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ASSESSING THE YIELD POINT OF CONCRETE STEELS BASED UPON KNOWN CHEMICAL COMPOSITION

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Preliminary Note – Prethodno priopćenje

This research is based on both, theoretical and experimental work and aims to assessment the yield point of concrete steels, based on the known alloy chemical composition. The experimental portion of the work was performed at the Split steelmaking factory, which produces concrete steels from the waste iron. The theoretical portion of this study involves mathematical modelling carried out using the software package MATLAB. The work presented here provides both a scientific and practical contribution to the field. By using mathematical modelling, the accuracy of the estimation of the yield point is improved by 8,5%. Using this correlation enables the reduction of the concrete steel production costs because it is possible to reduce the use of expensive tests for the characterization of strength and mechanical properties.

Key words: yield point, assessment, steel, alloy elements

Prognoziranje granice razvlačenja betonskih čelika temeljem poznatog kemijskog sastava. Ovo istraživanje je teorijsko eksperimentalnog karaktera, a obrađuje procjenu granice razvlačenja betonskih čelika na temelju kemijskog sastava slitina. Eksperimentalni dio istraživanja realiziran je u željezari Split koja proizvodi betonske čelike iz otpada ili starog čelika. Teorijski dio rada - matematičko modeliranje realizirano je korištenjem softverskog paketa MatLab. Istraživanje je rezultiralo znanstvenim i praktičnim doprinosom. Matematičkim modeliranjem poboljšana je točnost do sada poznate početne korelacije određivanja granice razvlačenja za 8,5 %. Korištenjem ove korelacije omogućit će se smanjenje troškova proizvodnje betonskih čelika, jer je moguće smanjiti opseg skupih ispitivanja čvrstoće i mehaničkih svojstava vlačnom probom.

Ključne riječi: granica razvlačenja, prognoza, čelik, legirni elementi

INTRODUCTION

The incorporation of recycling, which is the production of raw materials from old buildings and devices, is an increasing trend in industries worldwide. This increase in recycling is motivated by the conservation of energy and environmental resources, in particular, the decrease of carbon dioxide and green house gas emission by the intensive burning during various technological processes.

The procedures for determining the yield point and the other relevant mechanical properties of concrete steels produced from waste irons are very expensive. The high expense is due to the relatively small production quantities and considerable variation of the chemical composition as a consequence of the variety of the raw materials associated with the use of waste iron.

The yield point is taken as a base point and is representative of the other mechanical properties (tensile, breaking strength and the proportion limit), enabling easier analysis. The yield point, Y, is defined as the stress value after which additional specimen elongation takes place, as clearly seen in Hook's diagram, Figure 1 [1].

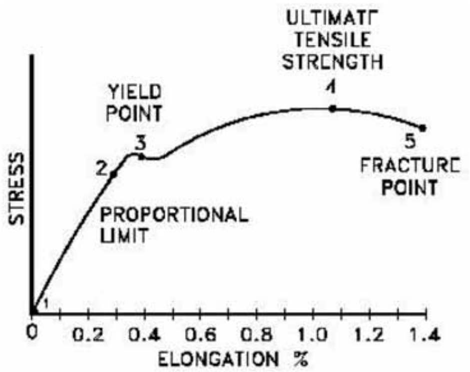

Figure 1 Hook's diagram

For further simplification, the number of chemical elements within an alloy is reduced to the six elements: Mn, Si, Cr, Cu and P. Their influence on the yield point is shown in Figure 2 [2,5].

This research represents an attempt to predict the mechanical properties of concrete steels produced by waste iron by means of mathematical modelling based on chemical analysis. This is a difficult problem to solve by classical programming due to the large number of variables. However, using the software package

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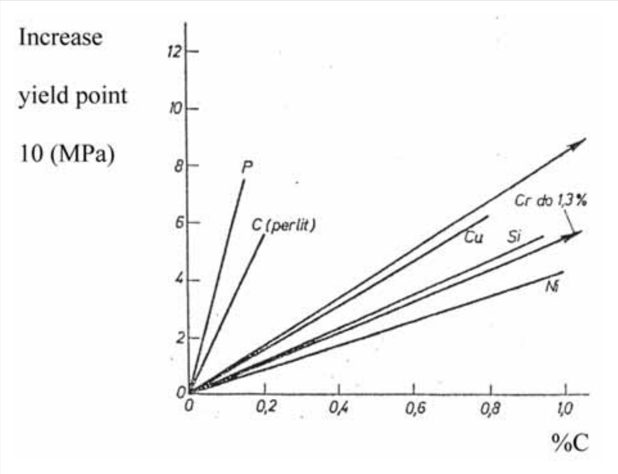

Figure 2 Influence of the alloy elements on the yield point increment

MATLAB (the name is derived from matrix laboratory) enables quality optimization of a great number of factors [6-7] that have considerable influence on the value of the yield point.

RESEARCH

The aim of this research is to successfully assessment the yield point of a steel material based on the chemical analysis of its components. Theoretically, the most secure and precise procedure is the laboratory estimation of the dependence of properties on chemical composition. First, a molten alloy in which each element is represented by the mean value of its weight fraction is produced. In this way, a reference with precisely determined quantities of alloy elements is obtained. For the other specimens, the concentration of particular alloy elements is changed to mimic realistic changes in chemical compositions. As a result of the changing weight proportions of alloy elements, the steels have different mechanical properties, i.e., different yield point values. For each change in an elemental weight proportion, it is necessary to produce a new alloy. When testing a wide range of possible chemical compositions, this technique quickly becomes overly tedious and not economically acceptable.

Considering the cost and long duration of the present procedures, we wanted to develop a way to estimate the yield point based on a mathematical model, where accurate results can arise from only one measurement of one composition of the alloy elements and the deviation of calculated and experimental values is small. In other words, we aim to develop a formula that yields an expected yield point value.

The materials under consideration are civil engineering steels that are produced in the Split steel factory using a melting procedure. Unlike alloyed carbon steels of trade quality, the concentration of carbon (C) is not the predominant influence on the final mechanical properties, including the yield point. In these steels, Mn, Si, Cr, Cu and P also have strong influences on the mechanical properties. This work takes into account the presence of these six elements and their effects on the material, while influence of the other chemical elements is neglected in order to avoid complicated analysis.

The content of each chemical element is defined by means of spectral analyses with a quant meter. Table 1 shows the range in possible concentration of single chemical elements and their minimal yield point values.

In this work, the yield point of 636 specimens collected immediately after production is measured. Modelling the relationship of chemical composition and mechanical properties, in order to assessment the yield strength, was completing according to the steps below.

First step – initial relationship

The yield point in (MPa) was calculated using the following (initial) relationship [2, 5]:

$$\sigma_Y = \left\langle \begin{matrix} 12{,}4 + 28\mathrm{C} + 8{,}4\mathrm{Mn} + 5{,}6\mathrm{Si} \\ +5{,}5\mathrm{Cr} + 4{,}5\mathrm{Ni} + 8\mathrm{Cu} + 5{,}5\mathrm{P} + \\ [3 - 0{,}2 \cdot (\mathrm{d} - 5)] \end{matrix} \right\rangle \cdot 10 \text{ MPa} \quad (1)$$

Where is d = Φ10
(specimens of standard dimensions).

The relative error between the measured value for each of these specimens and the calculated value was determined according to equation (2):

$$\delta = \frac{(\sigma_\mathrm{Y})_{\mathrm{calculated}} - (\sigma_\mathrm{Y})_{\mathrm{measured}}}{(\sigma_\mathrm{Y})_{\mathrm{calculated}}} \cdot 100\% \quad (2)$$

Deviations between calculated and experimental values using the initial relationship given in equation (1) are high (up to 49 %), suggesting that in addition to the chemical content there are other factors that influence the considered property.

Table 1 **Chemical elements concentration in the test steel specimen**

Steel	Min. G_y / MPa	C	Si	Mn	P	Cu	Cr
Č.0000	320	0,170-0,220	0,150-0,300	0,350-0,600	0,000-0,065	0,750-0,850	0,000-0,300
Č.0002	340	0,170-0,220	0,150-0,300	0,350-0,0600	0,000-0,060	0,650-0,750	0,000-0,300
Č.0261	330	0,110-0,150	0,0150-0,300	0,400-0,550	0,000-0,045	0,000-0,450	0,000-0,300
Č.0300	340	0,160-0,220	0,150-0,300	0,400-0,600	0,000-0,060	0,500-0,850	0,000-0,300
Č.0372	360	0,140-0,170	0,150-0,300	0,400-0,600	0,000-0,050	0,000-0,500	0,000-0,300
Č.0552	420	0,260-0,330	0,150-0,300	0,750-0,950	0,000-0,050	0,000-0,500	0,000-0,300

Second step – involving of correlation factors

This work aims to introduce various correlation factors into the initial relationship for yield point determination, and optimize them. These factors should compensate for the influence of the environment and other previously "neglected" elements on the yield point [5-9].

The correction factors were obtained by means of an iterative method. The relationship (1) can be multiplied with each of the following expressions:

$$- 1{,}05+C) \quad (3)$$

$$- (0{,}5+Mn) \quad (4)$$

$$- (0{,}5+Mn+C) \quad (5)$$

$$- (0{,}99+C) \quad (6)$$

The best results are obtained by multiplying the initial relationship with the correlation factor (0,99+C). Relationship (1) then becomes:

$$\sigma_Y = \langle\ 12{,}4 + 28C + 8{,}4Mn + 5{,}6Si + 5{,}5Cr + 8Cu + 5{,}5P + [3{,}0 - 0{,}2 \cdot (d - 5]\ \rangle \cdot (0{,}99 + C) \cdot 10 \quad (MPa) \quad (7)$$

Where is d=F10

(specimens of standard dimensions).

When relationship (7) is used to predict the yield point values of the 636 molten element test specimens, an acceptable deviation between experimental and calculated results of less than 10 % is achieved for only 86,5 % of the elements. The magnitude of the permissible deviation is defined by a DIN (Deutsches Institut für Normung) recommendation.

The third step – optimisation of influence of content of carbon

The software package MATLAB (Nelder – Meade simplex algorithm) was used to optimize the (0,99+C) correlation factor in relationship (7), thus optimizing the portion of the equation that represents the influence of carbon (the most influential factor in our system).

The following relationship was obtained:

$$\sigma_Y = (14{,}4 + 28C + 5{,}6Si + 5{,}5Cr + 8Cu + 5{,}5P) \cdot (1{,}06705 + 0{,}00336 \cdot C) \cdot 10 \quad (MPa) \quad (8)$$

Relationship (8) gives acceptable results for 90,5 % of the molten material specimens, proving that is it a more effective solution in comparison to the previous relationship (7), which predicted acceptable yield points for only 86,5 % of the molten materials.

The fourth step - optimisation of influence of the chemical elements

After the third step, it was logical to optimize the other influencing factors, obtaining the whole correlation. The new relationship becomes:

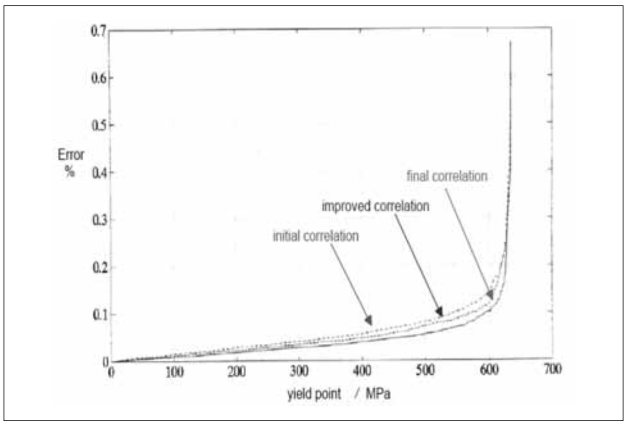

Figure 3 Results of deviation of the Yield Point for the three relationships

$$\sigma_Y = (25{,}9630 + 23{,}17C + 6{,}69Si + 6{,}66\ Mn + 2{,}13P + 3{,}92Cu + 2{,}81Cr) \cdot (0{,}8137 + 0{,}68C) \cdot 10 \quad (MPa) \quad (9)$$

The relationship was found to provide acceptable predictions for 95 % of the test specimens.

RESEARCH RESULTS

Figure 3 plots the deviation of the measured and calculated values of the yield point for each relationship: the initial (1), improved (7), and final (9) relationship.

In Figure 3, the molten materials are sorted on the x – axis according to increasing relative error, with the value for the relative error plotted on the y – axis. It is clear that the improved correlation (7) and final correlation · (9) gives better results than the initial correlation (1), which prior to this work was the preferred method for prediction for this author.

In this work, the assessment of the yield point was improved by 8,5% compared to results obtained using the initial relationship.

CONCLUSION

The most accurate way to determine the mechanical properties of steel is to measure its tensile strength using a tensile test. These properties are primarily influenced by the proportion of carbon and other alloy elements. The production of concrete steel (with the weight percent of carbon between 0,17 and 0,33 %) from waste iron in steel factories is cost effective - knowing the exact composition is not necessary for this quality of steel. Relationships developed in this work show that it is possible to accurately determine, by means of a mathematical method, the yield point of a concrete steel specimen. In other words, by knowing the chemical composition of the molten material, one can determine the necessary mechanical properties of the final alloy. This characterization is a critical part of the production process when casting concrete steel alloys.

The final correlation for assessing the yield point (9) is based on the chemical composition of the steels with carbon concentrations ranging from 0,17 to 0,33 % C.

The accuracy of results predicted using this correlation (9) in comparison to the initial (the previous preferred) correlation (1) is improved by 8,5 %.

Assessing the yield point on the basis of a steel's chemical composition allows for intervention before the casting. This capability has the potential to improve the required properties of the steel component, resulting in a decrease in the number of redundant procedures, which greatly reduces production costs.

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Note: The responsible translator for English language is Leslie, J.