Open Access Library Journal
2018, Volume 5, e4733
ISSN Online: 2333-9721
ISSN Print: 2333-9705

On Preliminary Study of Primary and Secondary Elements Affecting Mechanical Properties of Rebar

Qiaozhi Sang[1], Fengzhu Yao[2], Ying Zhang[2]

[1]Yisheng College, North China University of Science and Technology, Tangshan, China
[2]College of Architectural Engineering, North China University of Science and Technology, Tangshan, China
Email: 892965571@qq.com

How to cite this paper: Sang, Q.Z., Yao, F.Z. and Zhang, Y. (2018) On Preliminary Study of Primary and Secondary Elements Affecting Mechanical Properties of Rebar. *Open Access Library Journal*, **5**: e4733.
https://doi.org/10.4236/oalib.1104733

Received: June 21, 2018
Accepted: July 24, 2018
Published: July 27, 2018

Abstract

The microalloying method is most widely used in the production process of high strength steel bars. However, its cost factor has become the main bottleneck for its difficult promotion. The incomplete structure of analytic hierarchy model is established in this paper to identify the primary and secondary elements affecting the performance and investigate the influence mechanism. The dominance numbers are especially introduced to revise the final weights. Hence under the premise of ensuring the mechanical properties of the steel bars, the cost is controlled by increasing the input of certain elements and reducing the use of other expensive micro-alloying elements.

Subject Areas

Civil Engineering

Keywords

Incomplete Structure, Analytic Hierarchy Process, Micro-Alloying

1. Introduction

At present, Micro-alloying, a new technology in materials and metallurgy, is widely used in steel mills to produce HRB400 and higher grade threaded tubes. Microalloying elements form various compounds with carbon, nitrogen, oxygen, and sulfur in the steel, which hinder the growth of prior austenite grains during heating, suppress recrystallization during the rolling process, and grow after recrystallization, and play a role at low temperatures. Precipitation strengthens the effect and thus has multiple effects on performance. For a long time, Al has been used to refine grains and improve the toughness of steel [1], but the use of V elements was first used to increase the strength and weldability [2]. N not only acts as a solid solution strengthening element, but also plays an important role in improving the strengthening of the microalloy. Adding Cr element to large-size steel increases the hardenability of the steel and shifts the CCT curve of the steel to the upper right [3], which suppresses the precipitation of proeutectoid ferrite and improves the tensile strength of the steel. At present, micro-alloying technology has gradually penetrated into various fields of steel production, becoming a microcosm of the advanced level of a national steel company. Different elements have different ways of strengthening, rational use and optimization of components can significantly improve the performance of steel bars and reduce costs.

2. Data Preprocessing

A company's production data is collected for calculation in this paper. Due to the complexity of data collected in the actual process, there are many cases such as incorrect data (for example, the parameter is 0 or negative), missing data (with some parameters not recorded), and atypical data (data obviously deviated from the normal value and rarely occur). These data cannot be used as training samples and test samples and must be removed [4]. Generally, in the case of large samples, the data presents a normal distribution rule [5]. Therefore, the normal distribution test of chemical element data is performed by SPSS software [6]. By checking the normal PP map, it is determined whether the sample meets the normal distribution law. The normal PP diagram of *C* and *Alt* is as follows (**Figure 1**):

It has been found by inspection that elements do not conform to a normal distribution in the normal P-P plot of all chemical elements. Therefore, the use of a logarithmic transformation approach obeys the normalization of the log-normal distribution of data: $X' = \ln X$. When there exist a small value and zero, $X' = \ln(X+1)$.

3. The Primary and Secondary Factors Affecting Performance

Mechanical Properties of Steel Bars

The mechanical properties of hot-rolled ribbed bars are mainly embodied in the mechanical strength, bending and deformation properties. This article mainly uses the three indexes of yield strength, yield strength and tensile strength (yield ratio) and elongation at break.

1) Yield strength

The yield strength is the strength corresponding to the yield point. The internal crystal structure of the material is destroyed from this point, and the elasticity of the material begins to change to plasticity. This index reflects the strength of the material against external damage.

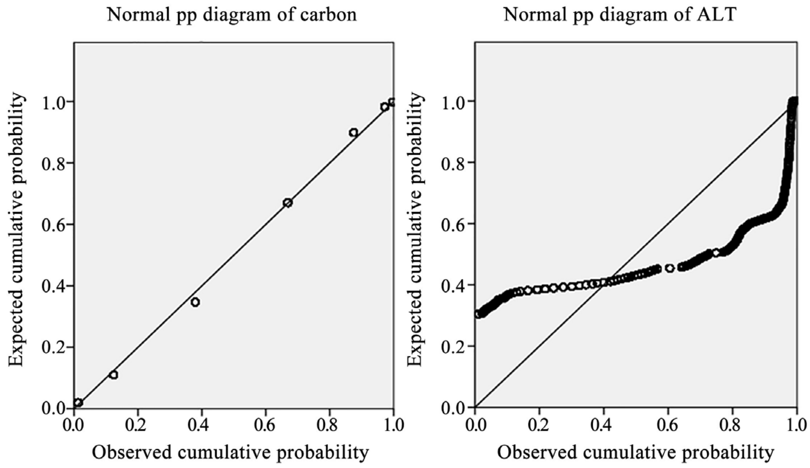

Figure 1. The normal PP diagram of *C* and *Alt*.

2) Yield ratio

The parameters yield ratio is an important indicator to measure the brittleness of steel bars. The definition is:

$$\text{yield ratio} = \frac{\text{yield strength}}{\text{tensile strength}}$$

The larger the value, the closer the yield and tensile strength values are, the greater the brittleness. At a constant loading rate, elongation is positively related to stretching time, which is used to measure the plasticity of the material.

3) Elongation

Elongation at break is the percentage of increase in length and initial length when the reinforcing bar is broken. The elongation at break can be measured to better reflect the toughness of the steel bar, and has a larger elongation at break. The steel bar has certain unisexual elongation when it is impacted and does not immediately break. At a constant loading rate, elongation is positively related to stretching time, which is used to measure the plasticity of the material. Therefore, the three main properties of deformed steel bars are studied: yield ratio, yield strength, and elongation after fracture. For the order of magnitude, change the yield strength to 100 Mpa and retain five decimal places.

4. Stepwise Regression

1) Rejection of irrelevant items

For each of the three properties, 12 chemical elements were subjected to stepwise regression processing. For the three common elements that were excluded during the stepwise regression process, their weak influence on the properties of deformed steel bars was ignored.

2) Regression coefficients

In the stepwise regression process, the regression coefficient between each performance and major elements can be obtained. The results of the SPSS operation are shown in the Appendix. The results are shown in **Table 1**.

Table 1. List of regression coefficients.

	Yield Strength	Yield ratio	Elongation
C	0	0.064	0
Mn	0	0.046	0
S	0.031	0	0
Si	0	0.117	0
Ceq	0	0	0.061
V	0	0.032	0
Cr	0	0.058	0
Ni	0	0	0.052
Cu	0	0	0.045
Mo	0	0	0.024
Alt	0	0.042	0

5. Incomplete Level Analysis

Due to the differences in the influence of different chemical element content on the microstructure and properties of steel bars, an incomplete hierarchical analysis structural model was established to describe this relationship [7]. For the elements excluded from the stepwise regression analysis of a certain performance, ignoring the relationship between them and the performance, according to the regression coefficient obtained in the above, the correlation between the performance of the reinforcing steel and the chemical elements can be determined. The final correlation result is shown in Figure 2:

In Figure 2, suppose the three properties of the standard layer reinforcement are C_1, C_2, C_3; the 11 chemical elements in the indicator layer are P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}, P_{11}. Let the weight vector of C_1, C_2, C_3 be $w^{(2)} = \left(w_1^{(2)}, w_2^{(2)}, w_3^{(2)}\right)^{\mathrm{T}}$, C_1 controls P_3 in the index layer, C_2 controls P_1, P_2, P_4, P_6, P_7, P_{11} correspondingly, C_3 controls P_5, P_8, P_9, P_{10}, the three weight vectors are denoted as:

$$w_1^{(3)} = \left(0, 0, w_{13}^{(3)}, 0, 0, 0, 0, 0, 0, 0, 0\right)$$

$$w_2^{(3)} = \left(w_{21}^{(3)}, w_{22}^{(3)}, 0, w_{24}^{(3)}, 0, w_{26}^{(3)}, w_{27}^{(3)}, 0, 0, 0, w_{211}^{(3)}\right)$$

$$w_3^{(3)} = \left(0, 0, 0, 0, w_{35}^{(3)}, 0, 0, w_{38}^{(3)}, w_{39}^{(3)}, w_{310}^{(3)}, 0\right)$$

The weight of the indicator layer on the target layer is $w^{(3)} = W^{(3)} \cdot w^{(2)}$，其中

$$W_3 = \left(w_1^{(3)}, w_2^{(3)}, w_3^{(3)}\right)$$

The importance of the three criteria of yield ratio, yield strength, and elongation after fracture is set to be the same., that is, $w^{(2)} = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)^{\mathrm{T}}$, The weights of the 11 chemical elements are then normalized using the regression coefficients in the stepwise regression process above. $w_{13}^{(3)} = 1$, $w_{21}^{(3)} = 0.064$, $w_{22}^{(3)} = 0.046$,

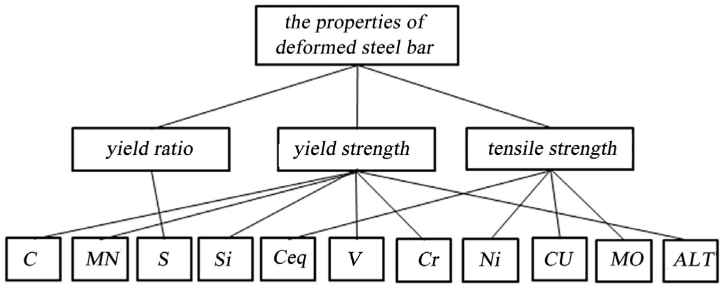

Figure 2. Analytic hierarchy of chemical elements and rebar performance.

Table 2. Primary and secondary factors.

Primary factors	C, Si, Ceq, Cr, Ni, Cu, T
Secondary factors	Mn, S, V, Mo, Alt

$w_{24}^{(3)} = 0.117$, $w_{26}^{(3)} = 0.032$, $w_{27}^{(3)} = 0.058$, $w_{211}^{(3)} = 0.042$, $w_{35}^{(3)} = 0.061$, $w_{38}^{(3)} = 0.052$, $w_{39}^{(3)} = 0.045$, $w_{310}^{(3)} = 0.024$.

To obtain a rationalized result, weight the weight vector $w^{(2)}$ by the number of dominant factors, the revised one is written as $\tilde{w}^{(2)}$, calculate $w^{(3)}$, the number of dominant factors C_1, C_2, C_3 is denoted as n_1, n_2, n_3 respectively:

$$\tilde{w}^{(2)} = \left(n_1 w_1^{(2)}, n_2 w_2^{(2)}, n_3 w_3^{(2)}\right) \Big/ \left(n_1 w_1^{(2)} + n_2 w_2^{(2)} + n_3 w_3^{(2)}\right)$$

$$w^{(3)} = W^{(3)} \tilde{w}^{(2)}$$

5. Conclusions

After solving, the final result can be obtained:

$$w^{(3)} = (0.097, 0.069, 0.091, 0.177, 0.122, 0.048, \\ 0.088, 0.104, 0.089, 0.0479, 0.064, 0.091)$$

Therefore, the primary and secondary factors affecting the deformed reinforcement performance are as follows (**Table 2**):

As can be seen from the reference data, as the carbon content in the steel increases, the yield point and tensile strength will increase. Si is added as reducing agent and deoxidizer in the steelmaking process. Si can significantly increase the elastic limit, yield point and tensile strength of steel; and Ceq, carbon equivalent, is the factor that determines strength and weldability in steel, carbon equivalent. With the improvement, the reinforcing steel performance will be improved accordingly; Cr can significantly increase the strength, hardness and wear resistance, enhance the oxidation resistance and corrosion resistance of steel, but at the same time reduce the plasticity and toughness; Ni can increase the strength of steel, and Maintain good plasticity and toughness; Cu can increase strength and toughness, and verify the applicability of this method.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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