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Development of Models for the Prediction of Mechanical Properties of Rolled Ribbed Medium Carbon Steel

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Abstract

The target of the contribution is to outline possibilities of applying modelling for the prediction of mechanical steel properties of ribbed medium carbon steel rods. The impact toughness; tensile properties - tensile strength at maximum load, tensile strength at break and yield strength; as well as hardness property of medium carbon steels rolled from inland rolling mills were determined experimentally and quantitatively. The experimental data obtained were used to develop models using stepwise techniques (statistical analysis). The precise tool used for development of these models was multiple regression analysis (Analysis of Variance- ANOVA) and the models were used to obtain the predicted (numerical) values of these properties for each of the materials investigated. The outcome models enable the prediction of mechanical properties of the material on the basis of decisive parameters influencing these properties. Both the experimental and calculated (numerical) values of these properties were subjected to statistical tests namely, paired t-tests, correlation coefficient, standard error, standard deviation and variance; which were found valid within the limit of experimental error.. By applying modelling that are combination of mathematical and physical analytical methods it will be possible to lower the manufacturing cost, environmental costs and enable the users of the products to also confirm the predicted properties easily before use.

Keywords: Modelling; mechanical properties; rolled-ribbed steel; multiple regression analysis, validation and statistical analysis

NOMENCLATURE

C=Carbon (%),

Mn=Manganese (%),

Si= Silicon (%),

Ni= Nickel (%),

Cr = Chromium (%),

P= Phosphorus (%),

S= Sulphur (%),

Cu= Copper (%),

Co= Cobalt (%),
W= Tungsten (%)
Fe= Iron (%)
Dia= Diameter of the steel rods (mm)
THV = Transverse Hardness Value (RHN)
LHV: = Longitudinal Hardness Value (RHN)
TS@L_{Max} = Tensile Strength At Maximum Load (N/mm^2)
$TS_{@Break}$ = Tensile Strength At Break (N/mm^2)
YS= Yield Strength (N/mm^2)
IS= Impact Strength (J)
THV_1 = Transverse Hardness Value Predicted from Model Type-1 (RHN)
LHV_1: = Longitudinal Hardness Value Predicted from Model Type-1 (RHN)
TS@$L_{Max\ 1}$ = Tensile Strength At Maximum Load Predicted from Model Type-1 (N/mm^2)
$TS_{@Break1}$ = Tensile Strength At Break Predicted from Model Type-1 (N/mm^2)
YS_1= Yield Strength Predicted from Model Type-1 (N/mm^2)
IS_1= Impact Strength Predicted from Model Type-1 (J)
THV_2 = Transverse Hardness Value Predicted from Model Type-2 (RHN)
LHV_2: = Longitudinal Hardness Value Predicted from Model Type-2 (RHN)
TS@$L_{Max\ 2}$ = Tensile Strength At Maximum Load Predicted from Model Type-2 (N/mm^2)
$TS_{@Break2}$ = Tensile Strength At Break Predicted from Model Type-2 (N/mm^2)
YS_2= Yield Strength Predicted from Model Type-2 (N/mm^2)
IS_2= Impact Strength Predicted from Model Type-2 (J)

1. Introduction

Mechanical properties of materials are of prime interest to the Engineers and the results of tests to determine these properties are used for various purposes. They are of concern to a variety of parties such as producers and consumers of materials, research organisations, government agencies, because they have different areas of application of the material. Consequently, it is imperative that there be some consistency in the manner in which tests are conducted, and in the interpretation of results so that appropriate choice of materials will be made by the users.

The possibility to model the microstructure and mechanical properties of ribbed steel components enables the engineers to use the property variation obtained in steel rolled as an input to structural simulation programs such as JAVAS, MATLAB and VISUAL BASIC, and thereby be able to make good progress in proper and accurate measurements. The mechanical properties of rolled steels are very sensitive to composition, rolling process, section sizes and solidification behaviour, and thermal treatment.

Bringing the rolling process and materials testing closer to the materials designers and end users will lead to a reliable, and optimised design of complex geometries of the materials. Improvement in the degree of integration between processing, metallurgical and mechanical properties of steel ribbed can also be achieved by the process. This will lead to a shorter lead-time, right from the first design attempt and sounder components which strengthen the competitiveness of the material and rolling industry. The linking between the process, microstructure and mechanical properties has been implemented in commercial simulation software by various researchers such as Bingji (2009) that worked on development of model-intensive web-based rolling mill applications. Study on application of artificial intelligence methods for prediction of steel mechanical properties was carried out by Jan^Íková et al , (2008). Myllykoski, et al (1996) studied the development of prediction model for mechanical properties of batch annealed thin steel strip by using artificial neural network modelling, and Dobrzański, et al (2005) studied methodology of the mechanical properties prediction for the metallurgical products from the engineering steels using the Artificial Intelligence methods ; and Simecek, and Hajduk (2007) studied the prediction of mechanical properties of hot rolled steel products. All the works reviewed did not address modelling to predict the following mechanical properties- impact toughness; tensile properties - tensile strength at maximum load, tensile strength at break and yield strength; as well as hardness property of rolled ribbed medium carbon steel. Fully know the engineering importance of this material in structural industry; it becomes highly imperative that a study on how these properties can rapidly be predicted for the use rolling industries, designers and end users should be investigated. To solve this problem of rapidly prediction of these mechanical properties of rolled ribbed medium carbon steel, a modelling approach was sought; this is rationale behind this work. Therefore, enabling the modelling and integration of these processes will lead to substantial shortening of the development time, cost reduction and fewer risks.

Hence, the research study the development of models for the rapid prediction of mechanical properties-Tensile Strength At Maximum Load ($TS@L_{Max}$), Tensile Strength At Break ($TS_{@Break}$), Yield Strength (YS) , Transverse Hardness Value (THV), Longitudinal Hardness Value (LHV), and Impact Strength (IS) of a very universal engineering material – rolled ribbed medium carbon steel, commonly used in various structural engineering designs. While the specific objectives towards achieving the set aim are to determine the chemical compositions of the as-received ribbed bars of diameters 12 mm, 16 mm 20 mm and 25 mm; experimental determination of mechanical properties of the medium carbon steel; development of models from experimental results and validation for rapid prediction of the mechanical properties.

2. Materials and Methods

The rolled ribbed medium carbon steel rods used were obtained from Nigerian Rolling Mills. The rods used were 12 mm, 16 mm, 20 mm and 25 mm in diameters. Other materials included abrasive papers and water as coolant.

2.1 Samples Preparation

A mass spectrometric analyzing machine was used to determine the chemical compositions of the steel rods in accordance with ASTM E50-00 (2005) standard. The as-received steel samples were machined using lathe machine with coolant into various standard tests specimens for hardness, tensile and impact tests. The standard tensile test specimens were prepared according to ASTM E370 standard specification of 130 mm long with a gauge length of 70 mm (Oyetunji, 2010) while the hardness samples were cut with power hacksaw machine into 20 mm long. The specimens for impact test were machined into standard samples in conformity with the Charpy V-notch impact machine specification (Oyetunji, 2010)

2.2 Tests

The experimentally determined mechanical properties on the various prepared standard specimens are tested for hardness, tensile strength, breaking strength, yield strength and impact toughness.

2.2.1 Tensile Test

The tensile test specimen shown in Figure 1 was mounted on the Istron universal testing machine at the jaws- one end stationary and the other movable. The machine was then operated which pulled the specimen at constant rate of extension. The tensile test were performed in accordance with ASTM E8-09/E8M-09 standards (Oyetunji and Alaneme, 2005).

2.2.2 Hardness Test

The surface of the entire hardness test specimen shown in Figure 2 in which an indentation was to be made were ground using 200 nm grinding papers to make them flat and smooth. A diamond indenter under the application of 60 KN was pressed into the surface. The hardness test was performed with the aid of digital Rockwell hardness tester and the machine operational procedure in line with ASTM E18-08b and ASTM E140-07 standards (Oyetunji and Alaneme, 2005).

2.2.3 Impact Test

Each test piece shown in Figure 3 was held horizontally on a vice attached to the impact testing machine such that the notched side faced the approaching hammer. The impact test was performed using V-notch pendulum-type impact testing machine in accordance with ASTM A350 / A350M - 10 standards, (Bello et al, 2007; Oyetunji, 2010 and Waid and Zantopulous,2000).

3.0 Model Development

In formulating the models, the following conditions were assumed: other elements in the materials were assumed insignificant; the materials samples were as-rolled from the companies; there was normal heating regime of the billets in the re-heating furnace; the system was under continuous rolling production; there was no over tension and looping on the rolling line, that is, normal rolling speed; similar rolling scheme was used; and normal water pressure.

Statistical analysis was used to develop the models. The results of the three tests namely tensile, hardness and impact were analyzed statistically by using a routine for correlation, that is, multiple regression analysis. The computation of the multiple regression parameters (coefficients) were obtained with the aid of computer in a stepwise technique using the package known as Statistical Package for Social Science (SPSS). Thereafter, the correlation between the predictors (independent variables) such as sample sizes, percentage carbon, percentage manganese, percentage silicon, percentage phosphorous, percentage sulphur, percentage chromium, percentage nickel, percentage copper, percentage cobalt, percentage tungsten and percentage iron shown in Table 1 with the tensile strength at maximum load, tensile strength at break, yield strength, impact energy and hardness were carried out. They all indicate good correlation. (with correlation coefficient ® ranges from 0.9492 to 0.9999). The multiple regression analysis in accordance with Oyetunji, 2010 was used to determine the respective relations for the tensile properties, impact energy and hardness with and without percentage iron for the four materials samples used.

Resulting models from multiple regression analysis that predict the mechanical properties of medium carbon rolled ribbed steel were presented in Appendix 1. Hence, the outcome models that predicted the mechanical properties of the rolled ribbed bars as obtained in SPSS (Appendix 1 were presented as equations 1 to 12.The predicted values were manually obtained from these models through the use scientific calculator.

MODELS TYPE-I (WITH IRON)

A_1: TRANSVERSE HARDNESS VALUE (THV)

$$\begin{aligned} THV_1 = {} & -8761.045 - 3.121Dia. + 368.952\%\mathrm{C} + 90.524\%\mathrm{Mn} + 63.113\%\mathrm{Si} - 1179.607\%\mathrm{P} \\ & - 497.482\%\mathrm{S} + 52.638\%\mathrm{Ni} - 19.221\%\mathrm{Cu} + 281.419\%\mathrm{Co} + 242.816\%\mathrm{W} \\ & + 88.434\%\mathrm{Fe} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1) \end{aligned}$$

B_1: LONGITUDINAL HARDNESS VALUE (LHV)

$$\begin{aligned} LHV_1 = {} & -10185.1 - 3.918\mathrm{Dia.} + 478.255\%\mathrm{C} - 94.675\%\mathrm{Mn} + 217.623\%\mathrm{Si} + 454.022\%\mathrm{P} \\ & - 2576.025\%\mathrm{S} + 129.133\%\mathrm{Ni} - 858.781\%\mathrm{Cu} - 1436.090\%\mathrm{Co} + 1245.566\%\mathrm{W} \\ & + 104.783\%\mathrm{Fe} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2) \end{aligned}$$

C_1: TENSILE STRENGTH AT MAXIMUM LOAD ($TS@L_{Max}$)

$$\begin{aligned} TS_{@LMax\ 1} = {} & 94603.105 - 40.236Dia. + 8869.178\%C - 4228.685\%Mn + 2683.913\%Si \\ & + 42726.779\%P - 18345.1\%S - 2392.061\%Ni - 6662.409\%Cu - 20887.8\%Co \\ & + 12707.265\%W - 965.300\%Fe \qquad \ldots\ldots\ldots\ldots\ldots (3) \end{aligned}$$

D_1: TENSILE STRENGTH AT BREAK ($TS_{@Break}$)

$$\begin{aligned} TS_{@Break\ 1} = {} & 29685.912 - 24.84Dia. + 6672.319\%C - 2449.659\%Mn + 1983.252\%Si \\ & + 23344.305\%P - 15350.3\%S - 1043.603\%Ni - 5179.974\%Cu \\ & - 13607.1\%Co + 8505.157W - 303.993\%Fe \qquad \ldots\ldots\ldots\ldots\ldots (4) \end{aligned}$$

E_1: YIELD STRENGTH (YS)

$$\begin{aligned} YS_1 = {} & 18771.779 - 47.062\ Dia. + 6806.016\%C - 2642.321\%Mn + 2267.215\%Si \\ & + 26006.971\%P - 17867.7\%S - 1080.794\%Ni - 6223.144\%Cu - 15487.0\%Co \\ & + 11112.811\%W - 190.116\%Fe \qquad \ldots\ldots\ldots\ldots (5) \end{aligned}$$

F_1: IMPACT STRENGTH (IS)

$$\begin{aligned} IS_1 = {} & 49533.516 + 18.746Dia. - 3143.437 * \%C - 1210.22\%Mn + 293.275 * \%Si \\ & + 10289.641\%P - 2665.421\%S - 596.001\%Ni - 1908.336\%Cu - 5937.968\%Co \\ & + 1756.776\%W - 486.748\%Fe \qquad \ldots\ldots\ldots\ldots (6) \end{aligned}$$

MODELS TYPE-II (WITHOUT IRON)

A_2: TRANSVERSE HARDNESS VALUE (THV)

$$\begin{aligned} THV_2 = {} & 79.057 - 3.20Dia. + 292.132\%C + 1.789\%Mn - 24.753\%Si - 1259.459\% \\ & - 598.514\%S - 89.020\%Cr - 36.112\%Ni - 108.391\%Cu + 192.169\%Co \\ & + 160.011\%W \qquad \ldots\ldots\ldots\ldots\ldots (7) \end{aligned}$$

B_2: LONGITUDINAL HARDNESS VALUE (LHV)

$$\begin{aligned} LHV_2 = {} & 289.360 - 4.012Dia. + 387.232\%C - 199.816\%Mn + 113.513\%Si + 359.407\%P \\ & - 2695.735\%S - 105.478\%\ Cr + 23.974\%Ni - 964.437\%Cu - 1541.841\%Co \\ & + 1147.451\%W \qquad \ldots\ldots\ldots\ldots\ldots (8) \end{aligned}$$

C_2: TENSILE STRENGTH AT MAXIMUM LOAD (TS_{Max})

$$\begin{aligned} TSL_{max\,2} = {} & -1891.430 - 39.370Dia + 9707.708\% - 3260.090\%Mn + 3643.010\%Si \\ & + 43598.406\%P - 7242.3\%S + 971.700\%Cr - 1423.307\%Ni - 5689.067\%Cu \\ & - 19913.6\%Co + 13611.132\%W \qquad \ldots\ldots\ldots\ldots (9) \end{aligned}$$

D_2: TENSILE STRENGTH AT BREAK ($TS_{@Break}$)

$$\begin{aligned} TS_{@Break\,2} = {} & -702.189 - 24.569Dia. + 6936.389\%C - 2144.629\%Mn + 2285.292\%Si \\ & + 23618.798\%P - 15003.0\%S + 306.008\%Cr - 738.523\%Ni \\ & - 4873.448\%Cu - 13300.3\%Co + 8789.803\%W \qquad \ldots\ldots\ldots\ldots (10) \end{aligned}$$

E_2: YIELD STRENGTH (YS)

$$\begin{aligned} YS_2 = {} & -232.782 - 46.891Dia. + 6971.164\%C - 2451.557\%Mn + 2456.109\%Si \\ & + 26178.638\%P - 17650.5\%S + 191.376\%Cr - 889.998\%Ni - 6031.445\%Cu \\ & - 15295.1\%Co + 11292.827\%W \qquad \ldots\ldots\ldots\ldots (11) \end{aligned}$$

F_2: IMPACT STRENGTH (IS)

$$\begin{aligned} IS_2 = {} & 876.643 + 19.182Dia. - 2720.612\%C - 721.811\%Mn + 776.895\%Si \\ & + 10729.154\%P - 2109.332\%S + 489.975\%Cr - 107.512\%Ni - 1417.534\%Cu \\ & - 5446.725\%Co + 2212.546\%W \qquad \ldots\ldots\ldots\ldots (12) \end{aligned}$$

3.1 Validation of the Developed Models

Validation of the developed models was carried out in two stages: first by verification through manual computation and second by statistical analysis. The verification was done by using a set of predetermined data for the prediction of the mechanical properties of the specimen. The theoretical (numerical) results obtained were compared to experimental results as shown in Table 2. From the results, it was shown that theoretical and experimental values were approximately equal. To further ascertain the consistency of this result, validation by statistical test was carried.

The experimental and numerical data of each property were subjected to the following statistical tests: Paired t-tests; Correlation Coefficient; and Standard Error of Prediction.. The validation tests indicate that there was good agreement between the numerical and experimental values. From the paired t-tests results in Tables 3 –8, the pair difference and the standard deviations values were very small. The acceptable interval range was also very narrow and these confirmed that there was no significant difference between the predicted and experimental values. According to Oyetunji (2010), a very high positive correlation (R) was observed when the coefficient of correlation test was carried out on the predicted and experimental data of all the mechanical properties estimated. This was an indication of excellent reliability of the obtained data. Also, there was none of the data that its standard error value was more than 2.721 % for both the predicted and experimental data. This implies good agreement in the two data as the standard error values *in* Tables 9-14 were considered insignificant and therefore neglected because standard error values were less than 10% (Kusiak and Kuziak,2002; and Oyetunji, 2010). There were good agreements between the predicted and experimental data for all validation tests done on the data collected, it can therefore be said that the developed models were reliable and valid. And they can be used to predict the mechanical properties of rolled ribbed medium carbon steels that were studied.

3.2 Models with and without Iron

A critical observation of both types-models developed was made. This revealed that the type-2, that is, models without iron inclusive predicted the observed value more accurately than the type-1 (models with iron inclusive). This could be seen as calculated and shown in Tables 8 –14 as the standard error of the models for types-1 and 2 models indicated. The standard errors values of the predicted values from developed models and experimental values were very close and are less than 10%. This shows that both the experimental values and predicted values from developed models were valid (Kusiak and Kuziak, 2002; and Oyetunji, 2010). Though, both models types are valid, but type-2 predicted almost exactly the same values of the mechanical properties-Tensile Strength At Maximum Load ($TS@L_{Max}$), Tensile Strength At Break ($TS_{@Break}$), Yield Strength (YS) , Transverse Hardness Value (THV), Longitudinal Hardness Value (LHV), and Impact Strength (IS) of rolled ribbed medium carbon steel rods as the experimental values. Hence, type-2 models are more preferred for perfect accuracy and reliability with insignificant error of prediction.

4. Conclusions

In the field of research oriented on metallurgical technologies control with the aim to optimize a quality of materials by applying models for predicting mechanical properties of rolled ribbed steel rods after experimental works, models were developed and manually tested. These models predicted final mechanical properties-Tensile Strength At Maximum Load ($TS@L_{Max}$), Tensile Strength At Break ($TS_{@Break}$), Yield Strength (YS) , Transverse Hardness Value (THV), Longitudinal Hardness Value (LHV), and Impact Strength (IS) of rolled ribbed medium carbon steel rods on the basis of the knowledge of chemical steel compositions, steel rods section diameters 12 mm, 16 mm , 20 mm and 25 mm; and the conditions of rolling of ribbed medium carbon steel bar.

Thus from the results, the following conclusions were drawn;

The multiple regression analysis is a powerful tool (Analysis of Variance- (ANOVA)) to develop models that predict theoretically the mechanical properties of rolled ribbed medium carbon steel rods.

The predicted and experimental values were in good agreement with each other.

The models developed are excellent in predicting the mechanical properties of the materials studied.

The models type-2 (models without iron inclusive). is more accurate than the models type-1 (models with iron inclusive). in predicting the mechanical properties of rolled ribbed medium carbon steel rods.

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Table 1 Chemical Compositions of the Rolled Ribbed Medium Carbon Steels used in the Research and Predictors (Independent Variables)

X_1 Diameter (mm	X_2 %C	X_3 %Mn	X_4 %Si	X_5 %P	X_6 %S	X_7 %Cr	X_8 %Ni	X_9 %Cu	X_{10} %Co	X_{11} %W	X_{12} %Fe
12	0.359	0.72	0.171	0.016	0.015	0.780	0.080	0.221	0.038	0.157	97.443
12	0.357	0.63	0.101	0.016	0.015	0.690	0.080	0.276	0.016	0.158	97.661
12	0.355	0.74	0.18	0.016	0.014	0.720	0.070	0.249	0.024	0.158	97.474
16	0.358	0.62	0.18	0.041	0.039	0.019	0.075	0.250	0.031	0.148	98.239
16	0.359	0.60	0.19	0.039	0.038	0.021	0.074	0.270	0.028	0.147	98.234
16	0.362	0.67	0.2	0.038	0.042	0.017	0.074	0.260	0.019	0.151	98.167
20	0.389	0.68	0.16	0.042	0.031	0.015	0.026	0.251	0.016	0.121	98.269
20	0.391	0.67	0.18	0.04	0.028	0.018	0.021	0.248	0.014	0.11	98.28
20	0.39	0.61	0.17	0.041	0.031	0.011	0.072	0.253	0.022	0.119	98.281
25	0.422	0.691	0.224	0.031	0.042	0.010	0.021	0.248	0.018	0.158	98.135
25	0.415	0.685	0.219	0.03	0.041	0.010	0.020	0.248	0.017	0.156	98.158
25	0.418	0.72	0.222	0.032	0.038	0.010	0.020	0.252	0.018	0.158	98.112

Table 2: Transverse Hardness Value (Experimental and Numerical Data) with models type-1 (models with iron inclusive) of rolled ribbed medium carbon steel using Chemical Compositions in Table 1

S/ No	Diameter (mm)	Exp. Value	Numerical value	Difference (Exp. Value-Numerical Value)	Remark
A	12	49.60	49.64	-0.04	Insignificant Difference
B	12	48.57	48.61	-0.04	Insignificant Difference
C	12	48.98	49.02	-0.04	Insignificant Difference
D	16	52.25	52.29	-0.04	Insignificant Difference
E	16	52.33	52.37	-0.04	Insignificant Difference
F	16	52.30	52.34	-0.04	Insignificant Difference
G	20	47.45	47.49	-0.04	Insignificant Difference
H	20	49.93	49.97	-0.04	Insignificant

					Difference
I	20	47.94	47.98	-0.04	Insignificant Difference
J	25	54.05	54.09	-0.04	Insignificant Difference
K	25	53.50	53.53	-0.03	Insignificant Difference
L	25	53.72	53.76	-0.04	Insignificant Difference

Table 3. Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Transverse Rockwell Hardness Value A (THV) of Rolled Ribbed Medium Carbon Steel.

S/N	Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steels (THV)	Pair Difference (d)	Square of Pair Difference (d^2)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference (Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α) (99.9%)	Degree of Freedom $t_{v(0.001)}$	Acceptable Interval ($\bar{d}$ + $t_{v(1-\alpha)}$) Sd)	
										Lower Limit	Upper Limit
1	THV_1	5.096E-2	2.2251E-2	4.250E-2	5.569E-5	4.641E-6	2.154E-3	9.99E-1	4.44	3.29E-2	5.207E-2
2	THV_2	-3.421E-2	1.0351E-2	-2.8508E-3	9.3214E-4	7.7678E-5	8.813	9.99	4.44	-4.2E-2	3.63E-

							E-3	E-1			2

Table 4: Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Longitudinal Rockwell Hardness Value A (LHV) of Rolled Ribbed Medium Carbon Steel.

S/N	Longitudinal Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steels (LHV)	Pair Difference (d)	Square of Pair Difference (d^2)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference (Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α) (99.9 %)	Degree of Freedom $t_{v(0.001)}$	Acceptable Interval ($\bar{d}$ + $t_{v(1-\alpha)}$. Sd)	
										Lower Limit	Upper Limit
1	LHV_1	-9.366	8.7648	0.7805	0.1323	0.0110	0.105	0.999	4.44	0.3143	-1.2467
2	LHV_2	-.9.48 E-1	0.9131	-0.079	0.0762	6.350E-3	0.0797	0.999	4.44	-0.4329	0.2749

Table 5.Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Tensile Strength at maximum Load (TS@Lmax) of Rolled Ribbed Medium Carbon Steel.

S/N	**T**ensile Strength at Maximum Load of Rolled Ribbed Medium Carbon Steels (TS@Lmax)	Pair Difference (d)	Square of Pair Difference (d^2)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference (Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α) (99.9 %)	Degree of Freedom $t_{v(0.001)}$	Acceptable Interval ($\bar{d}$ + $t_{v(1-\alpha)}$. Sd)	
										Lower Limit	Upper Limit
1	TS@Lm	-6.268	43.994	-0.522	3.7018	0.3085	0.5554	0.999	4.44	-2.988	1.9436

	ax_1										
2	TS@Lm ax_2	-5.763	32.459	-0.480	2.699	0.2249	0.4743	0.999	4.44	-2.5861	1.6257

Table 6: Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Tensile Strength at Break (TS@Break) of Rolled Ribbed Medium Carbon Steel.

S/N	**T**ensile Strength at Break of Rolled Ribbed Medium Carbon Steels (TS@Break)	Pair Difference (d)	Square of Pair Difference (d^2)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference (Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α) (99.9%)	Degree of Freedom $t_{v(0.001)}$	Acceptable Interval ($\bar{d}$ + $t_{v(1-\alpha)}$ Sd)	
										Lower Limit	Upper Limit
1	$TS@Break_1$	-5.493	27.148	-0.458	2.2395	0.1866	0.432	0.999	4.44	-2.3758	1.4604
2	$TS@Break_2$	-4.914	23.788	-0.410	1.98	0.165	0.406	0.999	4.44	-2.2121	1.3931

Table 7.Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Yield Strength (YS) of Rolled Ribbed Medium Carbon Steel.

S/N	Yield Strength of Rolled Ribbed Medium Carbon Steels **(YS)**	Pair Difference (d)	Square of Pair Difference (d^2)	Mean of Pair Difference ($\bar{d}$)	Variance of Pair Difference Var (d)	Mean of Variance of Pair Difference (Var ($\bar{d}$)	Standard Deviation (Sd)	Confidence Interval (α) (99.9%)	Degree of Freedom $t_{v(0.001)}$	Acceptable Interval ($\bar{d}$ + $t_{v(1-\alpha)}$ Sd)	
										Lower Limit	Upper Limit
1	YS_1	1.116	32.655	0.093	2.959	0.2466	0.4966	0.999	4.44	-2.1119	2.2979
2	YS_2	0.071	0.0012	0.0059	7.0E-5	5.833E-6	2.42E-3	0.999	4.44	-0.0048	0.0167

Table 8.Pair t-test Analysis that Determine the Acceptable Confidence Interval Range of Impact Toughness (IS) of Rolled Ribbed Medium Carbon Steel.

S/	Impact Strength of	Pair	Square of Pair	Mean of Pair	Variance of	Mean of	Standard Deviation	Confidence	Degree of	Acceptable Interval

N	Rolled Ribbed Medium Carbon Steels **(IS)**	Difference (d)	Difference (d^2)	Difference $(\bar{d})$	Pair Difference Var (d)	Variance of Pair Difference (Var $(\bar{d})$	(Sd)	Interval (α) (99.9%)	Freedom $t_{v(0.001)}$	$(\bar{d} + t_{v(1-\alpha)}$ Sd)	
										Lower Limit	Upper Limit
1	IS_1	-2.09	3.6930	-1.8E-1	3.0 E-1	2.5E-2	1.558E-1	0.999	4.44	-0.8796	0.5306
2	IS_2	-1.46	2.0251	-1.2E-1	1.7E-1	1.4E-2	1.183E-1	0.999	4.44	-0.6471	0.4035

Table 9: Correlation Coefficient and Standard Error Analysis of Transverse Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel

S/N	TRANSVERSE HARDNESS VALUE (THV) OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS
1	THV_1	0.9998	0.043
2	THV_2	0.9998	0.029

Table 10: Correlation Coefficient and Standard Error Analysis of Longitudinal Rockwell Hardness Value A of Rolled Ribbed Medium Carbon Steel

S/N	LONGITUDINAL HARDNESS VALUE (LHV) OF ROLLED RIBBED MEDIUM CARBON STEELS	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS
1	LHV_1	0.9492	0.855
2	LHV_2	0.9948	0.276

Table 11.Correlation Coefficient and Standard Error Analysis of Tensile Strength at maximum Load of Rolled Ribbed Medium Carbon Steel

S/N	TENSILE STRENGTH AT	CORRELATION	STANDARD

	MAXIMUM LOAD OF ROLLED RIBBED MEDIUM CARBON STEELS **(TS@Lmax)**	COEFFICIENT OF MODELS	ERROR OF MODELS
1	Tensile Strength @ Max Load$_1$	0.99943	1.915
2	Tensile Strength @ Max Load$_2$	0.99958	2.705

Table 12: Correlation Coefficient and Standard Error Analysis of Tensile Strength at Break of Rolled Ribbed Medium Carbon Steel

S/N	TENSILE STRENGTH AT BREAK OF ROLLED RIBBED MEDIUM CARBON STEELS **(TS@Break)**	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS
1	Tensile Strength @ Break$_1$	0.999788	1.504
2	Tensile Strength @ Break$_2$	0.999814	1.408

Table 13: Correlation Coefficient and Standard Error Analysis of Yield Strength of Rolled Ribbed Medium Carbon Steel

S/N	YIELD STRENGTH OF ROLLED RIBBED MEDIUM CARBON STEELS (YS)	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS
1	Yield Strength$_1$	0.998058	2.721
2	Yield Strength$_2$	0.9999995	0.01

Table 14: Correlation Coefficient and Standard Error Analysis of Impact Toughness of Rolled Ribbed Medium Carbon Steel

S/N	IMPACT STRENGTH OF ROLLED RIBBED MEDIUM CARBON STEELS (IS)	CORRELATION COEFFICIENT OF MODELS	STANDARD ERROR OF MODELS
1	Impact Strength$_1$	0.9997	5.548E-1
2	Impact Strength$_2$	0.9999	4.109E-1

APPENDIX !

Regression Model for Transverse Hardness Value

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	79.057	.000		.	.
	X1 DIAMETER (mm)	-3.200	.000	-6.733	.	.
	X2 %C	292.132	.000	3.204	.	.
	X3 %Mn	1.789	.000	.034	.	.
	X4 %Si	-24.753	.000	-.348	.	.
	X5 %P	-1259.459	.000	-5.465	.	.
	X6 %S	-598.514	.000	-2.736	.	.
	X7 %Cr	-89.020	.000	-12.071	.	.
	X8 %Ni	-36.112	.000	-.418	.	.
	X9 % Cu	-108.391	.000	-.609	.	.
	X10 %Co	192.169	.000	.583	.	.
	X11 %W	160.011	.000	1.188	.	.

a. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Regression Model for Longitudinal Hardness Value

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88.437	11	8.040	.	.[a]
	Residual	.000	0	.		
	Total	88.437	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	289.360	.000		.	.
	X1 DIAMETER (mm)	-4.012	.000	-7.117	.	.
	X2 %C	387.232	.000	3.580	.	.
	X3 %Mn	-199.816	.000	-3.241	.	.
	X4 %Si	113.513	.000	1.346	.	.
	X5 %P	359.407	.000	1.315	.	.
	X6 %S	-2695.735	.000	-10.390	.	.
	X7 %Cr	-105.478	.000	-12.060	.	.
	X8 %Ni	23.974	.000	.234	.	.
	X9 % Cu	-964.437	.000	-4.572	.	.
	X10 %Co	-1541.841	.000	-3.943	.	.
	X11 %W	1147.451	.000	7.184	.	.

a. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Regression Model for Tensile Strength at Maximum Load

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Y3 TS@max

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39403.772	11	3582.161	.	.[a]
	Residual	.000	0	.		
	Total	39403.772	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y3 TS@max

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1891.430	.000		.	.
	X1 DIAMETER (mm)	-39.370	.000	-3.308	.	.
	X2 %C	9707.708	.000	4.252	.	.
	X3 %Mn	-3260.090	.000	-2.505	.	.
	X4 %Si	3643.010	.000	2.046	.	.
	X5 %P	43598.406	.000	7.556	.	.
	X6 %S	-17242.3	.000	-3.148	.	.
	X7 %Cr	971.700	.000	5.263	.	.
	X8 %Ni	-1423.307	.000	-.658	.	.
	X9 % Cu	-5689.067	.000	-1.278	.	.
	X10 %Co	-19913.6	.000	-2.412	.	.
	X11 %W	13611.132	.000	4.037	.	.

a. Dependent Variable: Y3 TS@max

Regression Model for Tensile Strength at Break

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Y4 T S@break

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	64178.059	11	5834.369	.	.[a]
	Residual	.000	0	.		
	Total	64178.059	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y4 T S@break

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-702.189	.000		.	.
	X1 DIAMETER (mm)	-24.567	.000	-1.618	.	.
	X2 %C	6936.389	.000	2.381	.	.
	X3 %Mn	-2144.629	.000	-1.291	.	.
	X4 %Si	2285.292	.000	1.006	.	.
	X5 %P	23618.798	.000	3.208	.	.
	X6 %S	-15003.0	.000	-2.146	.	.
	X7 %Cr	306.008	.000	1.299	.	.
	X8 %Ni	-738.523	.000	-.268	.	.
	X9 % Cu	-4873.448	.000	-.858	.	.
	X10 %Co	-13300.3	.000	-1.262	.	.
	X11 %W	8789.803	.000	2.043	.	.

a. Dependent Variable: Y4 T S@break

Regression Model for Yield Strength (Y.S)

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8415.832	11	765.076	.	.[a]
	Residual	.000	0	.		
	Total	8415.832	11			

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-232.782	.000		.	.
	X1 DIAMETER (mm)	-46.891	.000	-8.526	.	.
	X2 %C	6971.164	.000	6.607	.	.
	X3 %Mn	-2451.557	.000	-4.076	.	.
	X4 %Si	2456.109	.000	2.985	.	.
	X5 %P	26178.638	.000	9.818	.	.
	X6 %S	-17650.5	.000	-6.974	.	.
	X7 %Cr	191.376	.000	2.243	.	.
	X8 %Ni	-889.998	.000	-.891	.	.
	X9 % Cu	-6031.445	.000	-2.931	.	.
	X10 %Co	-15295.1	.000	-4.009	.	.
	X11 %W	11290.827	.000	7.247	.	.

a. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Regression Model for Impact Strength

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobolt, Nickel, Carbon, Sulphur, Chromium[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Impact Strength

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobolt, Nickel, Carbon, Sulphur, Chromium

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6372.667	11	579.333	.	.[a]
	Residual	.000	0	.		
	Total	6372.667	11			

a. Predictors: (Constant), Tungsten, Copper, Diameter, Manganese, Silicon, Phosphorus, Cobolt, Nickel, Carbon, Sulphur, Chromium

b. Dependent Variable: Impact Strength

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	876.643	.000		.	.
	Diameter	19.182	.000	4.008	.	.
	Carbon	-2720.612	.000	-2.963	.	.
	Manganese	-721.811	.000	-1.379	.	.
	Silicon	776.895	.000	1.085	.	.
	Phosphorus	10729.154	.000	4.624	.	.
	Sulphur	-2109.332	.000	-.958	.	.
	Chromium	489.975	.000	6.599	.	.
	Nickel	-107.512	.000	-.124	.	.
	Copper	-1417.534	.000	-.792	.	.
	Cobolt	-5446.725	.000	-1.641	.	.
	Tungsten	2212.546	.000	1.632	.	.

a. Dependent Variable: Impact Strength

Regression Model for Transverse Hardness Value

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	62.870	11	5.715	.	.[a]
	Residual	.000	0	.		
	Total	62.870	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8761.045	.000		.	.
	X1 DIAMETER (mm)	-3.121	.000	-6.566	.	.
	X2 %C	368.952	.000	4.046	.	.
	X3 %Mn	90.524	.000	1.741	.	.
	X4 %Si	63.113	.000	.887	.	.
	X5 %P	-1179.607	.000	-5.118	.	.
	X6 %S	-497.482	.000	-2.274	.	.
	X8 %Ni	52.638	.000	.609	.	.
	X9 % Cu	-19.221	.000	-.108	.	.
	X10 %Co	281.419	.000	.853	.	.
	X11 %W	242.816	.000	1.803	.	.
	X12 %Fe	88.434	.000	11.750	.	.

a. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	X7 %Cr	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y1 TRANSVERSE HARDNESS VALUE (THV)

Regression Model for Longitudinal Hardness Value

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88.437	11	8.040	.	.[a]
	Residual	.000	0	.		
	Total	88.437	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-10185.1	.000		.	.
	X1 DIAMETER (mm)	-3.918	.000	-6.950	.	.
	X2 %C	478.255	.000	4.422	.	.
	X3 %Mn	-94.675	.000	-1.536	.	.
	X4 %Si	217.623	.000	2.580	.	.
	X5 %P	454.022	.000	1.661	.	.
	X6 %S	-2576.025	.000	-9.928	.	.
	X8 %Ni	129.133	.000	1.261	.	.
	X9 % Cu	-858.781	.000	-4.071	.	.
	X10 %Co	-1436.090	.000	-3.672	.	.
	X11 %W	1245.566	.000	7.799	.	.
	X12 %Fe	104.783	.000	11.739	.	.

a. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Excluded Variables[b]

						Collinearity Statistics
Model		Beta In	t	Sig.	Partial Correlation	Tolerance
1	X7 %Cr	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y2 LONGITUDINAL HARDNESS VALUE (LHV)

Regression Model for Tensile Strength at Maximum Load

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y3 TS@max

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39403.772	11	3582.161	.	.[a]
	Residual	.000	0	.		
	Total	39403.772	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y3 TS@max

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	94603.105	.000		.	.
	X1 DIAMETER (mm)	-40.236	.000	-3.381	.	.
	X2 %C	8869.178	.000	3.885	.	.
	X3 %Mn	-4228.685	.000	-3.249	.	.
	X4 %Si	2683.913	.000	1.507	.	.
	X5 %P	42726.779	.000	7.405	.	.
	X6 %S	-18345.1	.000	-3.350	.	.
	X8 %Ni	-2392.061	.000	-1.106	.	.
	X9 % Cu	-6662.409	.000	-1.496	.	.
	X10 %Co	-20887.8	.000	-2.530	.	.
	X11 %W	12707.265	.000	3.769	.	.
	X12 %Fe	-965.300	.000	-5.123	.	.

a. Dependent Variable: Y3 TS@max

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	X7 %Cr	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y3 TS@max

Regression Model for Tensile Strength at Break

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y4 T S@break

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	64178.059	11	5834.369	.	.[a]
	Residual	.000	0	.		
	Total	64178.059	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y4 T S@break

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	29685.912	.000		.	.
	X1 DIAMETER (mm)	-24.840	.000	-1.636	.	.
	X2 %C	6672.319	.000	2.290	.	.
	X3 %Mn	-2449.659	.000	-1.475	.	.
	X4 %Si	1983.252	.000	.873	.	.
	X5 %P	23344.305	.000	3.170	.	.
	X6 %S	-15350.3	.000	-2.196	.	.
	X8 %Ni	-1043.603	.000	-.378	.	.
	X9 % Cu	-5179.974	.000	-.912	.	.
	X10 %Co	-13607.1	.000	-1.292	.	.
	X11 %W	8505.157	.000	1.977	.	.
	X12 %Fe	-303.993	.000	-1.264	.	.

a. Dependent Variable: Y4 T S@break

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	X7 %Cr	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y4 T S@break

Regression Model for Yield Strength (Y.S)

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8415.832	11	765.076	.	.[a]
	Residual	.000	0	.		
	Total	8415.832	11			

a. Predictors: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	18771.779	.000		.	.
	X1 DIAMETER (mm)	-47.062	.000	-8.557	.	.
	X2 %C	6806.016	.000	6.451	.	.
	X3 %Mn	-2642.321	.000	-4.393	.	.
	X4 %Si	2267.215	.000	2.755	.	.
	X5 %P	26006.971	.000	9.753	.	.
	X6 %S	-17867.7	.000	-7.059	.	.
	X8 %Ni	-1080.794	.000	-1.082	.	.
	X9 % Cu	-6223.144	.000	-3.024	.	.
	X10 %Co	-15487.0	.000	-4.060	.	.
	X11 %W	11112.811	.000	7.133	.	.
	X12 %Fe	-190.116	.000	-2.183	.	.

a. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	X7 %Cr	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X12 %Fe, X9 % Cu, X8 %Ni, X11 %W, X4 %Si, X2 %C, X10 %Co, X3 %Mn, X6 %S, X1 DIAMETER (mm), X5 %P

b. Dependent Variable: Y5 YIELD STRENGTH (Y.S)

Regression Model for Impact Strength

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobolt, Manganese, Sulphur, Diameter, Phosphorus[a]	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Impact Strength

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobolt, Manganese, Sulphur, Diameter, Phosphorus

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6372.667	11	579.333	.	.[a]
	Residual	.000	0	.		
	Total	6372.667	11			

a. Predictors: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobolt, Manganese, Sulphur, Diameter, Phosphorus

b. Dependent Variable: Impact Strength

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	49533.516	.000		.	.
	Diameter	18.746	.000	3.917	.	.
	Carbon	-3143.437	.000	-3.424	.	.
	Manganese	-1210.220	.000	-2.312	.	.
	Silicon	293.275	.000	.410	.	.
	Phosphorus	10289.641	.000	4.435	.	.
	Sulphur	-2665.421	.000	-1.210	.	.
	Nickel	-596.001	.000	-.685	.	.
	Copper	-1908.336	.000	-1.066	.	.
	Cobolt	-5937.968	.000	-1.789	.	.
	Tungsten	1756.776	.000	1.296	.	.
	Iron	-486.748	.000	-6.424	.	.

a. Dependent Variable: Impact Strength

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Chromium	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), Iron, Copper, Nickel, Tungsten, Silicon, Carbon, Cobolt, Manganese, Sulphur, Diameter, Phosphorus

b. Dependent Variable: Impact Strength

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.	.

a. Predictors: (Constant), X11 %W, X9 % Cu, X1 DIAMETER (mm), X3 %Mn, X4 %Si, X5 %P, X10 %Co, X8 %Ni, X2 %C, X6 %S, X7 %Cr

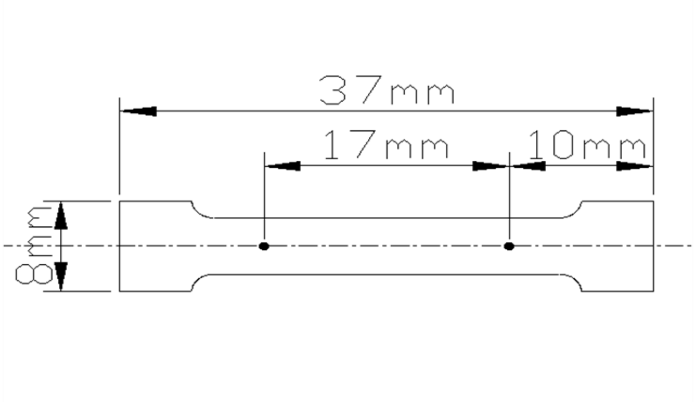

Figure 1: Standard Tensile Test Piece

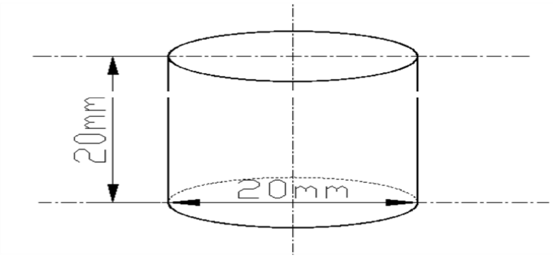

Figure 2: Hardness Test Piece

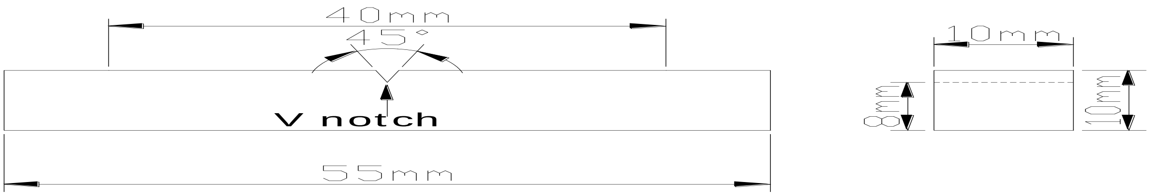

Figure 3. V-notch Impact Test Piece

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