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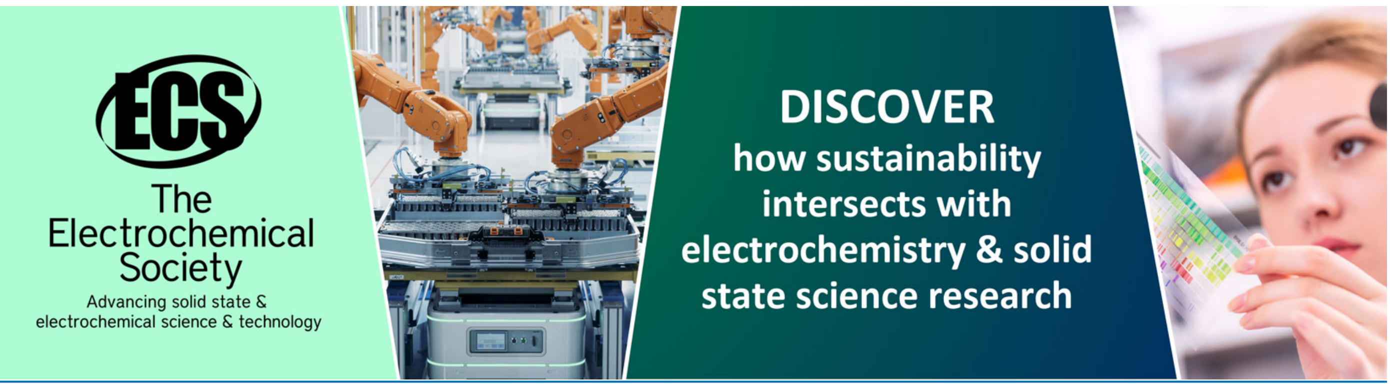

Meta-analysis of the influence of different element contents on selecting the prediction model of gray cast iron's elastic modulus

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Abstract-In order to explore the influence of different element contents on selecting the prediction model of gray cast iron's modulus, we apply Meta-analysis to retrieve Chinese journals related to gray cast iron and elastic modulus and adopt fixed effect models to evaluate and analyze the introducedδ value, hoping to provide theoretical basis for prediction model of elastic modulus. According to the analytical results: (1) When the silicon content is relatively low, the model E_0=101.32+2.51Si/C is suggested for prediction. (2) When the carbon content is relatively low, the model E_0=313.175-49.014C-14.082Si is suggested for prediction. (3) When the two elements are both relatively low, Si/C value-based judgment needs to be made that the model E_0=101.32+2.51Si/C is suggested when the value is relatively low. (4) When either the silicon content or the CE (carbon equivalent) is relatively low, the model E_0=194.55-27.85CE+58.2Si/C or the model with three variables-E_0=20.527-0.021Si/C+59.2841Si+0.004CE is suggested for prediction. (5) When some of the above cases exist simultaneously, the preferable model selection should be considered in the following order of priority: C=Si>Si/C>CE>S.

1. Introduction

Elastic modulus E_0 is a proportional coefficient demonstrating the relation between the stress and the strain. The existence of graphite tissue within the gray cast iron causes it to deform under such little stress, the distortion curve of which is free of straight-line segment and yield point. Thus, the gray cast iron has no fixed elastic modulus[1]. When the gray cast iron is working under a low stress state, its elastic modulus is more likely to replace the anti-deformation capability of the materials with tensile strength characterization[2]. Therefore, a series of elastic modulus prediction models based on that have been put forward for better exploration of gray cast iron's capability[1,3-5], which can reflect the influence of different element contents on the elastic modulus, to further find the method of improving the gray cast iron's elastic modulus.

But the prediction precision and service conditions are various. Currently, it is still unknown which prediction model should be used for prediction under a certain condition. Based on above, the research comprehensively evaluates how to select prediction model according to different element contents and interprets for that, using the software of Review Manage5.4 and applying the Meta-analysis.

2. Materials and Methods

2.1 Retrieval method
The author retrieved relevant academic dissertations through CNKI (China National Knowledge Internet) and Wanfang Database with retrieval terms of gray cast iron and elastic modulus, etc. Then the already identified records were screened by the criteria including titles and abstracts. Finally, all the records that had been screened out were downloaded for reading.

2.2 Screening method

2.2.1 The criteria of screening
(1) prediction models of elastic modulus proposed in the journal; (2) different element contents in the gray cast iron and elastic modulus for tests.

2.2.2 Exclusion criteria
(1) Fuzzy indicators and incomplete data; (2) No proposed prediction model; (3) Records unrelated to our research. (see Figure1)

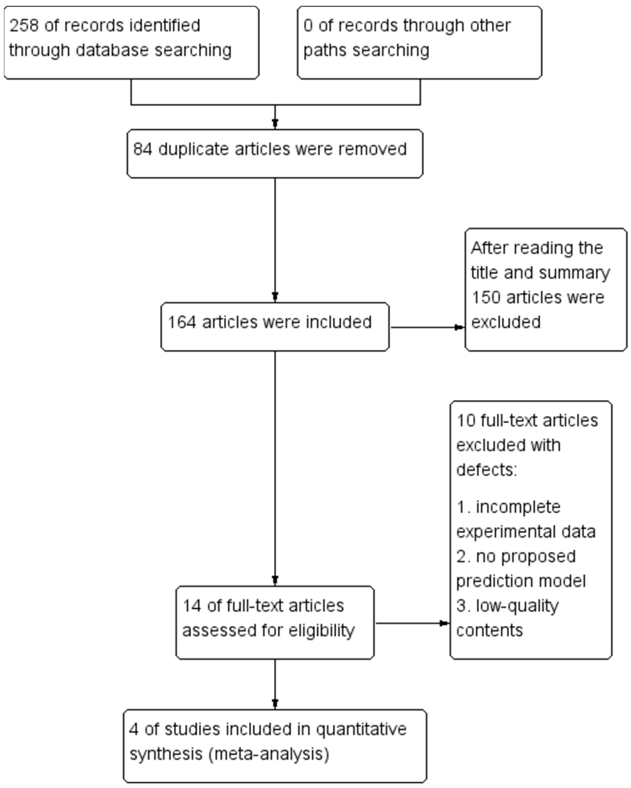

Figure 1 Flow figure of screening process

2.3 Material extraction and quality evaluation

2.3.1 Material extraction
The two researchers firstly screened the identified records according to the record-screening process, and then compared the screened records. When the results were inconsistent, a third researcher would participate in discussion to decide whether to include them or not. The materials of the records including the name of the author, the time of publication, the proposed prediction models were sorted out after the records to be included in Meta-analysis had been determined. (see table 1)

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Table 1 Basic features of the records included in Meta-analysis

Author	First published	Proposed prediction model	Variable number	CE considered or not
Zemao Qu [3]	2013	E_0=101.32+2.51Si/C	1	No
Xueyou Zhong [4]	1988	E_0=194.55-27.85CE+58.2Si/C	2	Yes
Hao Lin [5]	2010	E_0=313.175-49.014C-14.082Si	2	No
Xijie He [1]	2014	E_0=20.527-0.021Si/C+59.2841Si+0.004CE	3	Yes

For more convenient analysis, we introduce the coefficient δ, which is calculated according to the following equation:

$$\delta = \frac{E_{0P} - E_0}{E_0}$$

In the equation, E_{0P} stands for the calculated value and E_0 stands for the experimental value.

And 22 groups of data from the records [3] were put into the equation to calculate δ value and mean values were calculated according to different elements. The data above the mean value are defined as experimental groups and the data below the mean value are defined as the control groups. The data were classified, sorted out and induced by different elements. (see table 2)

Table 2 Scope of different element contents between experimental and control groups

Element (%)	Experimental	control
C	3.01-3.091	3.091-3.2
Si	1.6-1.722	1.7221.83
Mn	0.766-0.861	0.861-0.909
P	0.024-0.029	0.029-0.033
S	0.066-0.079	0.079-0.091
CE	3.56-3.675	3.675-3.76
Si/C	0.51-0.558	0.558-0.6

2.4 Quality Evaluation

The Figure of research records was created by the software-Review Manage5.4 for quality evaluation, Every indicator is divided into three risk levels- low, unclear and high. (see Figure2)

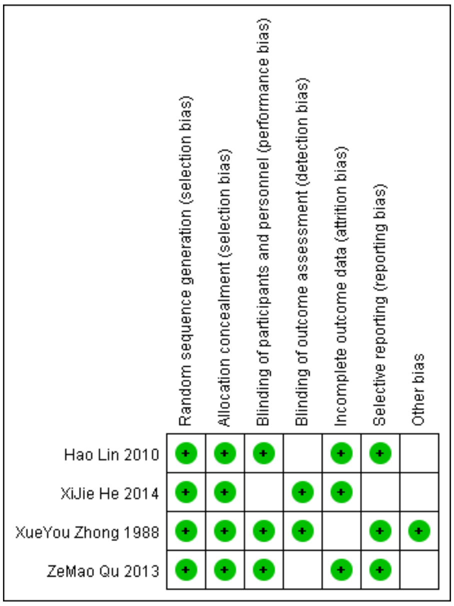

Figure 2 Quality evaluation of the records

2.5 *Statistical Treatment*

The influence of the content of carbon, silicon, manganese, phosphorus, sulfur, CE and Si/C on the δ value of different prediction models were analyzed. δ is used as the statistical effect amount and provides its 95% CI. If $P<0.05$, then the statistical difference is considered to exist between experimental and control groups. Therefore, subgroup analysis is conducted to evaluate the influence of grouping factor on the results. Instead, there is no statistical difference. Meanwhile, using the method of statistics to test the statistical heterogeneity: if $I^2 \geq 50\%$, the statistical heterogeneity is indicated; instead, it shows no statistical heterogeneity. The fixed effect models were used to analyze.

3. The results of Meta-analysis

3.1 *The influence of carbon content on the δ value of prediction models*

The results demonstrate that the combinative effects of the records MD (mean difference) is-0.10 and the 95% Cl (confidence interval) is [-0.12, -0.08], $X^2=0.23$, DF=3, $I^2=0$, indicating no heterogeneity among the records. Therefore, the fixed effect models should be applied. Besides, $P<0.00001$, it indicates heterogeneity. Thus, relatively low carbon content (3.01%-3.091%) enables the δ value to reduce by 0.10 times.

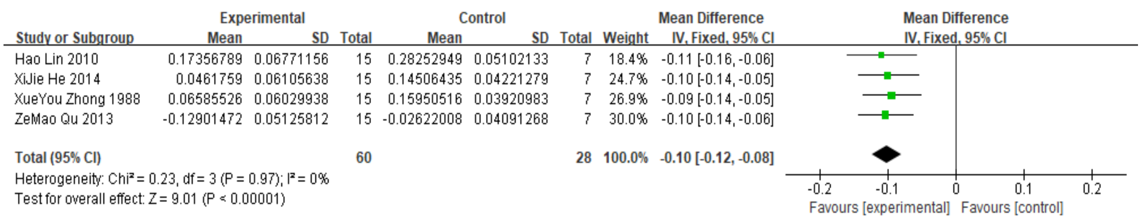

Figure 3 The forest plot indicating the influence of the carbon content on prediction models

In order to evaluate the influence of grouping factors on the results, subgroup analysis was conducted to determine whether CE was considered in the prediction models or not. The results indicate that low carbon content (3.01%-3.091%) enables the δ values of the models with CE to reduce by 0.1 times and the models without CE by 0.11 times. This indicates that when predicting the elastic modulus of gray cast iron, if the content of C is relatively low, the model with two variables and without CE considered proposed by Hao Lin[5] is recommended for prediction.

3.2 The influence of silicon content on the δ value of prediction models

In the influence of silicon content on how to select the prediction model, the MD is 0.05, the combinative effect value test Z=3.76, P=0.0002<0.05, and the HDL-C effect value falls on the right of the invalid line, which indicates statistical significance. Heterogeneity test results: X^2=1.64, DF =3, P=0.65, I^2=0, so selecting fixed effect model, showing that relatively low silicon content (1.6%-1.722%) enables the δ value to increase by 0.05 times.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Hao Lin 2010	0.25121133	0.06644769	10	0.17242595	0.07560488	12	22.7%	0.08 [0.02, 0.14]
XiJie He 2014	0.09043039	0.07160966	10	0.06698209	0.07410281	12	21.5%	0.02 [-0.04, 0.08]
XueYou Zhong 1988	0.12579644	0.05949838	10	0.07053337	0.06971905	12	27.5%	0.06 [0.00, 0.11]
ZeMao Qu 2013	-0.06528687	0.06463665	10	-0.12215773	0.06180327	12	28.3%	0.06 [0.00, 0.11]
Total (95% CI)			**40**			**48**	**100.0%**	**0.05 [0.03, 0.08]**

Heterogeneity: Chi^2 = 1.64, df = 3 (P = 0.65); I^2 = 0%
Test for overall effect: Z = 3.76 (P = 0.0002)

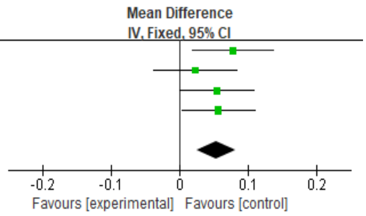

Figure 4 The forest plot indicating the influence of the silicon content on prediction models

Subgroup analysis was conducted to determine whether CE was considered in prediction models. The results indicate that the relatively low silicon content (1.6%-1.722%) has no difference in the model with CE considered, while enables the δ value of the model without CE to increase by 0.11 times. When predicting the elastic modulus of gray cast iron, if the silicon content is relatively low, the model with one variable and without CE considered proposed by Maoze Qu[3] is recommended for prediction.

3.3 The influence of manganese and phosphorus contents on δ values of prediction models

In researching the influence of manganese content on how to select the prediction model, it was found that P=0.49>0.05, and the HDL-C effect crossed the invalid line, which indicated that there was no statistical difference, so the prediction model could not be selected simply according to the manganese content.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Hao Lin 2010	0.19742336	0.11036223	9	0.21572419	0.05571662	13	20.6%	-0.02 [-0.10, 0.06]
XiJie He 2014	0.07166357	0.10510982	9	0.08177822	0.04145813	13	24.1%	-0.01 [-0.08, 0.06]
XueYou Zhong 1988	0.08716669	0.09820252	9	0.10152806	0.04447863	13	26.7%	-0.01 [-0.08, 0.05]
ZeMao Qu 2013	-0.1013419	0.09341902	9	-0.09282188	0.04748316	13	28.6%	-0.01 [-0.07, 0.06]
Total (95% CI)			**36**			**52**	**100.0%**	**-0.01 [-0.05, 0.02]**

Heterogeneity: Chi^2 = 0.04, df = 3 (P = 1.00); I^2 = 0%
Test for overall effect: Z = 0.69 (P = 0.49)

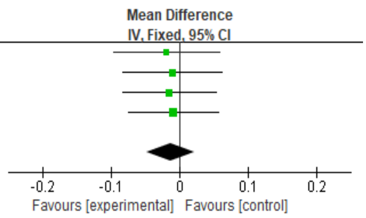

Figure 5 The forest plot indicating the influence of the manganese content on prediction models

We found, in the influence of phosphorus content on how to select the prediction model, that P=0.24>0.05, indicating no statistical difference, so the prediction model should not be selected simply according to the phosphorus content.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Hao Lin 2010	0.20264112	0.0932658	12	0.21495313	0.06663449	10	19.7%	-0.01 [-0.08, 0.05]
XiJie He 2014	0.0650033	0.08287888	12	0.09280494	0.05752297	10	25.5%	-0.03 [-0.09, 0.03]
XueYou Zhong 1988	0.08709237	0.08082739	12	0.10592565	0.0559648	10	26.9%	-0.02 [-0.08, 0.04]
ZeMao Qu 2013	-0.10132705	0.07924916	12	-0.09028368	0.05528596	10	27.8%	-0.01 [-0.07, 0.05]
Total (95% CI)			**48**			**40**	**100.0%**	**-0.02 [-0.05, 0.01]**

Heterogeneity: Chi^2 = 0.19, df = 3 (P = 0.98); I^2 = 0%
Test for overall effect: Z = 1.16 (P = 0.24)

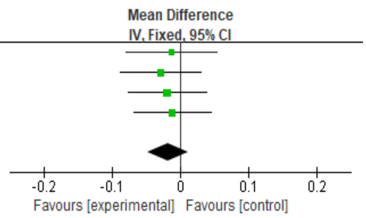

Figure 6 The forest plot indicating the influence of the phosphorus content on prediction models

3.4 The influence of sulfur content on δ values of prediction models

A total of 88 groups of data were analyzed. The results suggested that the MD was -0.05, the 95%CI was [-0.08, -0.02], $X^2 = 0.26$, DF = 3, and $I^2 = 0$, indicating that there was no heterogeneity among the articles. Therefore, the fixed effect model should be applied, and $P=0.002<0.05$, which showed a statistical difference, indicating that relatively low sulfur content (0.066%-0.079%) enables the δ value to reduce by 0.05 times.

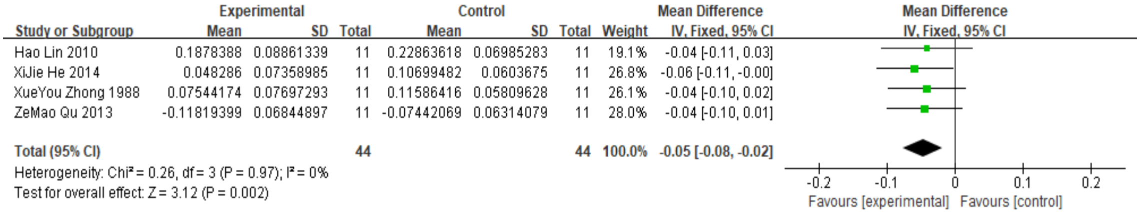

Figure 7 The forest plot indicating the influence of the sulfur content on prediction models

Subsequently, we analyzed the subgroups basing on the questing whether CE was considered in prediction models. The results indicated that relatively low sulfur content （0.066%-0.079%）enables the δ value of models with CE considered to reduce by 0.05 times, has no statistical difference to models without CE considered. When predicting the elastic modulus of gray cast iron with relatively low silicon content, it is recommended to use the model with two variables and with CE considered proposed by Xueyou Zhong[4] or the model with three variables and with CE considered proposed by Xijie He[1].

3.5 The influence of CE content on δ values of prediction models

In researching of the influence of CE equivalent on how to select the prediction model, we found that the MD was -0.05, and the 95% CI was [-0.08, -0.02], $X^2 = 1.26$, DF = 3, and $I^2 = 0$, indicating no heterogeneity among the records. Therefore, the fixed effect model should be applied, $P = 0.002 < 0.05$, and the HDL-C effect quantity fell on the left side of the invalid line, showing a statistical difference, indicating that the relatively low CE (3.56%-3.675%) enables the δ value to reduce by -0.05 times.

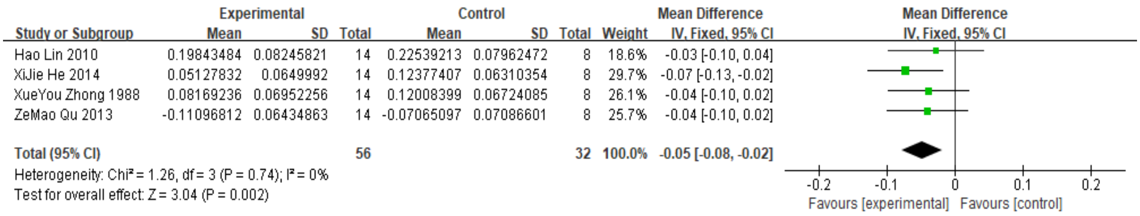

Figure 8 The forest plot indicating the influence of CE on prediction models

Subsequently, subgroup analysis was conducted based on whether considered in the prediction model. The results indicated that relatively low CE (3.56%-3.675%) enables the δ value of the model with CE considered to reduce by 0.06 times, and has no statistical difference to the model without CE considered. When predicting the elastic modulus of gray cast iron, if CE is relatively low, it is recommended to use the model with two variables and with CE considered proposed by Xueyou Zhong[4] or the model with three variables and with CE considered proposed by Xijie He[1].

3.6 The influence of the Si/C (Si is short for silicon and C is short for carbon) value on δ values of prediction models

In researching the influence of Si/C value on how to select the prediction model, it was found that the MD was 0.09, and the 95%CI was [0.06, 0.11], $X^2 = 1.26$, DF = 3, and $I^2 = 0$, indicating no heterogeneity among the records. Therefore, the fixed effect model should be used; $P < 0.00001$, and HDL-C effect amount fell on the right side of the invalid line, showing a statistical difference, indicating that a relatively low Si/C (0.51%-0.558%) enables the δ value to increase by 0.09 times.

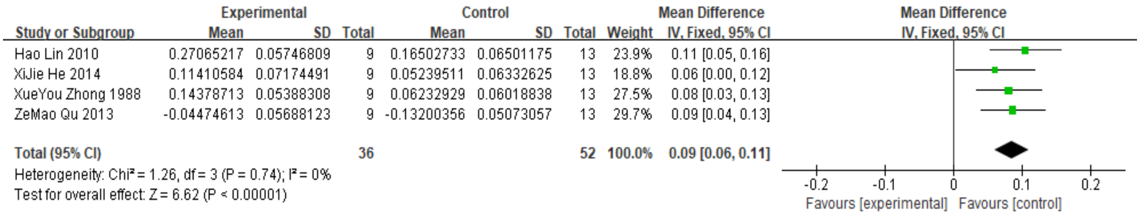

Figure 9 The forest plot indicating the influence of Si/C on prediction models

After subgroup analysis, we found that relatively low Si/C enables the δ value of the prediction model with CE considered to increase by 0.07 times and without CE considered to increase by 0.10 times. All these demonstrate that in the prediction of elastic modulus of gray cast iron, when Si/C (0.51%-0.558%) is relatively low, the model with one variable and without CE considered proposed by Maoze Qu[3] is recommended for prediction.

4. Discussion and conclusion

The research has conducted synthetic evaluation and analysis of the influence of different element content on selecting the prediction model of gray cast iron through detailed retrieval strategy and strict record-screening criteria according to the steps of Meta-analysis. The results suggest that the content of different element in gray cast iron plays a vital role in the selection of different elastic modulus prediction models. (see table 3)

Table 3 The influence of different element content on selecting different elastic modulus prediction model

Element content conditions	Change of δ value (times)	Recommended prediction model
Relatively low silicon content	+0.11	E_0=101.32+2.51Si/C
Relatively low Si/C	+0.10	
Relatively low carbon content	-0.11	E_0=313.175-49.014C-14.082Si
Relatively low sulfur content	-0.05	E_0=194.55-27.85CE+58.2Si/C
Relatively low CE	-0.06	E_0=20.527-0.021Si/C+59.2841Si+0.004CE

In practice, different relations of element content often exist simultaneously. If the content of carbon element conflicts with that of silicon element, the model should be selected according to Si/C, while for other elements, it should be determined according to the absolute value of δ value change in Meta-analysis. The larger the absolute value of δ change, the recommended prediction model should be selected accordingly, which is C=Si>Si/C>CE>S in this paper.

This study has the following limitations: (1) The number of both records and samples included in this study is small, which may have a certain impact on the evaluation results; (2) In the record screening, only Chinese records such as records from CNKI were drawn, and no relevant research record from abroad was collected. It is necessary to collect higher-quality relevant research records in the future to further update the evaluation of this research system.

To sum up, this paper makes meta-analysis by including four records on prediction models, and puts forward some suggestions on the selection of prediction models with different element contents:

(1) When the silicon content is relatively low (1.6%-1.722%), it is suggested to apply the model E_0=101.32+2.51Si/C without CE considered for prediction.

(2) When the carbon content is relatively low (3.01%-3.091%), it is suggested to apply the model E_0=313.175-49.014C-14.082Si and without CE considered for prediction.

(3) When both the silicon and carbon contents are relatively low, the Si/C should be judged. If the

Si/C is relatively low (0.51%-0.558%), it is suggested to apply the model E_0=101.32+2.51Si/C and without CE considered for prediction.

(4) When the sulfur content is relatively low (0.066%-0.079%) or CE is relatively low (3.56%-3.675%), it is recommended to apply the model E_0=194.55-27.85CE+58.2Si/C or the model E_0=20.527-0.021Si/C+59.2841Si+0.004CE, both with CE considered.

(5) When some of the above cases exist simultaneously, the preferable model selection should be considered in the following order of priority: C=Si>Si/C>CE>S.

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