EVALUATION OF THE UNCERTAINTY OF MEASUREMENT OF MECHANICAL PROPERTIES ON THE TENSILE TESTING

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Abstract: The objective of this study was to develop a methodology for determining the result of measurement concerning tensile mechanical properties and their respective uncertainties. Such methodology, which has a possible systematic application, is associated with advanced metrology concepts, aiming a guarantee of metrological reliability to the results of the tensile properties, as well as the possibility of implementation in industrial laboratories, researches centers and in the Testing Laboratory Network.

1. INTRODUCTION

Metrology is the science of the measurement. All of the measurements are affected by errors that can be coming from the mensurand, of the measurement instrument and/or of influence quantity it expresses. Considering that the errors can not perfectly be known, it can be affirmed that the result of the measurement is affected by an uncertainty. Even if the result of the measurement is not perfect, it is possible to obtain reliable information, since the result of the measurement is associated with its respective uncertainty, that its translates, in a complete way, an interval of values inside of which will be a true value of a quantity. The result of a measurement is composed on two parts; the first one corresponds to a more probable value of the mensurand, while the second part is its uncertainty which is defined as a parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the mensurand [1].

The objective of this study was to develop a methodology for determining the result of measurement concerning tensile mechanical properties and their respective uncertainties [2]. Such methodology, which has a possible systematic application, is associated with advanced metrology concepts, aiming a guarantee of metrological reliability to the results of the tensile properties, as well as the possibility of implementation in industrial laboratories, researches centers and in the Testing Laboratory Network.

In order to reach this objective, the study started with the making of a group of proof bodies with form and dimensions that were standardized according to reference [3], being followed of the standard tensile testing. After that, a statistical analysis of the test results was carried out with the purpose of assessing their reliability. Finally, a methodology was applied for the evaluation of the measurement uncertainty associated with the test results, aiming to obtain the final mechanical properties of the material with their respective uncertainties within a defined probability.
The analysis of the final results leads to conclude that there is no significant influence of the specimen's geometry on the mechanical properties of the material regarding standard tensile testing.

2. METHODOLOGY

The international standard ISO/IEC 17025 [4] it is the basic document and I accept in international character, as the guide for the accreditation of the technical competence of laboratories that execute calibration services and testing. In her chapter 5, regarding the technical requirements, it is outstanding that:

1. A calibration laboratory or a rehearsal laboratory that it accomplishes their own calibrations should have and it should apply a procedure to esteem the uncertainty of measurement of all of the calibrations and types of calibrations;
2. The rehearsal laboratories should have and they should apply procedures for calculation of the measurement uncertainties. In some cases the nature of the rehearsal method can impede the rigorous calculation, metrological and valid statistical of the measurement uncertainty. In those cases,

the laboratory owes at least to try to identify all the uncertainty components and to do a reasonable estimate. The laboratory should guarantee that the form of telling the result doesn't give a wrong impression of the uncertainty. The reasonable estimate should be based on the knowledge of the acting of the method and in the mark of the measurement, and it should make use, for instance, of experience and data of previous validation;
3. When it is dear the measurement uncertainty, all the uncertainty components that are important for a certain situation they should be considered being used appropriate analysis methods.

The presentation of the results of mechanical rehearsals for the main laboratories of rehearsals has been made in a limited way, that is, just a value for the final result is informed, without the respective uncertainty of associated measurement. The uncertainty of the result of the testing is made necessary in several situations, as for instance in the analysis of the conformity or in the interpretation of results. An estimate, or at least a based consideration, of the components of the influence quantity that compose the calculation of the uncertainty of the testing allows to establish a middle of evaluating the capacity of the used equipment is adapted for the validation of the obtained results. The consideration of a given component of the uncertainty can also indicate aspects of the testing to the which one should give more attention or even to perfect procedures.
For us to accomplish the calculation of the uncertainty of the testing, step by step, we must:

1st) to list all the factors that can influence the measured values;
2nd) to do a preliminary estimate of the values of the components of the uncertainty, excluding the insignificant values;
3rd) to esteem the values that are attributable to each component significant of the uncertainty and, to express in the form of a standard deviation;
4th) to consider the components and to decide which are dependent and if there is a dominant component. On this step is important to take into consideration the sensitivity coefficients;
5th) to add the dependent components (which are the correlated input quantities);
6th) to add the variances of the independent components with to component resulting from the previous item, in the case of the non existence of a dominant component to extract the square root from that sum, generating the combined uncertainty;
7th) to multiply the value of the previous item for an inclusion factor k, chosen with base in the confidence level requested;
8th) to tell the final result.

The mathematical model is according to the tensile properties measured [3].

3. RESULTS

The material used for the development of the study was the steel structural degree RQ 3 [5], with 0,26% C + 1,75% Mn + 0,20% Cr + 0,35% Ni and 97,44% Fe, with applications in systems of anchorage of flotation units of the type" offshore", according to specification of American Bureau of Shipping (ABS) [2]. The proof bodies were solitary of a bar of circular section, with nominal diameter of 85 mm, in the condition of as received and presenting ferrite and pearlite as characteristic microstructures. The chemical composition of the steel in study, as certificate of the material supplied by the plant and in accordance with ABS [5]. The proof bodies for the tensile testing they were solitary of circular bars, in agreement with the norm ISO 377 [6]. The orientation adopted for the retreat of the proof bodies was of the type L-T, that is, with the longitudinal axis of the parallel proof body to the direction of lamination of the bar.
In the tensile testing an Universal Machine of Testing was used, it marks Instron model 5500R, with nominal range of scale by 9807 daN, equipped with two load cells marks Instron, models A401-1 and A30-4, with nominal range of scale by 2452 daN and 9807 daN, respectively. Both load cells presented scale division of 0,980665 daN, in agreement with his calibration certificate. They were testing, in the total, 10 proof bodies to the rupture. The testing speed adopted was of 1 mm / min and they were certain the following mechanical properties: Yield Strength, Tensile Strength, Reduction of Area and Percent Elongation. For the measurement of the initial and final diameters and lengths of the proof bodies testing, an Universal Caliper was used, it marks Mitutoyo. For the determination of the Yield Strength of the testing material it was used, together with the Universal Machine of Testing, an extensometer eletro-mechanic marks Instron, model 2630-100, series Clip-On.
The conditions environmental measures during the rehearsals were: Temperature = 23 ± 2 ºC and Humidity = 59 ± 5 %

Table I - Summary of standard uncertainty components for Yield Strength .

Source of Uncertainty	Estimate Value	Distribution	Divisor	Sensitivity coefficients	Standard Uncertainty (MPa)	Degrees of freedom
Mensurand	4,45 MPa	Normal	1	1	4,45	9
Machine Uncertainty	3,72 N	Normal	2	0,036	0,07	Infinite
Machine Resolution	9,81 N	Rectangular	1,732	0,036	0,20	Infinite
Mean Area	0,070 mm^2	Normal	1	14,43	1,01	1
Extensometer Uncertainty	1,2 %	Normal	1	4,04	4,85	Infinite
Combined Standard Uncertainty		Normal			6,66	46
Expanded Uncertainty		k = 2 (P = 95 %)			**13**	

Table II – Summary of standard uncertainty components for Tensile Strength .

Source of Uncertainty	Estimate Value	Distribution	Divisor	Sensitivity coefficients	Standard Uncertainty (MPa)	Degrees of freedom
Mensurand	6,07 MPa	Normal	1	1	6,07	9
Machine Uncertainty	3,72 N	Normal	2	0,036	0,07	Infinite
Machine Resolution	9,81 N	Rectangular	1,732	0,036	0,20	Infinite
Mean Area	0,070 mm^2	Normal	1	23,25	1,64	1
Combined Standard Uncertainty		Normal			6,29	10
Expanded Uncertainty		k = 2,23 (P = 95 %)			**14**	

Table III - Summary of standard uncertainty components for Reduction of Area .

Source of Uncertainty	Estimate Value	Distribution	Divisor	Sensitivity coefficients	Standard Uncertainty (%)	Degrees of freedom
Mensurand	0,99 %	Normal	1	1	0,99	9
Machine Uncertainty	0,015 mm	Normal	2	0,5	0,00	Infinite
Machine Resolution	0,05 mm	Rectangular	1,732	0,5	0,01	Infinite
Initial Mean Area	0,070 mm^2	Normal	1	1,62	0,11	1
Final Mean Area	0,047 mm^2	Normal	1	3,57	0,17	1
Combined Standard Uncertainty		Normal			1,01	10
Expanded Uncertainty		k = 2,23 (P = 95 %)			**2**	

Table IV - Summary of standard uncertainty components for the Percent Elongation .

Source of Uncertainty	Estimate Value	Distribution	Divisor	Sensitivity coefficients	Standard Uncertainty (%)	Degrees of freedom
Mensurand	0,48 %	Normal	1	1	0,476	9
Machine Uncertainty	0,03 mm	Normal	2	0,5	0,007	Infinite
Machine Resolution	0,05 mm	Rectangular	1,732	0,5	0,014	Infinite
Initial Mean Length	0,015 mm	Normal	2	4,19	0,031	1
Final Mean Length	0,015 mm	Normal	2	3,33	0,025	1
Combined Standard Uncertainty		Normal			0,48	9
Expanded Uncertainty		k = 2,26 (P = 95 %)			**1**	

Table V - Mechanical Properties goes the body of proof of nominal diameter of 6 mm.

Final Results				
Mechanical Properties	**Symbol**	**Results**	**Uncertainty**	**Coverage factor k (95 %)**
Yield Strength	**LE**	**404 MPa**	**± 13 MPa**	**2**
Tensile Strength	**LRT**	**651 MPa**	**± 14 MPa**	**2,23**
Reduction of Area	**Z**	**55%**	**± 2%**	**2,23**
Percent Elongation	**A**	**26%**	**± 1 %**	**2,26**

The result of a measurement of a physical quantity it is a value attribute to a mensurand by measurement or testing [1]. When a result is informed, it should be indicated, clearly, if the same refers to an indication, the uncorrected result, the corrected result or to the medium value of several measurements and, his complete expression owes includes information on its measurement uncertainty [7]. The case in study, the results presented to proceed refer to the medium value of the several obtained measurements of the studied mechanical properties, that is, the medium values of the Yield Strength, of the Tensile Strength, of the Reduction of Area and of the Percent Elongation, added of information of its measurement uncertainty, for a probability coverage of 95%. The Table 5 presents the values of the results of the measurement of the mechanical properties of the steel structural degree RQ3, where the certain conventional tensions were round to 1 MPa, the reduction area were round to 1% and, the percent elongation determined were round to 0,1%, in agreement with the recommendations [3].

4. CONCLUSIONS

As conclusions of this research can stand out:

- Although the great majority of the materials adopted in Engineering possesses heterogeneous structures, what drives alterations in its properties, as well as every measurement instrument, no matter how optimized is its acting capacity, it is not exempt of provoking mistakes when of its use, the tensile testing rehearsals can supply reliable information of the mechanical properties of the rehearsed materials. For such, it is done necessary a treatment mathematical and statistical of the values of the mechanical properties after the rehearsal, with the intention of identifying the errors of nature systematic or random committed in the measurement process and to apply an appropriate methodology to minimize them;

- The main influence factor in the determination of the uncertainty of measurement of the studied mechanical properties was the variation attributed to the mensurand, that is, the repeatability obtained in the measurements of the studied properties. Such variation presented, on average, values among 75 and 99% of the total uncertainty for the different mechanical properties;
- In spite of the domain of the associated uncertainty the variation of the mensurand in the parameter drainage limit to be of approximately 75% of the total uncertainty, it was observed, also, that the uncertainty associated with the extensometer represented the variation from 59 to 73% of the total uncertainty, in function of the nominal diameter of the proof bodies. Such verification takes to have faith that the extensometer, fundamental instrument for the determination of the limit of yield strength of the materials, it should previously be gagged to the tensile testing, so that it is determined his true acting capacity;
- Even if the result of the measurement is not perfect, it is possible to obtain reliable information, since the result of the measurement is associated with its respective uncertainty. In this study was to develop a methodology for determining the result of measurement concerning tensile mechanical properties and their respective uncertainties. Such methodology, which has a possible systematic application, is associated with advanced metrology concepts, aiming a guarantee of metrological reliability to the results of the tensile properties, as well as the possibility of implementation in industrial laboratories, researches centers and in the Testing Laboratory Network.

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