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ORIGINAL RESEARCH PAPER

Measurement uncertainty for mechanical resistance of manufactured steel bar

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ABSTRACT

This research work has been focused on estimation of the measurement uncertainty for different steel reinforcement bars. The investigated material was HRB400 steel reinforcement with approximately diameter 16 mm and length 500 mm by using uniaxial tensile testing device. International standard ISO 6892: 2016 and guide for measurement uncertainty have been implemented an accurate method to determine the measurement uncertainty of HRB400 steel reinforcement bar measurements. The results of expanded uncertainty for 569.47 N/mm^{-2} correspond to 0.76 N/mm^{-2}, which fulfil the international standard requirements. This accurate method can be used in most of the accredited laboratories as inspection services of steel reinforcement bar by using uniaxial tensile testing device at good accuracy.

KEYWORDS

measurement uncertainty, steel reinforcement bar, mechanical resistance, tensile strength

1. INTRODUCTION

Steel industry have widely used in the Republic of Albania during the last decade due to development of the urbanization process. Kurum Ltd is the leading metallurgical industry that is located in Elbasan in Albania and covers all the national request for manufacturing the HRB400 steel reinforcement bars [1, 2]. HRB400 steel reinforcement bars are the most widely used materials in constructions due to many engineering applications. Furthermore, HRB400 reinforcement steel bars have been used to improve concrete withstand tension forces in different building constructions.

Figure 1 depict manufacturing process scheme for HRB400 steel reinforcement bar at Kurum Ltd.

From the above metallurgical scheme, the importance of the inspection services for ensuring the quality of the HRB400 steel reinforcement bar production can be seen. There are many indicators that can influence in the mechanical resistance of the HRB400 steel reinforcement bar during the inspection services. Some of the important inspection services of HRB400 reinforcement steel bar would be related to chemical composition, casting and molten process, heating and cooling on rolling process, specification process and tensile strength test.

This paper has been focused at tensile strength test, which is one of the principal indicators that can affect the mechanical resistance of the different metallic materials. The most useful testing method that corresponds to HRB400 steel reinforcement bar is the evaluation of their mechanical resistance by using uniaxial tensile strength. In the previous research work it has been faced with a lack of an accurate and simply method for estimation the measurement uncertainty for determination of the HRB400 steel reinforcement bar

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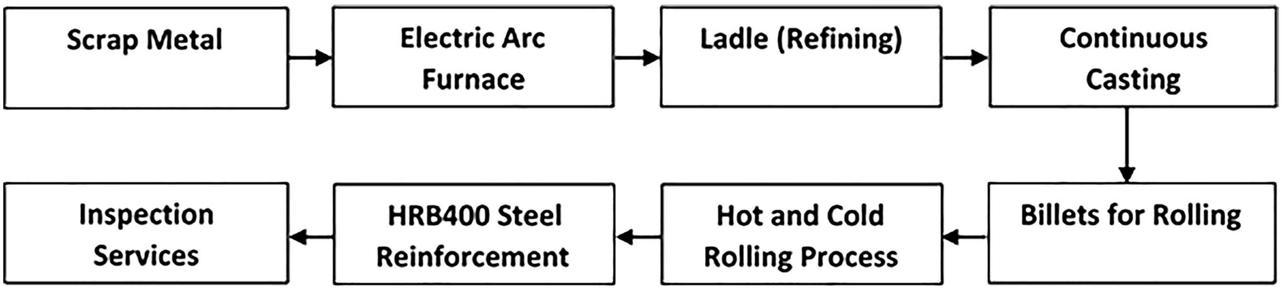

Fig. 1. Metallurgical scheme of HRB400 steel reinforcement bar at Kurum Ltd

mechanical resistance by using tensile strength device [1, 3–13]. Furthermore, this paper will be focused on implementation of the accurate measurement model and evaluation of the measurement uncertainty of measured uniaxial tensile strength, which correspond to the force that can be applied at HRB400 steel reinforcement bar [14, 15]. This accurate method can be used in most of the inspection services of steel reinforcement bar by using uniaxial tensile testing device with very good precision.

2. MATERIALS AND METHODS

Most of the samples of HRB400 steel reinforcement bar were selected randomly from metallurgical industry Kurum Ltd and have been sent for tensile strength analysis at accredited "ITM" laboratory. Table 1 depict the composition of the manufactured HRB400 steel reinforcement bar samples that have been produced from metallurgical scheme mentioned in Fig. 1.

Figure 2 depict the uniaxial tensile strength device type "Matest H010-02N" that has been located at "ITM" laboratory in Albania where the measurement range of uniaxial tensile strength device varied from 0 until 500 kN [16].

In the present test setup, 10 samples of HRB400 steel reinforcement bars were tested to evaluate the mechanical resistance. The manufactured HRB400 steel reinforcement bar samples with approximately diameter 16 mm and length 500 mm have been placed at uniaxial tensile strength device. The whole measurements of the loads and displacements have been registered in real time by using data acquisition system from computer that is connected with tensile strength device.

Table 1. Composition of the manufactured HRB400 steel reinforcement bar samples [1]

Elements	Composition (%)
Carbon	≤0.250
Silicon	≤0.800
Mangan	≤1.600
Phosphorus	≤0.045
Sulphur	≤0.045
Equivalent Carbon	≤0.540

Fig. 2. Matest H010-02N uniaxial tensile strength device located at "ITM" laboratory

The function of the tensile strength device consists by pulling the HRB400 steel reinforcement bar sample with a constant speed until to know sample ultimate tensile strength at its breaking point. The tensile strength of the HRB400 steel bars samples have been determined by dividing the maximum applied load at the beginning sectional area of the sample. Table 2 depict the measurement results of the applied force and the diameters of HRB400 steel reinforcement bars.

Table 2. Summary of test results on HRB400 steel reinforcement bars samples

Measurements No.	Force (N)	Diameters (mm)
1	114,400.11	15.991
2	114,400.27	15.997
3	114,400.14	15.992
4	114,400.18	15.994
5	114,400.23	15.995
6	114,400.22	15.995
7	114,400.15	15.993
8	114,400.08	15.991
9	114,400.12	15.992
10	114,400.05	15.991

3. MEASUREMENT UNCERTAINTY

The tensile strength of the manufactured HRB400 steel reinforcement bar has been determined indirectly by the measurements and was realized through the measurement of the applied force to each sample. According to (1) it has been estimated the sample stress σ of the tensile strength through the ratio of maximum force $F_{\max}$ applied to the sectional area S_0 of HRB400 steel reinforcement bar sample,

$$\sigma = \frac{F_{\max}}{S_0}. \tag{1}$$

A sectional area S_0 of the manufactured steel bar sample has been calculated and expressed by (2),

$$S_0 = \frac{\pi d^2}{4}, \tag{2}$$

where d is the HRB400 steel reinforcement bar diameter of the sample without considering longitudinal and transverse ribs. By substituting sectional area of (2) to (1) it will be estimated the uniaxial tensile strength by using (3),

$$\sigma = \frac{4F_{\max}}{\pi d^2}. \tag{3}$$

According to (3) it has been calculated the uniaxial tensile strength, which correspond to the value 569.47 $\mathrm{N/m^{-2}}$ by using the maximum force and diameter from measurement number 2. Based on the (3), uncertainty of stress measurement will rely from two important factors that correspond to uncertainty of the tensile force and sectional area of the sample. A GUide to the Measurement (GUM) uncertainty will be used to implement the rules for identifying all possible sources of uncertainty and afterward to estimate their measurement uncertainties [15]. Furthermore, the uncertainty measurement model of uniaxial tensile strength was realized by considering all sources of uncertainty and will be expressed by (4) [4, 15–26],

$$y = x + K_1 + K_2 + K_3 + K_4 + K_5, \tag{4}$$

where, x is uniaxial tensile strength of the measured value; K_1 is correction that arises from calibration of tensile strength device; K_2 is correction through the sample centering; K_3 is correction from resolution of the caliper; K_4 is correction from the reading force that has been applied in the sample; and K_5 is correction from the reading of sectional area of the sample. Through propagation law of measurement uncertainties and uncertainties of all input quantities mentioned in (4) the combined standard uncertainty has been evaluated by (5),

$$u_c^2(y) = \sum\nolimits_{i=1}^{n} c_i^2 . u^2(x_i) = \sum\nolimits_{i=1}^{n} \left(\frac{\partial f}{\partial x}\right)^2 . u^2(x_i). \tag{5}$$

According to (5), $u(x_i)$ express standard uncertainty of all input quantities and c_i will express sensitivity coefficient, which can be estimated from partial derivate of these input quantities. The sensitivity coefficients have been estimated from partial derivate of (3) for maximal tensile force and corresponding diameter as it can be expressed respectively in (6) and (7),

$$c_{F_{\max}} = \frac{\partial \sigma}{\partial F_{\max}} = \frac{4}{\pi \cdot d^2}, \tag{6}$$

$$c_d = \frac{\partial \sigma}{\partial d} = -\frac{8 \cdot F_{\max}}{\pi \cdot d^3}. \tag{7}$$

Furthermore, the combined standard uncertainty has been expressed by (8),

$$u_c^2(y) = c_{F\max}^2 . u_1^2 + c_{F\max}^2 . u_2^2 + c_d^2 . u_3^2 + c_{F\max}^2 . u_4^2 + c_d^2 . u_5^2, \tag{8}$$

where u_1 is uncertainty from calibration of tensile strength device; u_2 is uncertainty from load application rate to HRB400 steel reinforcement bar sample test; u_3 is caliper resolution uncertainty; u_4 is uncertainty from reading of the applied force; u_5 is uncertainty of the reading of sectional area of manufactured HRB400 steel reinforcement bar sample test.

Evaluations of the measurement uncertainty that arise from calibration of the tensile strength device are expressed by (9) [5, 27],

$$u_1 = \sqrt{\left(\frac{U_1}{k}\right)^2 + \left(\frac{F_a}{\sqrt{3}}\right)^2}, \tag{9}$$

where U_1 is expanded uncertainty from calibration of tensile strength device, which indicate the value 50 N that has been taken from previous calibration certificate with coverage factor k equal to 2 and F_a is device scale of the test and corresponds to the value 100 N.

Due to the difficulty of the determination more accurately the effect of HRB400 steel reinforcement sample centering it has been assumed from technical documents to simplify the evaluation of the uncertainty by using (10) [28],

$$u_2 = 0.1\% \cdot F_{\max} = \frac{0.1}{100} \cdot F_{\max}. \tag{10}$$

Afterward, uncertainty from caliper resolution has been calculated by (11). The resolution R of the caliper was 0.01 mm where the possible rounding error consists of 0.01 mm,

$$u_3 = \frac{R/2}{\sqrt{3}}. \tag{11}$$

According to (12) it has been estimated the standard uncertainty of the reading of indications of applied load, which is calculated by dividing the ratio of standard deviation of the readings of applied loads S_F and number of complete set of measurements n_F.

$$u_4^2 = \frac{S_F^2}{n_F} = \frac{\frac{1}{n_F - 1} \sum_{i=1}^{n_F} (x_i - x_m)^2}{n_F}, \tag{12}$$

where x_i is the value of individual measurements where x_m was the average value of individual measurements.

Furthermore, standard uncertainty of the reading of indications of the HRB400 steel reinforcement bar sample sectional area u_5 has been estimated as standard uncertainty

Table 3. Uncertainty budged for determination of mechanical resistance of HRB400 steel reinforcement bar

Uncertainty Sources	Standard Uncertainty	Probability Distribution	Sensitivity Coefficient	Uncertainty (N/mm^{-2})
Calibration, u_1	62.900 [N]	Rectangular	0.0005 [$1/mm^{-2}$]	$3.14 \cdot 10^{-2}$
Sample centering, u_2	114.400 [N]	Rectangular	0.0005 [$1/mm^{-2}$]	$5.71 \cdot 10^{-3}$
Caliper Resolution, u_3	0.003 [mm]	Rectangular	71.19 [N/mm^{-3}]	$2.12 \cdot 10^{-1}$
Reading Force, u_4	0.069 [N]	Normal	0.0005 [$1/mm^{-2}$]	$3.13 \cdot 10^{-4}$
Diameter dimensional variation, u_5	0.002 [mm]	Normal	71.19 [N/mm^{-3}]	$1.42\ 10^{-1}$
Combined Uncertainty, $u_c(y)$, $k = 1$				$3.78 \cdot 10^{-1}$
Expanded Uncertainty, U, $k = 2$				$7.56 \cdot 10^{-1}$

of the reading of dimensional variation along the specimen diameter S_d and is estimated by (13),

$$u_5^2 = \frac{S_d^2}{n_d} = \frac{\frac{1}{n_d-1}\sum_{i=1}^{n_d}(x_i - x_m)^2}{n_d}. \quad (13)$$

Afterward, combined standard uncertainty $u_c(y)$ can be estimated in accordance to (8). Expanded uncertainty U has been estimated by (12) for coverage factor $k = 2$ with confidence level that correspond to the probability of 95%,

$$U = k \cdot u_c(y). \quad (14)$$

In Table 3 uncertainty budget for determination the mechanical resistance of HRB400 steel reinforcement bar samples have been shown.

According to (3) and (8), the estimated results of the HRB400 steel reinforcement bar samples stress of tensile strength have determined that expanded uncertainty of 569.47 N/mm^{-2} was approximately 0.81 N mm^{-2}. From the above results it has been seen that the larger uncertainty components come from caliper resolution and diameter dimensional variation. Furthermore, this research results are acceptable and fulfilling the request of the standard ISO 6892-1:2016 [14]. The future research work will be concentrated to reducing the largest uncertainty components by improving the measurement setups.

4. CONCLUSIONS

In this research work it has briefly described the technological scheme of the production of HRB400 steel reinforcement bar and an accurate measurement method by associated uncertainty contributions results that have been obtained through tensile testing. The accuracy of HRB400 steel reinforcement bar results will be realized by estimation of measurement uncertainty in determination of tensile strength of reinforcement steel.

The novelty of this paper has been focused on the measurement model associated with thorough sources of uncertainty that can be used for the all types of steel reinforcement bar production by using uniaxial tensile strength device with good precision. The method has been tested for a HRB400 steel reinforcement bar with an approximately diameter 16 mm and length 500 mm. The expanded uncertainty results for the measured value 569.47 N/mm^{-2} correspond to 0.76 N/mm^{-2}.

The larger uncertainty come from calibration of tensile strength device, caliper resolution and diameter dimensional variation. The future research work will be concentrated to reducing the largest uncertainty components by improving the measurement setups.

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