JKAU: Eng. Sci., **Vol. 22** No. 2, pp: 49-60 (2011 A.D./1432 A.H.)
DOI: 10.4197 / Eng. 22-2.3

Determination of Concrete Reinforcing Bars Characteristics

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Abstract. The objective of this study is to demonstrate the ability to determine the main characteristics of concrete reinforcing bars using simple methods. Most mechanical properties such as yield strength, tensile strength and elongation were determined through the tensile test. The chemical composition was determined using X-Ray Fluorescence (XRF) technique. Three sets of concrete reinforcing bars with diameter 8-20 mm manufactured by different companies were used in those analyses. The results obtained for mechanical properties conform to the specifications values of international standards. The chemical compositions also were in general conforming to the specifications claimed; except that for silicon and manganese which exhibit slightly higher value for some rebars products.

Keywords: Concrete reinforcing bars, Mechanical properties, Chemical analysis, Conformity.

1. Introduction

The fast growth in the Gulf region and especially in the Kingdom of Saudi Arabia in the last few decades was accompanied by large building construction and industrial activities. The quantities of steel products needed for different infrastructure construction and industrial activities are enormous. The concrete reinforcing bars used for these purposes are locally made or imported. The verification of conformity of the main mechanical properties and the chemical compositions of these bars using simple methods is very important and needed not only for the users, but also for the manufacturers as well.

The physical properties of structural materials determine the behavior of reinforcement for concrete that is of prime importance for engineered structure. These properties must meet the specification values of international standards in order to reinforce the safety of the construction along its life. However, the minimum strain in the steel at fracture is defined in steel specifications, since it is essential for the safety of the structure that the steel be ductile enough to undergo large deformations before fracture [1, 2]. Therefore, most mechanical properties such as yield strength, tensile strength and elongation are determined through the tensile test in this study. The calculation of those properties is based on the data provided by the curve of stress-strain obtained during this test [3].

The structural engineer may seem to be more interested in the physical properties of steel, but these properties, however, cannot be realistically attained without the proper chemical composition of the steel. A simple method to evaluate the elemental composition of the concrete reinforcing bars is the use of XRF technique, which has many advantages; it is fast, accurate, non destructive and has a limit of detection in the range of few part per million (ppm) of most elements [4, 5]. For these reasons, the XRF analysis method is widely used in many fields such as metallurgy, industry, geology and mineralogy, food industry and environmental management. The analysis of steel is useful for various purposes, such as the inspection of raw materials, intermediate product and end products, process control in iron, steel manufacturing and quality control [6]. However, most of routine steel analysis involves standard wet chemical method or inductively coupled plasma atomic emission. These methods are destructive and require dissolution of the alloy and long sample preparation. Use of the XRF technique is very attractive in many fields and especially for metal and alloy analysis [7, 8]. The sample preparation for XRF is relatively simple and requires less time consumption and effort. For example, when the solid sample is homogeneous then it needs only polishing to be ready for analysis [9].

These simple methods were used in this study to verify the conformity of concrete reinforcing bars characteristics. Therefore, different types of bars were chosen from the local market to determine their mechanical properties and chemical compositions. Three sets of various rebar grades and diameters varying from 8 to 20 mm were analyzed. Two sets of them were manufactured by local companies while the third one was imported. The verification of conformity of the main characteristics of these products was determined through the comparison of the results obtained in this analysis and the specification values given in international standards or with the claimed values given by the manufacturing company.

2. Equipment

The mechanical properties of the reinforcing rebar were measured by the INSTRONE 1197 machine. This tensile testing machine is designed to elongate the specimen at a constant rate, and to continuously and simultaneously measure instantaneous applied load and the resulting elongation. The full capacity of this machine is about 500 kilo-Newton (kN) and has variable cross head speed. The output curve of tensile testing is recorded on a strip chart as load or force versus elongation. The stress-strain test is destructive; the test specimen is permanently deformed and usually fractured after few minutes.

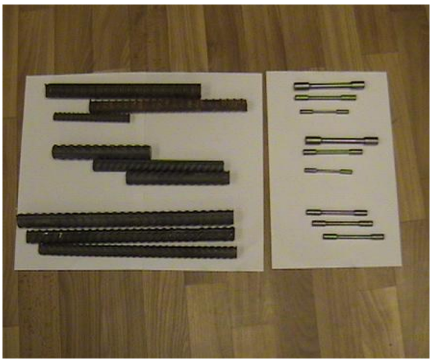
The Energy Dispersive X-ray Fluorescence spectrometer (EDXRF) unit, JSX-3202-M used in this study was manufactured by JEOL Company in Japan. This unit is able to analyze a wide range of specimen samples in the form of solid, powder and liquid. The elements, that can be measured by this instrument unit range from sodium (Na) to uranium (U). The spectrometer consists of a main unit and a computer system [10]. The main unit incorporates an X-ray tube, an Si(Li) detector with 133 eV resolution at 5.9 keV (Mn-k_α), an analyzing chamber and a specimen chamber. The computer system contains software to drive the unit and spectrum analysis software. This software allows simultaneous multi-element spectral measurement, qualitative and quantitative elemental analysis using fundamental parameter (FP) and reference methods. The detection limit of the system varies from 10 ppm to 100 ppm depending on the inverse of the atomic weight of the element [11].

3. Measurement and Methods

3.1 Mechanical Properties Testing

The samples preparation is a very important step in the mechanical properties testing procedure. The specimen sample must have a standard form such as that presented in Fig. 1 before the tensile testing. The circular cross-section is common, but rectangular specimens can also be used. The cross-section must be uniform along the specimen length to avoid weak points where the deformation can abnormally take place. In general, the deformation is confined to the narrow center region. The standard is approximately 12.8 mm (0.5 in), whereas the reduced section length should be at least four times this diameter; 60 mm (2.25 in) is common. The specimen is mounted by its ends into the holding grips of the testing machine. During the test, the specimen is deformed usually to fracture, with a gradually increasing tensile load that is applied uniaxially along the long axis of the specimen.

Most mechanical properties such as yield strength, tensile strength and elongation are determined through these tensile tests for each rebar product type. The calculation of those properties is based on the data provided by the curve of the stress-strain obtained during this test. As an example, one curve of stress-strain is illustrated in Fig. 1.



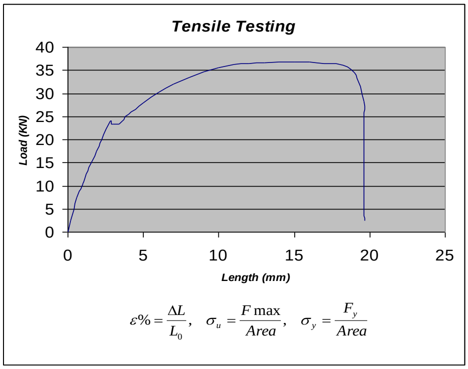


Fig. 1. Sample preparation and example of one curve of stress-strain.

3.2 *Chemical Composition Analysis*

The sample preparation is an important step that can affect the precision and the accuracy of the analysis. At least two conditions must be satisfied for XRF analysis, the first one is that the sample must be representative to the entire material and the second is that the surface of the sample must be smooth to reduce the diffraction of the X-ray [9]. Therefore, three samples of 4 cm length were cut in the workshop from each rebar product type. The second important treatment is grinding and polishing of the two faces of each sample. The last step of this sample preparation is the cleaning by acetone of the polished sample faces.

Therefore, for each rebar type product there were six faces ready to be measured by XRF.

The qualitative analysis is the identification of all elements present in the x-ray fluorescence spectra, which is based on the determination of the correct top position of each peak (centroid). The conversion of the peak centroid channels to energy lines is made using energy calibration curve. Therefore, different standard reference elements with known energies lines K_α or K_β were chosen to cover the interesting energy region of 1-25 keV for this energy calibration. The spectrum obtained of each standard reference was analyzed by the spectrum analysis software to determine the energy-channel relationship using the least square fitting method [5]. The linear calculated energy-channel relationship is expressed as follows:

$$E(keV) = A + BX \tag{1}$$

Where X is the number of channels, A = 0.01000 and B = 0.00216 (keV/channels),

This relationship is used to identify the unknown elements present in the spectrum with the help of x-ray line energies database of all elements.

The quantitative analysis is the conversion of the net peak intensity present in the x-ray fluorescence spectra to element concentration. Therefore, the first step is to determine the correct net peak intensity of each x-ray line present in the analyzed sample. The spectrum analysis software was guided to deconvolute the overlapping peaks and calculates the net peak intensity of each peak by subtracting the background using a mathematical model. The second step is to calculate the element concentration using a combination of the fundamental parameter (FP) method and the reference method. The reference method used in this study allows more accurate analysis providing some references standards of known composition. This method has the advantage to combine the data collected from the measured spectra of the known references and the powerful FP method calculation to adjust the instrument parameters [5]. Table 1 presents the main characteristics of the steel standards used in this work for the quantitative analysis.

Table 1. Steel Standards compositions in %.

Standard	3-A	20-A	RS-125	105-C	260-A
C	3.31	1.01	-	0.10	0.10
Si	3.09	0.22	-	-	-
S	0.13	-	-	0.03	-
P	0.66	-	0.20	-	-
Cr	-	0.06	-	17.93	14.40
Mn	0.72	0.25	0.02	-	-
Fe	94.18	98.46	99.65	72.20	6.00
Ni	-	-	0.06	9.44	58.00
Mo	-	-	-	-	17.00
W	-	-	-	0.30	4.50

After the equipment setting, the XRF measuring time was fixed to 2 minutes that is enough to collect sufficient statistic counting even for the small peak present in the spectra. The spectrum of each sample was identified by a code containing the name of the manufacturer, the number of the sample, the diameter and the number of the faces. All spectra were stored in the hard disk of the computer and also in a flash memory for later analysis. As an example, Fig. 2 shows the spectrum obtained for one rebar product with its respective qualitative and quantitative analysis.

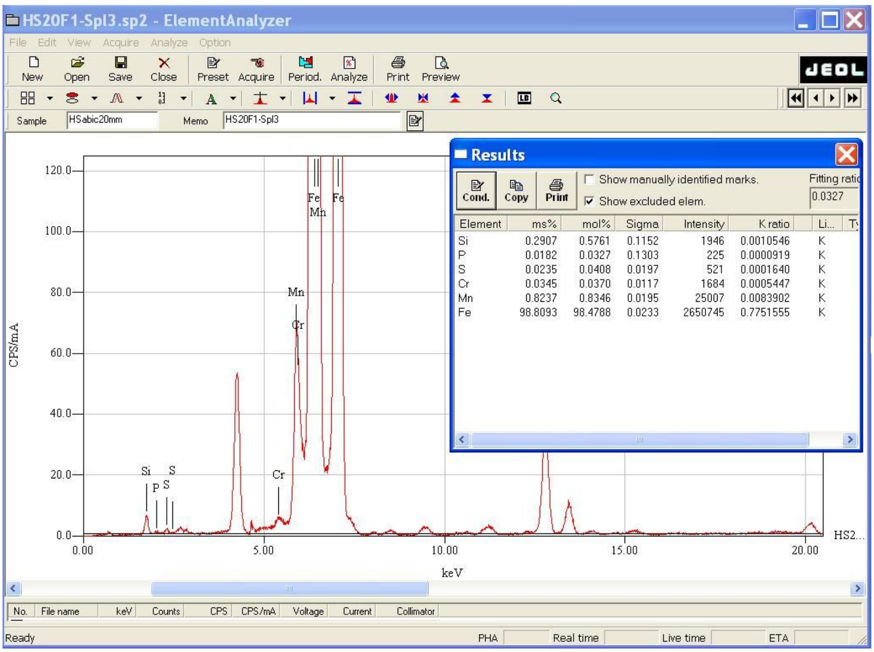


Fig. 2. XRF Elemental analysis spectrum of one concrete reinforcing bar.

4. Results and Discussion

4.1 Verification of Conformity

The verification of conformity is based on statistical hypothesis testing which needs in advance to fix the significance level α and the value of the test statistic. In most engineering problems, the sample size is usually small and the confidence level must be at least equal to 95 %. When the specification value (μ : the test value) must be less or more than a fixed value (μ_0 as a minimum or a maximum value), the test hypothesis is called one-sided hypothesis [12].

- For one-sided alternative hypothesis ($H_1 : \mu > \mu_0$), minimum fixed value; the null hypothesis ($H_0 : \mu = \mu_0$) is rejected if :

$$Y_0 = \frac{\overline{X} - \mu_0}{s/\sqrt{n}} > t[\alpha, n-1] \quad \Rightarrow \quad \mu = \overline{X} - t[\alpha, n-1].s/\sqrt{n} > \mu_0 \qquad (2)$$

- For one-sided alternative hypothesis ($H_1 : \mu < \mu_0$), maximum fixed value; the null hypothesis ($H_0 : \mu = \mu_0$) is rejected if :

$$Y_0 = \frac{\overline{X} - \mu_0}{s/\sqrt{n}} < -t[\alpha, n-1] \quad \Rightarrow \quad \mu = \overline{X} + t[\alpha, n-1].s/\sqrt{n} < \mu_0 \qquad (3)$$

Where $\overline{X}$ is the mean of the sample (average value), μ_0 is the mean of the distribution, s is the sample standard deviation, n is the sample size and $t[\alpha, n-1]$ is a value extracted from the standard distribution table.

4.2 Mechanical Properties of Steel Bars

The tensile testing procedure described above was used to determine the mechanical properties for steel bars of different grades. Figure 1 shows, as an example, the output graph obtained of one tensile test and the calculation of the mechanical properties of the bar. The mechanical properties of concrete reinforcing bars of grade 40 and grade 60 produced by the different companies are compared to the specification values of ASTM-A615M Standard [13] and presented in Tables 2 and 3.

Table 2. Mechanical properties of steel bars (grade 403) produced by local company No. 1.

Grades	Bar Diameter	Yield Strength	Tensile Strength	Elongation
	mm	N/mm^2	N/mm^2	%
Grade 40	10	364.37	451.20	24.54
	12	319.28	427.44	26.85
	14	328.62	445.39	27.24
	Average	337.42	441.34	26.21
	$s/\sqrt{n}$	13.74	7.15	0.84
ASTM-A615M (Min. values)		**280**	**420**	**12**
Test value μ		**297.30**	**420.46**	**23.75**
Conformity		√	√	√

Table 3. Mechanical properties of steel bars (grade 60) produced by the three companies.

Company	Results	Yield Strength	Tensile Strength	Elongation
		N/mm^2	N/mm^2	%
Local No.1	Average	506.62	651.91	21.30
	$s/\sqrt{n}$	20.65	10.57	1.87
	ASTM-A615M (Min. values)	**420**	**620**	**9**
	Test value μ	**446.33**	**621.06**	**15.84**
	Conformity	√	√	√
Local No.2	Average	484.21	700.67	21.91
	$s/\sqrt{n}$	6.02	19.54	2.81
	ASTM-A615M (Min. values)	**420**	**620**	**9**
	Test value μ	**466.63**	**643.62**	**13.72**
	Conformity	√	√	√
Foreign	Average	502.81	809.55	16.53
	$s/\sqrt{n}$	15.89	22.97	0.74
	ASTM-A615M (Min. values)	**420**	**620**	**9**
	Test value μ	**456.42**	**742.49**	**14.36**
	Conformity	√	√	√

The results of the mechanical properties testing presented in the above tables show that all concrete reinforced bars of different grades produced by the above three companies conform to the AMST 615M specifications as claimed by those companies.

4.3 Chemical Composition of Steel Bars

The results of chemical composition in % of the concrete reinforcing bars, determined using XRF technique, and their conformity to the claimed values by those companies are presented in Tables 4 and 5.

Table 4. Chemical composition and conformity of steel bars (grade 40) produced by the local company No. 1.

Elements	C	Si	P	S	Cr	Mn
Claimed Max. Values	0.24	0.23	0.05	0.05	0.3	0.7
Average	-	0.3379	0.0176	0.398	0.0273	0.7362
$s/\sqrt{n}$	-	0.0097	0.0015	0.0051	0.0013	0.0295
Test value μ	-	0.3559	0.0205	0.0493	0.0295	0.7876
Conformity	-	**X**	√	√	√	**X**

Table 5. Chemical composition and conformity of steel bars (grade 60).

Company	Elements	C	Si	P	S	Cr	Mn
	Claimed Max. values	0.3	0.23	0.05	0.05	0.3	0.7
Local No.1	**Average**	-	0.3549	0.0169	0.0318	0.0325	0.8446
	$s/\sqrt{n}$	-	0.0096	0.0011	0.0025	0.001	0.0049
	Test value μ	-	0.3719	0.0187	0.0362	0.0342	0.8533
	Conformity	-	**X**	√	√	√	**X**
	Elements	**C**	**Si**	**P**	**S**	**Cr**	**Mn**
	Claimed Max. values	0.3	0.3	0.05	0.06	0.2	1.5
Local No.2	**Average**	-	0.2876	0.0206	0.0676	0.097	1.4672
	$s/\sqrt{n}$	-	0.0057	0.0015	0.0027	0.0025	0.0151
	Test value μ	-	0.2975	0.0232	0.0722	0.1013	1.4935
	Conformity	-	√	√	√	√	√
	Elements	**C**	**Si**	**P**	**S**	**V**	**Mn**
	Claimed Max. values	-	0.35	0.05	0.05	-	1.8
Foreign	**Average**	-	0.3332	0.0238	0.0245	0.0387	1.5737
	$s/\sqrt{n}$	-	0.0071	0.0015	0.0023	0.0133	0.0522
	Test value μ	-	0.3457	0.0264	0.0285	0.0441	1.6645
	Conformity	-	√	√	√	-	√

According to the statistical hypothesis testing mentioned above, the conformity is proved, if the test value μ is smaller than the manufacturer maximum claimed values. It can be noted from Table 4 and 5 that most percentage values for the elements present are less than the maximum values claimed, except those of silicon and manganese for the concrete reinforcing bars manufactured by the local company No.1. Therefore, the company has to put more effort to control the percentage level of these elements.

5. Conclusions

The determination of the main characteristics of concrete reinforcing bars such as yield strength, tensile strength and elongation were determined through the tensile test; while the chemical composition was measured using X-Ray Fluorescence. These methods are relatively simple and fast compared to the traditional methods which require time-consuming procedures and well equipped analysis laboratories.

The above mentioned simple methods are enough to verify the conformity of many steel products including the concrete reinforcing bars. The results obtained in this study show that most of the mechanical properties of these reinforcing bars manufactured locally or imported conform to the international standards (ASTM-A615M). The chemical composition of these products is also conforming to the specifications of this international standard, but the maximum values for silicon and manganese exhibit slightly higher values than those claimed by one local company. However, this company should put more effort in the control quality in order to avoid the exceeding percentage especially for those elements (Si, Mn) or to rectify the maximum claimed values.

The weak point of the chemical analysis for steel bars using XRF technique is its limitation to measure the carbon content which requires a complementary analysis method. However, the analyses of these products using these simple above methods are instructive not only for the consumers, but also for the manufacturer company in order to upgrade the quality of its final steel products.

Acknowledgment

The author would like to acknowledge the Research Center and Sustainable Energy Technologies program at the College of Engineering, King Saud University for providing grant, technical support, coordination, and following up the progress of this work.

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تحديد خصائص قضبان خرسانة التسليح

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المستخلص. هدف هذه الدراسة هو إظهار القدرة على تحديد الخصائص الرئيسية لقضبان خرسانة التسليح باستخدام وسائل بسيطة. تم في هذه الدراسة تحديد الخصائص الميكانيكية مثل مقاومة الإجهاد، والشد والاستطالة من خلال اختبار الشد. وتم تحديد التركيب الكيميائي باستخدام تقنية الأشعة السينية المفلورة (XRF). استخدمت في تلك التحليلات ثلاث مجموعات من قضبان تسليح الخرسانة بأقطار تتراوح بين 8 و 20 ملم مصنعة من قبل شركات مختلفة. كانت النتائج التي تم الحصول عليها عن الخواص الميكانيكية مطابقة لقيم مواصفات المعايير الدولية. أما التركيبة الكيميائية فجاءت نتائجها مطابقة عموما لمواصفات المعايير التي وضعها المصنع؛ ماعدا نسب عنصري السيليكون والمنغنيز فقد كانت أعلى قليلا في بعض المنتجات.