ESTIMATION OF UNCERTAINTY IN DUCTILITY AND HARDNESS OF STEELS

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ABSTRACT

The fact that the world is now inserted in the context of the dynamism arising from the globalization, in which great part of its nations is interconnected, forces the companies to be more competitive when searching for customers. One of the ways to achieve competitiveness is by considering the uncertainties related to materials properties, which can lead the company to offer its product in a safer condition, contributing to the maintenance and growing of its reliability and, consequently, to the long-term relationship with the customer. The general objective of this paper is to point out a method to consider the uncertainties overall the process of obtaining ductility and hardness of steels. This research has theoretical character with quantitative approach, making use of literature review, resulting in a table containing generator factors, types, quantification methodology, and coverage factors of uncertainties related to the abovementioned properties.

Keywords: Uncertainty; Ductility; Hardness; Steel.

1. INTRODUCTION

1.1. Context

It is irrefutable that every practical measurement entails a degree of uncertainty in its result. In other words, uncertainty is inherent to every act of physical quantity mensuration. This statement is also valid in the context of obtaining mechanical properties of metallic materials (5).

With the purpose of using materials properly in a certain design, one must have a complete understanding about their mechanical properties. Therefore, reliable determination of mechanical properties of materials is crucial when selecting them for a suitable application (7).

As the designer often faces problems related to adequate material selection in projects, an appropriate decision must be substantiated on quality information, which will permit the selection of a material mechanically capable of performing the designed function (9).

1.2. Importance

The knowledge about uncertainties of mechanical properties is mainly important to laboratories, their customers, industries and all the institutions that make use of the results for comparative purposes of materials.

The quality of a test method or result may be measured by the act of quantifying the uncertainties involved. Besides that, this quantification allows comparison of results from different testers. For example, in the case of sorted batches, differences in results that eventually occur between them may not be always related to the properties themselves, but also to the uncertainties intrinsically present on processes for obtaining these properties.

Thus, the ability of evaluating the measurement uncertainty is crucial in scientific research (to establish the validity limits of theories) and in technological applications (to assess the reliability of products and procedures) (5).

1.3. Objectives

The general objective of this paper is to point out a method to estimate the uncertainties overall the process of obtaining ductility and hardness properties of steels.

The deployment of the general objective yields into the following specific objectives:

- To present a brief description of ductility and hardness of metallic materials.
- To point out the main uncertainty generator factors when obtaining the referred properties.
- To present the types of standard uncertainty and classify the abovementioned mechanical properties into these types.
- To establish the coverage factors for expanded uncertainty.

2. MATERIALS AND METHODS

2.1. Metallic Materials

The most common classification of metals results into two categories: ferrous and nonferrous. The former refers to base metals of iron, while the latter are out of iron (3). Currently, the demand for ferrous alloys exceeds the demand for all other metals combined (9).

Inserted in the ferrous alloys category, the steel presents great commercial availability, abundance of ore which is originated, and relatively economic techniques of processing, alloys formation, and manufacturing processes. This contributes to the numerous researches undertaken toward the progress of steels area.

Considering these facts, steels are relatively versatile when compared to other materials. They may present a wide range of variation in mechanical properties when designed and especially when tested. Therefore, the scope of work of this paper is restricted specifically on steels.

2.2. Mechanical Properties

The study of mechanical behavior has its background on the response of a body to a loading arrangement. Under the action of a loading configuration in an equipment, the measurement of body response furnishes data to obtain mechanical properties. In order to quantify these properties, the method of observation and measurement uses the comparative technique (5).

As there are many measurable, calculable and obtainable mechanical properties, the work scope of this paper is limited to the following:

- Ductility: basically, represents the degree of plastic deformation registered when the rupture occurs. Ductility is commonly obtained by performing a tensile test where one of the outputs of the test, the stress-strain curve, is used to determine this property.
- Hardness: resistance to indentation (localized plastic deformation). It also relates to material’s capacity to resist mechanical wear. In turn, hardness is extracted in an equipment called hardness-testing machine, adopting a hardness scale whereby there is a comparison with the physical impression caused by the penetrator in the specimen.

2.3. Uncertainties

The deterministic view is idealistic, impractical and economically infeasible because real processes and projects deal with uncertainties and lead to uncertain results. Therefore, even if it were possible, to obtain a certain value would be too onerous that it would not be financially feasible. Considering this scenario, the uncertainty arises primarily due to lack of reliable information (6).

In this context, the most general causes of uncertainty are (5):

- The quantity to be measured is not easily definable.
- Modus operandi characteristics of the instrument.
- Reciprocal action between instrument and system to be measured.
- Relation between instrument and experimenter.
- Measurement methodology.
- Environmental methodology.

In what concerns uncertainty behavior, some authors primarily classify uncertainty by its nature. Currently, following one of the most accepted classifications, uncertainty is classified into three categories (8):

- Aleatory: represented by the variability associated to the results obtained from a certain stochastic model due to spatial or temporal variations. A probability density function (PDF) or a cumulative distribution function (CDF) commonly characterizes the aleatory uncertainty.
- Epistemic: arises due to a lack of knowledge on the part of the people conducting the modeling. If knowledge is added (for example, improved numerical approximations), then the uncertainties can be reduced. An interval of values models its behavior.
- Mixed: it is a combination of the previous two uncertainties and, therefore, a PDF or CDF with interval defines it. For example, if an entry has a lognormal distribution (aleatory uncertainty), then its mean and standard deviation assume intervals (epistemic uncertainties).

As important as categorizing is pointing out the sources of uncertainty. Thus, one can study these sources aiming to mitigate or eliminate them. Therefore, when determining a mechanical property, there is a dependence on some generator factors related to the processes used for uncertainty obtainment such that the factors themselves indeed generate uncertainty.

2.3.1. Ductility

As regards ductility, there are usually two indicators of its magnitude. Assuming a circular cross-section overall the process (as per ASTM E8 / E8M-16a standard) (1), they are, respectively, percentage elongation (Eq. 1) and percentage reduction in area (Eq. 2), given by the following expressions:

$$AL(\%) = \left(\frac{L_f - L_0}{L_0}\right)100 \tag{1}$$

$$RA(\%) = \left(\frac{A_0 - A_f}{A_0}\right)100 = \frac{\pi}{4}\left(\frac{D_0 - D_f}{D_0}\right) \tag{2}$$

Where: L_0 = Initial length.

L_f = Final length.

A_0 = Initial cross-sectional area.

A_f = Final cross-sectional area.

D_0 = Initialdiameter.

D_f= Final diameter.

Figure 1 shows a specimen before and after a tensile test performed.

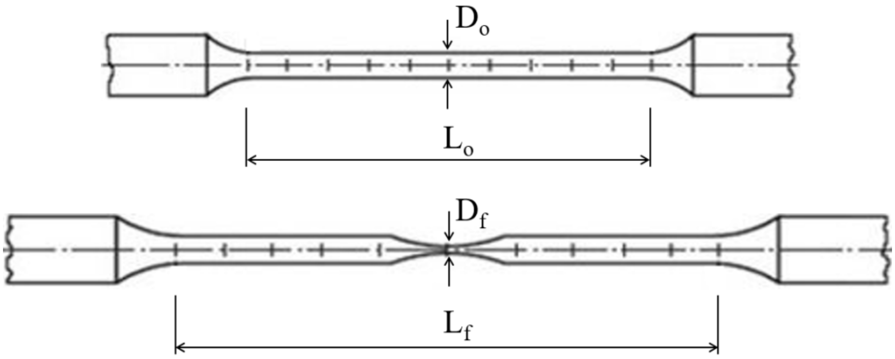

Figure 1 – Specimen Before and After Tensile Test.

2.3.1. Hardness

Strictly adopting hardness by penetration according to Figure 2 (specifically Brinell scale as per ASTM E10-15a standard) (2) as one of the mechanical properties which uncertainties are studied in this work, it is commonly obtained by the relation between the applied load and the surface area of the indentation from a hardness-testing machine (Eq. 3) (10), then:

$$H = \frac{F}{A_S} = \frac{F}{\pi D_b H} = \frac{2F}{\pi D_b \left(D_b \sqrt{D_b^2 - D_i^2} \right)} \qquad (3)$$

Where: F = Applied load.

A_s = Surface area of indentation.

D_b = Ball diameter.

H = Indentation height.

D_i = Indentation diameter.

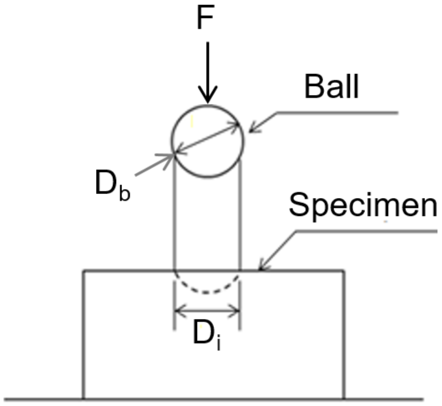

Figure 2 – Brinell Test Schematic.

Besides the uncertainty generator factors showed by the previous mathematical expressions (percentage elongation, percentage reduction in area and hardness), there are those from the machine used to perform the tests. Thus, the standard uncertainty is the result of a measurement (uncertainty generator factor), expressed as a probabilistic standard deviation.

In turn, the expanded uncertainty can be represented by an interval around the measurement result that is estimated to contain a significant fraction of the distribution. With the objective of representing expanded uncertainty numerically, a coverage factor is established. It is a numerical factor used as a multiple of standard uncertainty to obtain the expanded uncertainty (4).

3. RESULTS AND DISCUSSION

Uncertainty consideration and estimation is a fundamental step through the process of reliability analysis, which is subject of application in many practical cases. Therefore, an adequate procedure of uncertainty estimation is really important for mechanical properties determination.

Table 1 shows that the process of uncertainty mapping starts from defining the mechanical property to be determined. Once this is done, there is the determination of the factors involved in property obtainment, called generator factors. To each one of these factors are associated standard uncertainties. Applying a quantification methodology to the standard uncertainties, a coverage factor takes into account variability.

Table 1 – Uncertainties Generated in the Process of Obtaining Mechanical Properties

Mechanical property	**Uncertainty Generator Factor**	**Uncertainty - Uncertainty type**	**Uncertainty quantification methodology**	**Coverage factor for expanded uncertainty**
Ductility	Initial length	Caliper rule calibration - Aleatory	Instrument calibration certificate - Normal distribution - 95,45% of confidence level	k = 2
		Caliper rule accuracy Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$

		Temperature - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$
	Final length	Caliper rule calibration - Aleatory	Instrument calibration certificate - Normal distribution - 95,45% of confidence level	k = 2
		Caliper rule accuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$
		Temperature - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$
	Pi (π)	Accuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$
	Initial diameter	Caliper rule calibration - Aleatory	Instrument calibration certificate - Normal distribution - 95,45% of confidence level	k = 2
		Caliper rule accuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$
		Temperature - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$

Mechanicalproperty	**UncertaintyGeneratorFactor**	**Uncertainty - Uncertaintytype**	**Uncertaintyquantificationmethodology**	**Coverage factor for expanded uncertainty**
Ductility	Final diameter	Caliperrulecalibration - Aleatory	Instrument calibration certificate - Normal distribution - 95,45% of confidence level	k = 2
		Caliperruleaccuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	$k = (3)^{1/2}$

		Temperature - Epistemic	Half the value of the last significant digit - Rectangular distribution	k = $(3)^{1/2}$
Hardness	Appliedload	Hardness-testing machine calibration - Aleatory	Machine calibration certificate - Normal distribution - 95% of confidence level	k = 1.960
	Pi (π)	Accuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	k = $(3)^{1/2}$
	Ball diameter	Penetratorcalibration - Aleatory	Machine calibration certificate - Normal distribution - 90% of confidence level	k = 1.645
	Indentationdiameter	Hardness-testing machine calibration - Aleatory	Machine calibration certificate - Normal distribution - 95% of confidence level	k = 1.960
		Hardness-testing machine accuracy - Epistemic	Half the value of the last significant digit - Rectangular distribution	k = $(3)^{1/2}$

The results show that for ductility the greater contributor to uncertainty is the caliper rule (calibration and accuracy) because it presented the higher coverage factor for expanded uncertainty (k = 2). Thus, to mitigate great part of uncertainty the focus is to use a caliper rule with higher confidence level of calibration and greater accuracy or even to use a micrometer, considering that the cost of substitution is not prohibitive.

For the case of hardness determination, the testing machine (calibration of applied load and calibration of indentation diameter, both presented k = 1.960) is the main contributor for uncertainty. Therefore, in order to mitigate a considerable part of uncertainty, one should adjust the machine to provide a higher confidence level of calibration, considering that it is not possible to use another equipment without unwanted costs.

4. CONCLUSIONS

According to what was presented in this paper, it can be concluded that if the objective is to be as close as possible to reality, i.e., to have the highest reliability as possible, the uncertainties must be considered, since they are present in our everyday life, including mechanical properties determination.

In addition, when uncertainty is taken into account, ductility and hardness present variation in every generator factor, which amplifies the expanded uncertainty. Thus, observing the greater contributors to uncertainty it is possible to focus on just several generator factors and mitigate substantially the related uncertainty.

Therefore, with efforts directed on just few items, the related uncertainty is mitigated and the reliability of these mechanical properties improved, leading the materials in question to a new reliable landing in view of customer.

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