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The relation research of tensile strength and chemical components of HRB400 in China

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ABSTRACT

Hot-rolled ribbed steel bar (HRB), as a main structural material, plays an irreplaceable role in many fields. Chemical components of HRB directly influence basic mechanical properties. Through partial correlation analysis, we establish linear regression and polynomial regression models (quadratic and cubic) of tensile strength and chemical components of HRB400 in China. So we can control the production of HRB400 to ensure the mechanical properties by adjusting the contents of chemical components.

Key words: HRB, tensile strength, chemical components, regression model, partial correlation analysis

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INTRODUCTION

Steel is the main structural material of the current human society, which plays an irreplaceable role in the fields of basic industries, basic infrastructure and people's daily consumption. In the future, steel continues to be supportive of global economic developments and social civilization. Hot-rolled ribbed steel bar (HRB) is mainly used for reinforced concrete, mainly including HRB335, HRB400 and HRB500 [1-5].

Since chemical components design and production strategy of HRB335 are relatively simple, production technique of HRB335 is mature and used widely. But there exist some disadvantages of low strength, big size effect, high sensitivity to strain aging and poor anti-seismic capability, making HRB335 can’t satisfy social requirements. So HRB335 has already been replaced by HRB400. HRB400 is an important popularized new type steel in China. It has some good properties: 1) high strength and good ductility. Compared with HRB335, HRB400 can save steel quantities 10% ~18%; 2) stable properties and low sensitivity to strain aging [6-9]; 3) fine performance in welding; 4) good anti-seismic capability; 5) low transition temperature of ductile-brittle. For reason of the guidance of national policies and market requirements, HRB400 has become the leading product of steel mills, and many research institutes have began to do some research work about it in China [10-15]. HRB500 is the highest level of HRB in China, which can satisfy the requirements of high building, high-rise building and large frame structure.

The manufacturers of HRB are mainly located in the northeast and the northern part, whose output amounts to more than 50% of the total output. HRB is the key product of Hebei Iron & Steel Group Tangshan Iron & Steel Co.,Ltd. (HBIS), which has a market share of 30% in China.

From the point of production process, there are many factors influencing mechanical properties of HRB: 1) chemical components of HRB determinate basic mechanical properties directly; 2) all conditions of the casting of the molten steel influence mechanical properties; 3) all factors in the rolling process, such as heating temperature and cooling speed; 4) process specifications of sampling position, artificial error, internal stress and so on.

If HRB is produced only by controlling rolling and cooling, mechanical properties of HRB can be ensured, but the burden of steel mills was increased largely which results in a high-cost production. For example, Beijing Shougang Company Limited explored to produce HRB400 without micro-alloy elements by controlling rolling and cooling, but the operation cost of steel mills was increased. So the production of HRB always depends on the addition of micro-alloy elements.

According to the common sense, chemical components of HRB influence mechanical properties directly: with the increase of C content, the yield strength and the tensile strength increase, but the plasticity and the impact toughness decrease; chemical component Mn, as a good deoxidizer and desulfurizer, can improve the yield strength and the tensile strength of HRB, but have an adverse effect on the weldability and the ability to resist corrosion; chemical component Si, as a good reductant and deoxidizer, can improve the strength, but reduce the plasticity and the impact toughness of HRB; chemical component Cr can improve the strength, the rigidity, the antioxidant and the abrasion performance significantly, but reduce the toughness and the plasticity; chemical component V, as a good deoxidizer, can improve the strength and the toughness; chemical component P is harmful to HRB, can reduce the plasticity and worsen the weldability; other components S, N, Ni, Mo, Cu also influence mechanical properties. Many manufacturers always ensure mechanical properties of HRB by adding those micro-alloy elements. Then there is a natural question: if the accurate dependence relationships between mechanical properties and chemical components C, Mn, S, P, Si, Cr, Mo, Cu, Ni, Alt, V are unknown, how to add those micro-alloy elements? The research of dependence relationships between mechanical properties and chemical components is an important and popular topic.

Recently, many researchers have done a lot of works for this topic. For example, Zeng, Zhang and Xia[1] (2001) established a linear regression model to forecast and control the mechanical property of steels. Then, using the same statistical method for HRB335 twisted steel bar, Liu, Huang and You[2](2002) made statistical analysis on mechanical properties and chemical composition. And based on this study, a modification on steel bars chemical composition was proposed. Li and Lu[3](2006) established a statistical regression model on yield strength and Si content, carbon equivalent and diameter of HRB335 hot rolled ribbed bar. Kareem[5](2009) investigated three sizes of the two selected models of concrete reinforcement steel bars of Nigeria, and revealed that the steel bars are in good agreement with both local and international standards. Hao, Sun and Li[6] (2011) studied the influence of composition segregation to the microstructure and mechanical properties of SA508-3 steel by the comparison of three positions on the ingot. Ejeh and Jibrin[7](2012) investigated tensile behavior for reinforcing steel bars used in the Nigerian construction industry. Then they[8](2013) studied chemical concentration and percentage composition of reinforcing steel and observed that the presence of some elements such as Si and P coupled with the possible lack of N has impacted negatively on the strength and deformation characteristics of the bars. Krivy, Konecny and Urban[9] (2013) dealt with a statistical analysis of strength properties and chemical composition of weathering steels used for the construction of motorway bridges in the Czech Republic. Ponle, Olatunde and Awotunde[10](2014) presented comparative experimental data on mechanical properties of reinforced steel produced from scrap and imported reinforced steel, and observed that the locally produced steel from scrap were as good as the imported steel rods in terms of tensile strength, yield strength, breaking strength and hardness. However, the accurate dependence relationships between mechanical properties and chemical components C, Mn, S, P, Si, Cr, Mo, Cu, Ni, Alt, V are unknown, so we aim to explore the dependence relationships.

The organization of this article is as follows: Section 2 describes the collection and preprocessing of the samples data; The regression models (linear regression and polynomial regression) of tensile strength and chemical components will be established in Section 3; And Section 4 describes the application of the regression models; some feasible future work are given in the final section.

COLLECTION AND PREPROCESSING OF THE SAMPLES DATA

According to ISO 6935-2: 1991, Steel for the reinforcement of concrete-Part 2: Ribbed bars, NEQ (GB1499.2-2007), there is a standard about the range of chemical components of HRB400 as the following Table 1.

Table 1. The range of chemical components of HRB400

Chemical components /%					
C	Si	Mn	P	S	Ceq
⩽0.25	⩽0.80	⩽1.60	⩽0.045	⩽0.045	⩽0.54

HRB400 is the key products of Hebei Iron & Steel Group Tangshan Iron & Steel Co. Ltd. (HBIS), which has a market share of 30% in China. This paper aims to study HRB400 of HBIS with the gauge $\Phi 12 \sim \Phi 32$ (/mm diameter). We collected more than 5000 random samples of HRB400 from February 2011 to June 2012: first do mechanical tests of the samples to get the data of mechanical properties including yield strength, tensile strength and elongation; then use the spectrograph to get chemical components. The ranges of chemical components of the samples are as follows:

Table 2. The range of chemical components of HRB400 of HBIS

Chemical components /%					
C	Mn	S	P	Si	V
0.19～0.25	1.3～1.6	0.005～0.043	0.013～0.045	0.4～0.75	0.025～0.05
Cr	Ni	Cu	Mo	Alt	
0.009～0.062	0～0.033	0.009～0.066	0～0.011	0～0.2939	

Compared with Table 1, obviously chemical components of the samples are in good agreement with the standard of HRB400 in China, so the samples data are valid. We aim to model the accurate dependence relationship of tensile strength and chemical components by using those valid samples data. By the model we can reduce the production costs, predict and control tensile strength.

To ensure the accuracy and reliability of the model, we do some preprocessing to the samples data. According to the physical criteria and the Grrubbs test, we abandon some abnormal data, and modify mechanical properties data by deleting the influence of negative difference.

REGRESSION MODEL OF TENSILE STRENGTH

Multiple linear regression model of tensile strength

Assuming there exist a linear relation between tensile strength and chemical components C, Mn, S, P, Si, Cr, Mo, Cu, Ni, Alt, V, so we use multiple linear regression model to describe this relation as follows:

$$\mathbf{y} = \mathbf{k}_0 + \mathbf{k}_1 C + \mathbf{k}_2 Mn + \mathbf{k}_3 S + \mathbf{k}_4 P + \mathbf{k}_5 Si + \mathbf{k}_6 V + \mathbf{k}_7 Cr + \mathbf{k}_8 Ni + \mathbf{k}_9 Cu + \mathbf{k}_{10} Mo + \mathbf{k}_{11} Alt$$

Where the regression is constant, are the regression coefficients.

Using R, we can establish the multiple linear regression model (1) as follows:

$$\mathbf{y} = 238.74C + 18.18Mn - 373.02S + 236.3P + 39.82Si - 623.41V + 145.23Cr + 391.75Ni + 555.08Mo + 600.256 \tag{1}$$

where the regression coefficients are listed in Table 3. And we test the significance of the regression and the significance of the regression coefficients, please see Table 3.

Table 3. The regression coefficients and the significance test of model (1)

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	600.256	10.481	57.269	< 2e-16	***
c	238.735	25.308	9.433	< 2e-16	***
mn	18.182	7.861	2.313	0.020764	*
s	-373.023	60.114	-6.205	5.89E-10	***
p	236.301	56.131	4.21	0.000026	***
si	39.817	9.847	4.044	5.34E-05	***
v	-623.408	91.629	-6.804	1.14E-11	***
cr	145.232	62.936	2.308	0.021061	*
ni	391.748	112.876	3.471	0.000524	***
mo	555.077	162.089	3.425	0.000621	***

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Coefficients:
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Signif. codes:   0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 19.19 on 5161 degrees of freedom
(17 observations deleted due to missingness)
F-statistic: 29.12 on 9 and 5161 DF,    p-value: < 2.2e-16
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Obviously, from Table 3 we can see that both the regression model and the regression coefficients are significant at the significance level of 5%.

According to the regression model (1), chemical components C, Mn, S, P, Si, Cr, Mo, Ni, V significantly affect tensile strength. Chemical components C, Mn, P, Si, Cr, Mo, Ni are positive associated with tensile strength, namely, with the increase of chemical components C, Mn, P, Si, Cr, Mo, Ni contents, tensile strength will be improved. Conversely, chemical components S, V have significant negative effects. But, the results are contradictive with some common sense, such as the influence of P. So there is another question: whether the multiple linear regression models is appropriate?

Partial correlation analysis of tensile strength

Based on the analysis above, we try to consider nonlinear regression. First, we do partial correlation analysis of chemical components to test the reasonability of linear relation (see Table 4-14).

Table 4. Partial correlation analysis of C

Control variable			tensile strength	C
Mn & S & P & Si & V & Cr & Ni & Cu & Mo& Alt	tensile strength	correlation	1.000	.116
		significance(2-tailed)	.	.000
		Df	0	5159
	C	correlation	.116	1.000
		significance(2-tailed)	.000	.
		Df	5159	0

Table 5. Partial correlation analysis of Mn

Control variable			tensile strength	Mn
S & P & Si & V & Cr & Ni & Cu & Mo & Alt & C	tensile strength	correlation	1.000	.017
		significance(2-tailed)	.	.234
		Df	0	5159
	Mn	correlation	.017	1.000
		significance(2-tailed)	.234	.
		Df	5159	0

Table 6.Partial correlation analysis of S

control variable			tensile strength	P
Si & V & Cr & Ni & Cu & Mo & Alt & C & Mn & S	tensile strength	correlation	1.000	.044
		significance(2-tailed)	.	.001
		Df	0	5159
	P	correlation	.044	1.000
		significance(2-tailed)	.001	.
		Df	5159	0

Table 7. Partial correlation analysis of P

control variable			tensile strength	S
P & Si & V & Cr & Ni & Cu & Mo & Alt & C & Mo	tensile strength	correlation	1.000	-.071
		significance(2-tailed)	.	.000
		Df	0	5159
	S	correlation	-.071	1.000
		significance(2-tailed)	.000	.
		Df	5159	0

Table 8. Partial correlation analysis of Si

control variable			tensile strength	V
Cr & Ni & Cu & Mo & Alt & C & Mn & S & P & Si	tensile strength	correlation	1.000	.237
		significance(2-tailed)	.	.000
		Df	0	5159
	V	correlation	.237	1.000
		significance(2-tailed)	.000	.
		Df	5159	0

Table 9. Partial correlation analysis of V

control variable			tensile strength	Si
V & Cr & Ni & Cu & Mo & Alt & C & Mn & S & P	tensile strength	correlation	1.000	.049
		significance(2-tailed)	.	.000
		Df	0	5159
	Si	correlation	.049	1.000
		significance(2-tailed)	.000	.
		Df	5159	0

Table 10. Partial correlation analysis of Cr

control variable			tensile strength	Ni
Cu & Mo & Alt & C & Mn & S & P & Si & V & Cr	tensile strength	correlation	1.000	.036
		significance(2-tailed)	.	.010
		Df	0	5159
	Ni	correlation	.036	1.000
		significance(2-tailed)	.010	.
		Df	5159	0

Table 11. Partial correlation analysis of Ni

control variable			tensile strength	Cr
Ni & Cu & Mo & Alt & C & Mn & S & P & Si & V	tensile strength	correlation	1.000	.034
		significance(2-tailed)	.	.015
		Df	0	5159
	Cr	correlation	.034	1.000
		significance(2-tailed)	.015	.
		Df	5159	0

Table 12. Partial correlation analysis of Cu

control variable			tensile strength	Mo
Alt & C & Mn & S & P & Si & V & Cr & Ni & Cu	tensile strength	correlation	1.000	.052
		significance(2-tailed)	.	.000
		Df	0	5159
	Mo	correlation	.052	1.000
		significance(2-tailed)	.000	.
		Df	5159	0

Table 13. Partial correlation analysis of Mo

control variable			tensile strength	Cu
Mo & Alt & C & Mn & S & P & Si & V & Cr & Ni	tensile strength	correlation	1.000	-.029
		significance(2-tailed)	.	.036
		Df	0	5159
	Cu	correlation	-.029	1.000
		significance(2-tailed)	.036	.
		Df	5159	0

Table 14. Partial correlation analysis of Alt

control variable			tensile strength	Alt
C & Mn & S & P & Si & V & Cr & Ni & Cu & Mo	tensile strength	correlation	1.000	-.023
		significance(2-tailed)	.	.103
		Df	0	5159
	Alt	correlation	-.023	1.000
		significance(2-tailed)	.103	.
		Df	5159	0

From the tables above, we can conclude that the linear relations of chemical components Mn, Cr, Cu, Alt and tensile strength are not significant at the significance level of 5%. So considering the nonlinear regression is reasonable.

Pure quadratic polynomial regression model of tensile strength

For HRB400, a plausible starting nonlinear regression model might represent tensile strength as a pure quadric polynomial function without interactions of chemical components C, Mn, S, P, Si, Cr, Mo, Cu, Ni, ALT, V. Using R, we can establish a pure quadratic polynomial regression model as follows:

$$\mathbf{y} = \mathbf{545.1}\boldsymbol{C}^2 + \mathbf{6.17}\boldsymbol{Mn}^2 - \mathbf{369.19}\,\boldsymbol{S} + \mathbf{4155.9}\,\boldsymbol{P}^2 + \mathbf{40.87}\,\boldsymbol{Si} - \mathbf{9748.45}\boldsymbol{V}^2 + \mathbf{2710.27}\boldsymbol{Cr}^2 + \mathbf{411.4}\,\boldsymbol{Ni} + \mathbf{542.09}\boldsymbol{Mo} + \mathbf{634.08} \tag{2}$$

where the regression coefficients are listed in Table 15. And we test the significance of the regression and the significance of the regression coefficients, please see Table 15.

Table 15. The regression coefficients and the significance test of model (2)

	Estimate	Std.Error	t value	Pr(>|t|)	
(Intercept)	634.081	6.083	104.241	<2e-16	***
I(c^2)	545.099	57.861	9.421	<2e-16	***
I(mn^2)	6.171	2.766	2.231	0.025707	*
s	-369.186	60.092	-6.144	8.67e-10	***
I(p^2)	4155.905	968.414	4.291	1.81e-05	***
si	40.867	9.846	4.151	3.37e-05	***
I(v^2)	-9748.45	1410.987	-6.909	5.47e-12	***
I(cr^2)	2710.273	1042.975	2.599	0.009387	**
ni	411.402	103.351	3.981	6.97e-05	***
mo	542.093	160.114	3.386	0.000715	***

Coefficients:

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 19.18 on 5161 degrees of freedom
(17 observations deleted due to missingness)
F-statistic: 29.54 on 9 and 5161 DF, p-value: < 2.2e-16

Obviously, from Table 15 we can see that both the regression model and the regression coefficients are significant at the 5% significance level.

According to the regression model (2), chemical components C, Mn, S, P, Si, V, Cr, Mo, Ni significantly affect the tensile strength. Chemical components C2, Mn2, P2, Cr2, are positive associated with the tensile strength in the quadratic forms, namely, with the increases of components C2, Mn2, P2, Cr2 contents, tensile strength will be improved. Chemical components Si, Mo, Ni are positive associated with the tensile strength in the linear forms. Conversely, chemical components S, V2 have significant negative effects.

While, we use R to do analysis of variance to test the hypothesis that the linear regression model (1) is correct against the alternative model (2). The result indicates that there is no reason to accept the alternative model (2). So we need to continue to explore other models.

Pure cubic polynomial regression model of tensile strength

Based on the analysis above, using R we explore pure cubic polynomial regression model without interactions for HRB400 as follows:

$$\begin{aligned} \mathbf{y} &= 4.62\times10^4\,\boldsymbol{C} - 2.11\times10^5\,\boldsymbol{C}^2 + 3.221\times10^5\,\boldsymbol{C}^3 + 2.946\,\boldsymbol{Mn}^3 - 3.865\times10^3\,\boldsymbol{S} + 1.434\times10^5\,\boldsymbol{S}^2 \\ &-1.884\times10^6\,\boldsymbol{S}^3 + 9.392\times10^4\,\boldsymbol{P}^3 + 4.023\times10\,\boldsymbol{Si}^2 - 9.581\times10^3\boldsymbol{V}^2 + 2.183\times10^3\,\boldsymbol{Cr}^2 \\ &+6.463\times10^4\,\boldsymbol{Ni}^2 - 2.131\times10^6\,\boldsymbol{Ni}^3 + 4.653\times10^5\,\boldsymbol{Mo}^2 - 5.603\times10^7\,\boldsymbol{Mo}^3 - 2.679\times10^3 \end{aligned} \tag{3}$$

where the regression coefficients are listed in Table 16. And we test the significance of the regression and the significance of the regression coefficients, please see Table 16.

Table 16. The regression coefficients and the significance test of model (3)

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-2.679e+03	1.075e+03	-2.491	0.01276	*
c	4.620e+04	1.478e+04	3.125	0.00179	**
I(c^2)	-2.110e+05	6.764e+04	-3.119	0.00182	**
I(c^3)	3.221e+05	1.030e+05	3.127	0.00177	**
I(mn^3)	2.946e+00	1.300e+00	2.266	0.02346	*
s	-3.865e+03	1.679e+03	-2.302	0.02135	*
I(s^2)	1.434e+05	6.696e+04	2.141	0.03229	*
I(s^3)	-1.884e+06	8.749e+05	-2.153	0.03136	*
I(p^3)	9.392e+04	2.139e+04	4.39	1.16e-05	***
I(si^2)	4.023e+01	9.758e+00	4.123	3.79e-05	***
I(v^2)	-9.581e+03	1.412e+03	-6.785	1.3e-11	***
I(cr^2)	2.183e+03	1.056e+03	2.068	0.03871	*
I(ni^2)	6.463e+04	1.606e+04	4.025	5.79e-05	***
I(ni^3)	-2.131e+06	8.304e+05	-2.566	0.01031	*
I(mo^2)	4.653e+05	9.862e+04	4.719	2.44e-06	***
I(mo^3)	-5.603e+07	1.354e+07	-4.137	3.57e-05	***

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Coefficients:
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Signif. codes:   0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 19.14 on 5155 degrees of freedom
  (17 observations deleted due to missingness)
F-statistic: 19.77 on 15 and 5155 DF,   p-value: < 2.2e-16
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Obviously, from Table 16 we can see that both the regression model and the regression coefficients are significant at the 5% significance level.

According to the regression model (3), chemical components C, Mn, S, P, Si, V, Cr, Mo, Ni significantly affect the tensile strength. Chemical component C affects the tensile strength in the form of $4.62\times10^4 \boldsymbol{C}-2.11\times10^5 \boldsymbol{C}^2+3.221\times10^5 \boldsymbol{C}^3$; Chemical component Mn affects the tensile strength in the form of Mn3 ; Chemical component S affects the tensile strength in the form of $-3.865\times10^3 \boldsymbol{S}+1.434\times10^5 \boldsymbol{S}^2-1.884\times10^6 \boldsymbol{S}^3$; Chemical component P affect the tensile strength in the form of P3; Chemical components Si and Cr are positive associated with the tensile strength in the quadratic forms; Chemical component V has a significant negative effect on the tensile strength in the quadratic forms; Chemical component Ni affects the tensile strength in the form of $6.463\times10^4 \boldsymbol{Ni}^2-2.131\times10^6 \boldsymbol{Ni}^3$; Chemical component Mo affects the tensile strength in the form of $4.653\times10^5 \boldsymbol{Mo}^2-5.603\times10^7 \boldsymbol{Mo}^3$.

And we use R to do analysis of variance to test the hypothesis that the linear regression model (1) is correct against the alternative model (3). From the table above, we can see that there is no reason to not accept the alternative model (3).

Cubic polynomial regression model with interactions of tensile strength

Although the nonlinear model (3) is more reasonable than the linear model (1), the model (3) doesn’t consider the case of interactions. So using R we explore cubic polynomial regression model with interactions between any two factors for HRB400:

$$\begin{aligned}
&\mathrm{y}=-1.558\times10^3+6.624\times10^4 C^2+1.764\times10^7\,\mathrm{C}r^3+7.994\times10^5\,Ni^2-5.958\times10^7\,Ni^3\\
&+2.028\times10^4\,Mn*C-1.661\times10^5\,Mn*C^2+1.577\times10^5\,Mn*C^3-5.537\times10^3\,Mn*\mathrm{S}^2\\
&+4.698\times10^5\,Mn*Mo^2+2.145\times10^5\,Mn*ALT^2+3.116\times10^4\,Mn^2*\mathrm{V}^2-6.535\times10^5\,Mn^2*\mathrm{Cr}^2\\
&+7.132\times10^5\,Mn^2*\mathrm{Cr}^3+2.778\times10^5\,Mn^2*Cu-1.781\times10^7\,Mn^2*Cu^2+3.718\times10^8\,Mn^2*Cu^3\\
&+2.063\times10^3\,Mn^2*Mo-3.035\times10^6\,Mn^2*Mo^2+1.171\times10^8\,Mn^2*Mo^3-8.479\times10^4\,Mn^2*ALT^2\\
&-1.549\times10^6\,Mn^2*ALT^3+1.054\times10^4\,Mn^3*C^2+8.354\times10^3\,Mn^3*Cr-1.835\times10^5\,Mn^3*Cu\\
&+1.173\times10^7\,Mn^3*Cu^2-2.447\times10^8\,Mn^3*Cu^3+7.501\times10^5\,Mn^3*ALT^3+8.723\times10^4\,Cr*Si\\
&+1.705\times10^5\,Cr*Si^2-1.119\times10^5\,Cr*Si^3-4.272\times10^6\,Cr*V^2-5.383\times10^7\,Cr*Ni^2\\
&+3.964\times10^9\,Cr*Ni^3-3.536\times10^8\,Cr*Mo^2-1.611\times10^7\,Cr*ALT^2+1.156\times10^8\,Cr*ALT^3\\
&+9.078\times10^6\,Cr^2*C-1.972\times10^7\,Cr^2*C^2-4.276\times10^6\,Cr^2*S+1.758\times10^8\,Cr^2*S^2\\
&-2.297\times10^9\,Cr^2*S^3+1.056\times10^6\,Cr^2*P+1.037\times10^5\,Cr^2*Si+5.605\times10^7\,Cr^2*V^2\\
&+1.021\times10^9\,Cr^2*Ni^2-6.937\times10^{10}\,Cr^2*Ni^3-8.28\times10^6\,Cr^2*Mo+1.967\times10^{10}\,Cr^2*Mo^2\\
&-5.536\times10^{11}\,Cr^2*Mo^3+6.137\times10^8\,Cr^2*ALT^2-4.377\times10^9\,Cr^2*ALT^3-1.781\times10^8\,Cr^3*C
\end{aligned}$$

$$
\begin{aligned}
&+3.891\times10^{8}\,Cr^{3}*C^{2}-7.647\times10^{7}\,Cr^{2}*P+8.396\times10^{8}\,Cr^{3}*P^{2}-1.698\times10^{9}\,Cr*Cu\\
&+1.107\times10^{11}\,Cr^{3}*Cu^{2}-2.324\times10^{12}\,Cr^{3}*Cu^{3}-1.923\times10^{11}\,Cr^{3}*Mo^{2}-7.513\times10^{9}\,Cr^{3}*ALT^{2}\\
&+5.351\times10^{10}\,Cr^{3}*ALT^{3}
\end{aligned}
\tag{4}
$$

And we test the significance of the regression model and the regression coefficients. We find that both of them are significant at the 5% significance level.

And we use R to do analysis of variance to test the hypothesis that the regression model (3) is correct against the alternative model (4):

Model 1: Kx ~ c + I(c^2) + I(c^3) + I(mn^3) + s + I(s^2) + I(s^3) + I(p^3) + I(si^2) + I(v^2) + I(cr^2) + I(ni^2) + I(ni^3) + I(mo^2) + I(mo^3)

Model 2: Kx ~ I(c^2) + I(cr^3) + I(ni^2) + I(ni^3) + I(mn * c) + I(mn * c^2) + I(mn * c^3) + I(mn * s^2) + I(mn * mo^2) + I(mn * alt^2) + I(mn^2 * v^2) + I(mn^2 * cr^2) + I(mn^2 * cr^3) + I(mn^2 * cu) + I(mn^2 * cu^2) + I(mn^2 * cu^3) + I(mn^2 * mo) + I(mn^2 * mo^2) + I(mn^2 * mo^3) + I(mn^2 * alt^2) + I(mn^2 * alt^3) + I(mn^3 * c^2) + I(mn^3 * cr) + I(mn^3 * cu) + I(mn^3 * cu^2) + I(mn^3 * cu^3) + I(mn^3 * alt^3) + I(cr * si) + I(cr * si^2) + I(cr * si^3) + I(cr * v^2) + I(cr *ni^2) + I(cr * ni^3) + I(cr * mo^2) + I(cr * alt^2) + I(cr * alt^3) + I(cr^2 * c) + I(cr^2 * c^2) + I(cr^2 * s) + I(cr^2 * s^2) + I(cr^2 * s^3) + I(cr^2 * p) + I(cr^2 * si) + I(cr^2 * v^2) + I(cr^2 * ni^2) + I(cr^2 * ni^3) + I(cr^2 * mo) + I(cr^2 * mo^2) + I(cr^2 * mo^3) + I(cr^2 * alt^2) + I(cr^2 * alt^3) + I(cr^3 * c) + I(cr^3 * c^2) + I(cr^3 * p) + I(cr^3 * p^2) + I(cr^3 * cu) + I(cr^3 * cu^2) + I(cr^3 * cu^3) + I(cr^3 * mo^2) + I(cr^3 * alt^2) + I(cr^3 * alt^3)

```
    Res.Df    RSS       Df    Sum of Sq    F       Pr(>F)
1   5155      1888397
2   5109      1828935   46    59463        3.611   3.532e-15 ***
---Signif. codes:   0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

From the table above, we can see that the new model (4) is more reasonable than the model (3).

According to the regression model (4), chemical components C, Mn, S, P, Si, V, Cr, Mo, Ni, Cu, Alt significantly affect the tensile strength. But every chemical component affects the tensile strength with a more complex form compared with the model (3). For example, chemical component Mn affects the tensile strength in the form of interactions with C, S, Mo, Alt, V, Cr, Cu.

APPLICATION OF THE REGRESSION MODELS

According to the regression models, we can control the tensile strength of HRB400 by adjusting the contents of chemical components. According to the model (3), we can adjust the contents of chemical components C, Mn, S, P, Si, V, Cr, Mo and Ni appropriately to ensure the tensile strength. Especially as to expensive chemical components Mn and Cr, we can reduce Mn content and Cr content to reduce the production costs under other fixed condition. However chemical components Cu and Alt aren’t the main factors affecting tensile strength. Although the model (4) is more reasonable than the model (3), controlling the tensile strength by adjusting the contents of chemical components according to the model (4) is more complex than the model (3). As to each significant chemical component of the model (4), we adjust the content of a significant chemical component easily only if other significant chemical components are fixed. For example, as to expensive chemical component Mn, only if significant chemical components C, S, Mo, Alt, V, Cr and Cu are fixed, Mn content can be adjusted easily to ensure tensile strength of HRB400.

FUTURE WORK

This paper mainly establishes the regression model of tensile strength and chemical components. Similarly we can establish the regression models of other mechanical properties (yield strength, elongation) and chemical components. So we can also control other mechanical properties by adjusting the contents of chemical components. But if the adjustment of chemical components can’t ensure the mechanical properties, we should consider adjusting the production processes, such as tapping temperature, oxygen blowing parameter, casting temperature, heating temperature and cooling temperature of the steel rolling. Similarly we can establish the regression models of the mechanical properties and those factors, and we can adjust those factors of production processes to meet the requirements.

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REFERENCES

[1]Liu Xiao-lan. *China Sport Science and Technology*. **1984**, 29(13), 46-49.
[2]Luo Yang-chun. *Journal of Shanghai Physical Education Institute*. **1994**, 23(12), 46-47.
[3]Wan Hua-zhe. *journal Of Nanchang Junior Colle*ge. **2010**, 3, 154-156.
[4]Li Ke. *Journal of Shenyang Sport University.* **2012**, 31(2), 111-113.
[5]Zhang Shu-xue. *Journal of Nanjing Institute of Physical Education*. **1995**, 31(2), 25-27.
[6]Pan Li. *Journal of nanjing institute of physical education(natural science).* **2004**, 19(1), 54-55.
[7]Li Yu-he; Ling Wen-tao. *Journal of Guangzhou Physical Education Institute*. **1997**, 17(3), 27-31.
[8] Xu Guo-qin. *Journal Of Hebei Institute Of Physical Education*. **2008**, 22(2), 70-72.
[9] Chen Qing-hong. *China Sport Science and Technology*. **1990**, 21(10), 63-65
[10] Tian Jun-ning. *Journal of Nanjing Institute of Physical Education*. **2000**, 14(4), 149-150.
[11] Zhang B.; Zhang S.; Lu G.. *Journal of Chemical and Pharmaceutical Research*, **2013**, 5(9), 256-262.
[12] Zhang B.; *International Journal of Applied Mathematics and Statistics*, **2013**, 44(14), 422-430.
[13] Zhang B.; Yue H.. *International Journal of Applied Mathematics and Statistics*, **2013**, 40(10), 469-476.
[14] Zhang B.; Feng Y.. *International Journal of Applied Mathematics and Statistics*, **2013**, 40(10), 136-143.
[15] Bing Zhang. *Journal of Chemical and Pharmaceutical Research*, **2014**, 5(2), 649-659.