ASPECTS REGARDING THE EVALUATION OF THE UNCERTAINTY IN THE DETERMINATION OF THE RESIDUAL STRESS THROUGH THE HOLE DRILLING METHOD

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Abstract: Knowing the uncertainty result measurements of the trials is of a fundamental importance for the laboratories, their clients and for all the institutions which use these results in a comparative way. The competent laboratories know the performance of their methods of trying and the uncertainty associated with the measurement's results. This work presents the working way which includes the steps that have to be taken to evaluate the uncertainty at the determination of the residual stress through the hole drilling method. Here are presented the concepts that are the basis of the measuring uncertainty evaluation, parameters for which uncertainty is to be estimated, sources of uncertainty and influence of factors on the measuring uncertainty of the hole drilling method and their quantification.

Kewords: uncertainty, residual stress, strain gauge rosette, hole drilling method, sensitivity coefficient

1. INTRODUCTION

Trust in the quality of the products is determined by the trust in the results of the measuring implied in the production of those respective products. The quality of the measuring results is evaluated with the help of the "measuring uncertainty" characteristic. The uncertainty of the result of a measurement reflects the impossibility of the exact knowledge of the object being measured. The range in which is estimated, with a certain probability named level of trust, that the real value of the object being measured resides is called measuring uncertainty. Measuring uncertainty estimates the borders of the measuring errors. For an objective estimation it is necessary that together with the measuring result, the errors and the measuring uncertainty be specified.

The hole drilling method is a mechanic method of determination of the residual stress which is part of the semi-destructive methods, because the volume of material wasted is small and it is one of the most used techniques for measuring residual stress. This technique, is limited by the sensibility of the tensiometric marks towards deformations and the potential errors due to uncertainties related to the dimensions of the hole, the flatness and the quality of the surface, the uniformity of the apportion of the residual stress along the depth of the piece.

The method of determining the residual stress rests in the fixation of e tensiometric mark along the surface of the piece which is to be evaluated and the realization of a small dimension hole. The local deformations resulted in the making of the hole are constantly measured with the help of the tensiometric marc and the remanent stress is calculated upon these deformations with the help of some correcting coefficients obtained by calculation or experimental. Because of the small distance between the deformations translator and hole, the drilling introduces plastic deformations and significant heating. In principle the method is only valid for homogenous and isotropic materials. But, a number of publications show that the influence of the texture of the material can be neglected. Figure shows the definitions of the symbols used in residual stress measurement by the hole drilling method [1]. In the evaluation of the uncertainty of measuring at determining the residual stress through the hole drilling method will be taken into account the method of drilling, the speed and the advance of the drill, the worker's qualification, the standardizing factor, the quality of the installation of the tensiometric marks, the eccentricity and positioning of the testing object, the resolution and accurateness of the instrumentation, the usage, resistance to usage of the chipping tool, as well as the temperature induced in the process.

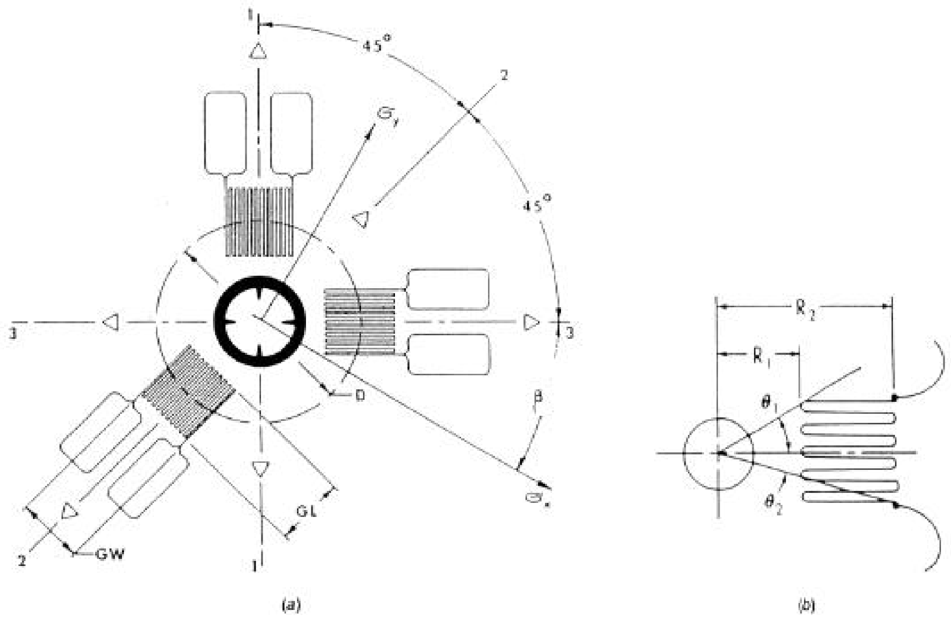

Fig. 1 Typical three-element clockwise strain gauge rosette for the hole-drilling method.

2. THE EVALUATION OF UNCERTAINTY IN MEASURING THE REMANENT STRESS.

At the evaluation of the uncertainty in measuring of the remanent stress the following concepts will be taken into account:

- In principal, knowledge of every size which influences the object to be measured is incomplete and can be expressed by a probability density function (PDF) for the values which can be attributed to the size based on this knowledge;
- The expected value of this PDF is considered as the best estimation of the size value;
- The standard experimental deviation of this PDF is taken as standard uncertainty assciated with this estimation;
- PDF bases on knowledge of a certain size that can be deduced by several repeated measuring – type A evaluation and, scientific judgement based on all available information regarding the posible size variability – type B evaluation.

Steps that need to be taken in the evaluation of the measuring uncertainty are:

1. Identifying the parameters for which uncertainty is to be estimated;
2. Identifying all sources of uncertainty in the test;
3. Classifying the uncertainty according to type A or B;
4. Estimating the sensitivity coefficient and standard uncertainty for each source;
5. Computing the combined uncertainty u_c;
6. Computing the expanded uncertainty U (is defined in reference [2] as “the interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand”.
7. Reporting of results.

Steps 1 and 2 are very important in the identification of the test parameter which contributes in a deciding way at the uncertainty. In this first stage all the input parameters need to be taken into account including the component or tested material, the method of measuring, test procedure, the operator and the ambiant environment. The operator has to make, after that, an analysis in what is the relative importance of the contribution of each parameter and the type of uncertainty.

Table 1 show the parameters that are usually reported in residual stress measurement by the hole drilling method.

Table 1 Measurands, measurements, their units and symbols

Measurands	**Units**	**Symbol**
Modulus of Elasticity	Mpa	E
Poissons ratio	dimensionless	μ
Maximum principal stress	Mpa	σ_{max}
Minimum principal stress	Mpa	σ_{min}
Direction of principal stress	deg(°)	β

Measurements	**Units**	**Symbol**
Strain from strain gauge 1	µm/m	ε_1
Strain from strain gauge 2	µm/m	ε_2
Strain from strain gauge 3	µm/m	ε_3
Drilling hole depth	mm	z
Drilling hole diameter	mm	D_0
Gauge circle diameter	mm	D
Calibration constant	Mpa^{-1}	$\overline{A}$
Calibration constant	Mpa^{-1}	$\overline{B}$
Coefficient	dimensionless	$\overline{a}$
Coefficient	dimensionless	$\overline{b}$

A calculation model is a physically based or empirical relation betwen relevant variables, which are in general random variables:

$$Y=f(x_1, x_2,...,x_n), \tag{1}$$

where Y – model output, f( ) – model function, x_i –basic variables.

The model f(...) may be complete and exact, so that, if the values of x_i are known in a particular experiment (from measurements), the outcome Y can be predicted without error. This, however, is not normally the situation. In most cases the model will be complete and inexact. This may be the result of lack of knowledge, or a deliberate simplification of the model, for the convenience of the designer. The difference between the model prediction and the real outcome of the experiment can be written down as:

$$Y=f'(x_1, x_2,...,x_n, \theta_1,...\theta_m), \tag{2}$$

θ_i are referred to as parameters which contain the model uncertainties and are treated as random variables. Their statistical properties can in most cases be derived from experiments or observations. Then mean of these parameters should be determined in such a way that, on average, the calculation model correctly predicts the results.

In step 2, the user must identify all posible sources of uncertainty that may have an effect (either directly of indirectly) on the test.

Table 2 lists the four categories and gives some examples of sources of uncertainty in each category.

Table 2 Typical sources of uncertainty and their likely contribution to uncertainties in residual stress measurement by the hole drilling method (1-major contribution, 2-minor contribution, blank-zero effect)

Source of uncertainty	Type	Measurands			Measurements					
		μ	E	σ_{max}, σ_{min}	β	$\varepsilon_{1,2,3}$	D_0	D	$\overline{A}$, $\overline{B}$	$\overline{a}$, $\overline{b}$
1. Test piece										
Surface finish	B			2	2	2	2	2		
Material characteristics	B	1	1	1	1	1			1	
2. Test system										
Alignment										
Measuring the drilling hole dimensions	A or B			1			1			1
Gauge circle dimensions	B			1				1		1
Uncertainty in strain measurement	B			1	1	1				
Drift in strain measuring system	B			2	2	2				
Stress and temperature initiation from drilling	B			2	2	2	2	2		
3. Environment										
Temperature and humidity	B									
4. Test procedure										
Calculation of $\overline{A}$	B	1	1	1					1	1
Calculation of $\overline{B}$	B		1	1					1	1
$\overline{a}$	B			1			1	1		1
$\overline{b}$	B			1			1	1		1

In third step, the sources of uncertainty are classified as Type A or B, depending on the way their influence is quantified. If the uncertainty evaluated by any other means it should be classified as Type B. The values associated with Type B uncertainties can be obtainted from a number of sources including a calibration certificate, manufacturee's information, or an expert's estimation. For Type B uncertainties, it is necessary for the user to estimate for each source the most appropriate probability distribution.

In 4 step the standard uncertainty, u, for each major input source is estimated. The standard uncertainty is defined as one standard deviation and is derived from the uncertainty of the input quantity divided by the parameter, d_v, associated with the assumed probability distribution. The standard uncertainty requires the determination of the associated sensitivity coefficient, c, which is usually estimated from the partial derivates of the functional relationship between the output quantity and the imput quantities.

The quantification of te sources of uncertainty listed in the table 3 is based on a literature study [3, 4]. The data from the literature are derived from practical and arithmetical investigation.

Table 3

Influence from the	Uncertainty	Remarks
1. Test piece		
Surface	negligible	
Heavy mismatch from plane surface	unknown	
Modulus of elasticity	±1%	measure using standard specimens of the same material
Poisson' ratio	±3%	see above
Stress distribution - 2-axial/biaxial - 3-axial/triaxial	 negligible ±15%	
Level of residual stress - <50%R_P - 50-70%R_P - >70%R_p	 negligible ±10% unknown	
Distance between measuring points - 5 times drilling hole diameter - 10 times drilling hole diameter	 ±8% ±2%	
2. Test system		
Measuring the hole drilling dimensions - diameter	Negligible	Measurement by light microscope
Irregularities in the drilling ole shape	Negligible	Use a new drill after 2 hole drillings
Drilling hole septh	Negligible	The uncertainty of the depth measurement has to be considered for >0,01mm.
Eccentricity of the hole to the center of the rosette	Negligible	For e≤0,05mm(0,1mm) For e≥0,05mm(0,1mm) the measurement has to be considered invalid
Perpendicularity of the ole axis relevant to the surface		
Gauge circle dimensions	negligible	Producer-data
Uncertainty in strain measurement technique	±2 till 5%	Experience from traditional Experimental stress analysis
Drift in strain measuring system	negligible	Zero adjustment before starting the measurement, short measuring cycle
Stress and temperature initiation from drilling	negligible	Use of high-speed-drilling equipment and new drill after 2 hole drillings
3. Environment		
Temperature and humidity	negligible	Measuring by different conditions, but zero adjustment before starting the measurement, short measurng cycle
4. Test procedure		
Calculation of $\overline{A}$, $\overline{B}$	dependent on the uncertainty of E, μ, $\overline{a}$, $\overline{b}$	
$\overline{a}$, $\overline{b}$	dependent on the uncertainty of D_0, D	

Step 5. Computing the combined uncertainty u_c.
Assuming that individual uncertainty sources are uncorrelated, the measurand's combined uncertainty, $u_c(y)$, can be computed using the root sum squares:

$$u_c(y) = \sqrt{\sum_{i=1}^{N} [c_i u(x_i)]^2} , \qquad (3)$$

where c_i is the sensitivity coefficient associated with x_i. this uncertainty corresponds to plus or minus one standard deviation on the normal distribution law representing the studied quantity. The combined uncertainty has an associated confidence level of 68,27%.

Step 6. Computing the expanded uncertainty U.
The expanded uncertainty, U, is obtained by multiplying the combined uncertainty, u_c, by a coverage factor, k, which is selected on the basis of the level of confidence required. For a normal probability distribution, the most generally used coverage factor is 2 which corresponds to a confidence interval of 95.4 %. The expanded uncertainty, U, is, therefore, broader that the combined uncertainty, u_c. Where a higher confidence level is demanded by the customer (such as for Aerospace or the Electronics industries), a coverage factor of 3 is often used so that the corresponding confidence level increases to 99.73 %.

Step 7. Reporting of results
Once the expanded uncertainty has been estimated, te results should be reported in the following way:

$$V = y \pm U, \tag{4}$$

where V is the estimated value of the measurand, y is the test (or measurement) mean result, U is the expanded uncertainty associated with y.

3. CONCLUSIONS

The uncertainty of the measurement is a very important measurmant of the quality of the results or the attempting methods. The uncertainty level that is accepted needs to be decided on the wanted goal, the decision being taken as a result of consultations with the client. The degree of strictness necessary in the estimation of the uncertainty depends on the requirement of the attempting methods, the clients demands and the existance of some narrow limits for the fundamentation of the concordance of the decision with a specification. When the uncertainty of the measurement is evaluated, all the components that are important in the given situation need to be taken into consideration using the most suitable method of analysis. Sources that contribute to the uncertainty include, without limitation to, referance units and materials, methods and used equipment, environment conditions, proprieties and conditions of the object under measurement, as well as operator. Long term behavior scheduled for the object under measurement is not, in a normal way, taken into consideration when the uncertainty of measuring is estimated.

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