of products in Line 650 is significantly more than that in Line 630. To be more precise, elongation of beams manufactured in Line 650, with an average of about 1.58061 units is greater than that of the beams produced in Line 630. Also, a 95% confidence interval of the difference of elongation in the two lines is (-2.44552, -.71571).

Based on the results of Table 2, tensile strength of products in Line 630 is significantly higher than that in Line 650. To be more precise, tensile strength of manufactured beams in Line 630, with an average of about 13.24490 unit is greater than that of the beams produced in Line 650. Also, a 95% confidence interval of the difference of tensile strength in the two lines is (5.03137, 21.45843). As shown in Table 3, although the yield stress is higher in the products of Line 630, the lines do not show any significant differences.

Table 1. T-test for the equality of the elongation (%) in Lines 630 and 650.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	13.583	.000	-3.604	194	.000	-1.580	.438	-2.445	-.715
Equal variances not assumed			-3.604	161.628	.000	-1.580	.438	-2.446	-.714

Table 2. T-test for the equality of the tensile strength (Nmm^{-2}) in Lines 630 and 650.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	15.648	.000	3.180	194	.002	13.244	4.164	5.031	21.458
Equal variances not assumed			3.180	154.626	.002	13.244	4.164	5.018	21.458

Table 3. T-test for the equality of the flow stress (Nmm^{-2}) in two Lines 630 and 650.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	16.988	.000	1.758	194	.080	7.489	4.261	-.914	15.894
Equal variances not assumed			1.758	150.76	.081	7.489	4.261	-.929	15.909

3. 2. Checking the assumptions of t-test

As previously mentioned, the use of the t-test is based on assumptions of normality of data provided in the two groups that are investigated in this sub section. Kolmogorov-Smirnov test is used for the normality of the data. The results of Kolmogorov-Smirnov test for mechanical properties in the two lines are presented in Table 4. Considering the p- values in Table 4, the normality assumption is rejected ($p<0.01$) in all cases. Thus, all groups must be considered non-normal. Hence the t-test results are not reliable. Due to the non-normality of data, we used Mann-Whitney test to compare the mechanical properties of the two production lines in the next sub section.

3. 3. Comparing the median of the mechanical properties using Mann-Whitney test

Here a Mann-Whitney test is used to determine whether the mechanical properties of the produced beams in one line significantly differ from those of the produced beams in the other one or not. The results of the test of yield stress, tensile strength and elongation are presented in Table 5r. With regard to the p-values, the tensile strength and elongation are significantly different ($p<0.01$) in the two production lines. In addition, the yield stress is significantly different ($p<0.05$) in the two production lines, which is against the t-test result.

According to the results of Tables 5 and 6, it can

Table 4. One-sample Kolmogorov-Smirnov test for Normal distribution of the elongation (%), tensile strength (Nmm^{-2}) and flow stress (Nmm^{-2}) in two Lines 630 and 650.

	Line 630			Line 650		
	Elongation	Tensile strength	Flow stress	Elongation	Tensile strength	Flow stress
Kolmogorov-Smirnov Z	.899	.579	.710	-.050	-.038	-.055
Exact Sig. (2-tailed)	.000	.000	.000	.000	.000	.000

Table 5. Mann-Whitney test for the equality of the mechanical properties in Lines 630 and 650.

	Flow stress (Nmm^{-2})	Tensile strength (Nmm^{-2})	Elongation (%)
Mann-Whitney U	3966.000	3389.000	3360.000
Wilcoxon W	8817.000	8240.000	8211.000
Z	-2.106	-3.559	-3.633
Asymp. Sig. (2-tailed)	.035	.000	.000

Table 6. Mean and sum of the ranks of mechanical properties in Lines 630 and 650.

Line		Mean Rank	Sum of Ranks
Flow stress (Nmm^{-2})	630	107.03	10489.00
	650	89.97	8817.00
Tensile strength (Nmm^{-2})	630	112.92	11066.00
	650	84.08	8240.00
Elongation (%)	630	83.79	8211.00
	650	113.21	11095.00

be argued that the yield stress and tensile strength are significantly higher in Line 630 products, while the elongation is significantly higher in Line 650.

3. 4. Comparing the properties using graphs

In this sub section, the mechanical properties of beam 14 in two lines 630 and 650 are compared using box-plot. The results of the comparisons can be seen in Fig. 1, Fig. 2 and Fig. 3 for the elongation, tensile strength and yield stress, respectively. The Figures confirm the Mann-Whitney test results. There are some outliers in these Figures. The presence of outliers in data is a good reason for using Mann-Whitney test instead of the t-test.

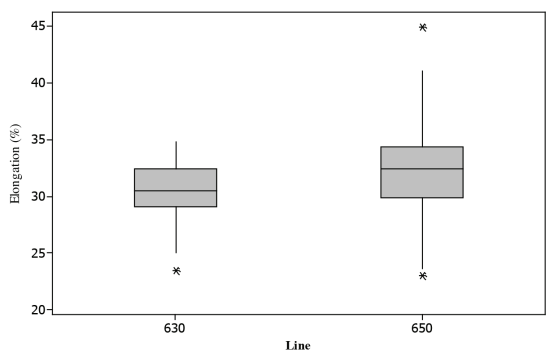

Fig. 1. A comparison of the elongation in manufactured products in the two lines.

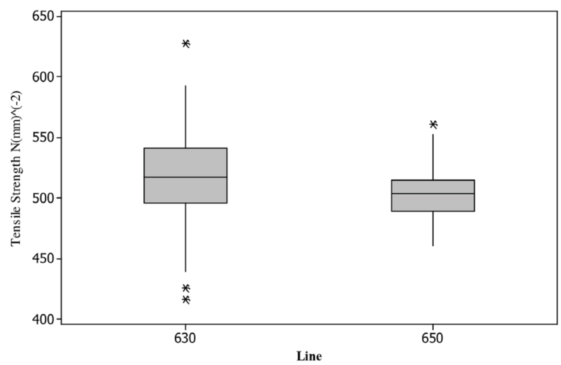

Fig. 2. A comparison of the tensile strength in the two lines.

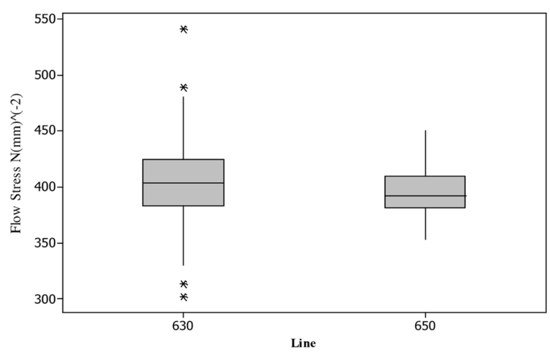

Fig. 3. A Comparison of the flow stress in the two lines.

3. 5. Variance equality test results of mechanical properties of beam 14 in a comparison of production lines 630 and 650

As already mentioned, in many cases, especially in the industry, comparing the homogeneity of two or more communities is necessary. In this part, our goal is to compare the products homogeneity in Lines 630 and 650. The variance equality tests such as Levene and Fisher's test were used. The more homogeneous the products were, the smaller variance we expected. Here are two assumptions. The null hypothesis states that the ratio of the two populations standard deviations is one (they are equal) and the alternative is that the ratio is not equal to one (they are not equal). The significance level of the test (Alpha) is 0.05. Table 7 represents the output for yield stress. The test results are at the bottom of the output.

For the yield stress, because the p-values of 0.000 are less than the significance level, the null hypothesis has been rejected that the standard deviations are equal. These data provide enough evidence to claim that the two populations have unequal standard deviations. Additionally, the confidence intervals for the standard deviation and the variance ratios both do not include one, further suggesting they are not equal. The variances in Lines 630 and 650 are 1366.211 and 413.289, respectively. Thus, it is reasonable to assume that Line 650 products are more homogeneous in terms of the yield stress.

Due to the similarity of the outputs, the outputs for the tensile strength and elongation are not presented. As with the tensile strength and elongation, because the p-values of 0.000 are less than the significance level, the null hypothesis has been rejected that the standard deviations are equal.

The variances of tensile strength in Lines 630 and 650 are 1278.650 and 420.980, respectively. Thus, it is reasonable to assume that Line 650 products are more homogeneous in terms of the tensile strength.

The variances of elongation in Lines 630 and 650 are 5.206 and 13.640, respectively. Thus, it is reasonable to assume that Line 630 products are more homogeneous as far as elongation is concerned.

Fig. 4, Fig. 5 and Fig. 6 show the interval plot of the yield stress, tensile strength and elongation, respectively. It can be seen that the Figures confirm the previous results.

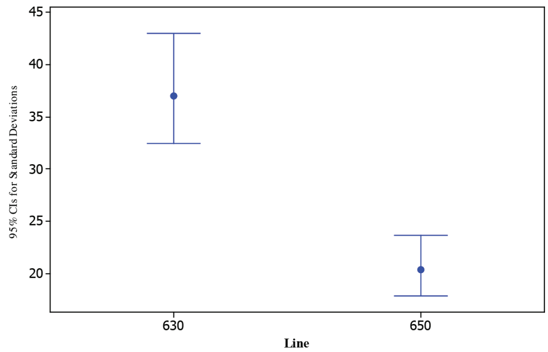

Fig. 4. Interval plot of the flow stress (Nmm^{-2}).

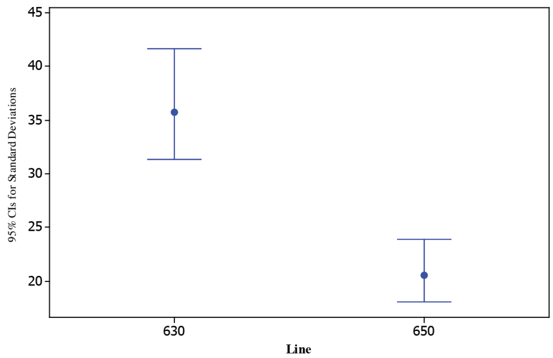

Fig. 5. Interval plot of the tensile strength (Nmm^{-2}).

Table 7. F and Levene's test for the equality of the flow stress (Nmm^{-2}) variances in Lines 630 and 650.

1) Method				
Null hypothesis Sigma(630 Flow Stress)(Sigma(650 Flow Stress))$^{-1}$ = 1 Alternative hypothesis Sigma(630 Flow Stress)(Sigma(650 Flow Stress))$^{-1}$ not = 1 Significance level Alpha = 0.05				
2) Statistics				
Variable N StDev Variance 630 Flow Stress 98 36.962 1366.211 650 Flow Stress 98 20.329 413.289 Ratio of standard deviations = 1.818 Ratio of variances = 3.306				
95% Confidence Intervals	CI for StDev Ratio		CI for Variance Ratio	
Distribution of Data	Lower bond	Upper bond	Lower bond	Upper bond
Normal	1.488	2.221	2.215	4.933
Continuous	1.344	2.180	1.806	4.752
3) Tests				
Method	DF1	DF2	Test Statistic	P-Value
F Test (normal)	97	97	3.31	0.000
Levene's Test (any continuous)	1	194	16.95	0.000

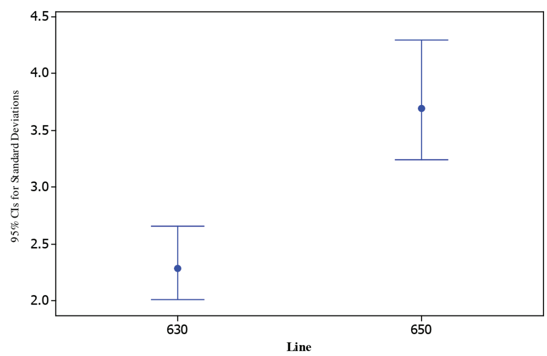

Fig. 6. Interval plot of the elongation (%).

4. Discussion and Conclusion

In this study, the mechanical properties of manufactured beams in Iran National Steel Industrial Group lines were compared. Based on the t-test results, the elongation is significantly higher in Line 650 products while tensile strength is higher in Line 630. However, the two lines do not show any significant differences in the yield stress. According to the results of Kolmogorov-Smirnov test, the normality assumption was rejected in all cases. Therefore, all groups of data must be considered non-normal. Also, there are some outliers in the data sets which are visible in box-plots. Hence, the t-test results are not reliable. We also used Mann-Whitney test to determine if one of the mechanical properties significantly differs in the two lines products. Based on the Mann-Whitney test, the tensile strength, elongation and yield stress are significantly different in the two production lines. According to the results, it can be said that the yield stress and tensile strength are significantly higher in Line 630 products, while elongation is significantly higher in Line 650.

According to the Levene and Fisher test, for the yield stress, tensile strength and elongation, the null hypothesis has been rejected that the standard deviations are equal in the two lines. Line 650 products are more homogeneous in terms of the tensile strength and yield stress while Line 630 products are more homogeneous with regard to the elongation.

Now, it may raise the question that why the mechanical properties are not the same in the two lines? Since the ingots used in the two production lines and other environmental conditions during the period of study were of the same quality, engineers are suspicious about the length of the production line. The length of the production line and the cooling time seem to affect the mechanical properties. Line 630 is shorter than Line 650. The short beam rolling process and thus less cooling time cause the tensile strength to be higher in Line 630 beams. it is also observed in this study that there is an inverse relationship between the tensile strength and beam elongation. Therefore, the higher the tensile strength in beams is, the less elongation they have.

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