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Hole Drilling Residual Stress Measurement – ASTM Standards and Evaluation Uncertainties

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Abstract. The paper deals in hole drilling residual stress measurement method. The basic principles of measurement and evaluation by the uniform stress and Integral methods are described. The uncertainties of the residual stress evaluation procedure based on the ASTM E837 standard are analyzed. Examples of residual stress evaluation and comparison of different ASTM E837 standard editions are presented.

Introduction

Residual stress is defined as the stress remaining in a solid material without an external load [1]. It originates in the material as a result of its manufacturing processes. Residual stress occurs practically in all technical materials. It affects material strength, corrosion or fatigue properties. Residual stress may be considered undesirable or beneficial, depending on whether it is tensile or compressive. However, high residual stresses can cause cracking, delamination or shape changes and are generally undesirable.

Residual stresses are mainly determined experimentally [2]. There are two basic measurement principles - destructive or non-destructive. The destructive methods are based on a relieving of original residual stresses and measurement of a response to the relieving. The non-destructive methods use relationships between residual stress and structural material properties. A different classification is based on measurement technique principles: mechanical methods, diffraction methods or methods based on physical properties measurement. The hole drilling method is one of the most used methods for residual stress measurement. It is the destructive mechanical method, sometimes called semi-destructive. One of the reasons for the popularity of this method is the fact, that the measurement and evaluation procedure are defined by the ASTM E837 standard. It is very helpful for results comparability and repeatability. However, it also brings some questions regarding measurement reliability and suitability of different measurement procedure definitions. Uncertainties of the evaluation were found even if the evaluation procedure is defined by the generally respected standard, as it is shown in this paper.

The Hole-drilling Residual Stress Measurement Method

The hole-drilling residual stress measurement method [3] is based on a drilling of a small hole to a measured material. The hole should be drilled in such a way that additional residual stresses are not introduced into the material - a high speed drilling is generally recommended. The hole is in most cases very small (1 - 2 mm) and the method is therefore called as semi-destructive.

The drilling of the hole causes an original residual stress relieving, which is accompanied by strains in a hole vicinity. Drilling of the hole in more subsequent steps (increments) allows evaluation of a residual stress depth profile. The relieved strains are measured, most often by strain gauges, and used for an evaluation of the original residual stress in the material. Different evaluation methods have been supposed, but in principle, it is practically a transformation of the relieved strains into the original residual stresses. This transformation uses mechanical properties of the measured material and a transformation function. The transformation function is mostly represented by a computational procedure and calibration coefficients, which are in most cases determined numerically by a finite elements method simulation.

A lot of modifications of the method can be found from the point of view of a drilling procedure, relieved strains measurement method and evaluation procedure. Nevertheless, the basic measurement procedure is standardized in the ASTM E837 international standard. This standard describes or recommends the procedure, conditions, equipment and evaluation procedure for a depth-uniform or non-uniform residual stress profile, which includes also the calibration coefficients for the uniform stress and Integral evaluation methods [3].

The uniform stress method, called as the equivalent uniform stress (EUS) method in case of non-uniform stress depth profile, evaluates the residual stress as a weighted average over a total hole depth at each increment. The EUS method requires calibration constant vectors, which are defined for the given hole diameter, strain gauge rosette diameter. The Integral method evaluates the residual stress in the each increment individually. It takes into account the total hole depth and the increment thickness in the each step. Thus, the Integral method requires calibration constant matrices unlike the EUS method, which uses calibration vectors. The result of the Integral method evaluation is a more reliable stress-depth profile. However, the Integral method is more sensitive to relieved strain measurement inaccuracies or data scatter. Therefore, it is more suitable to use the EUS method if a relieved strain measurement data are more scattered or influenced by some measurement errors.

Residual Stress Evaluation Uncertainties

The ASTM standard describes very extensively the measurement procedure and its presence is very important and very useful. It allows a standardized measurement, which should be comparable and repeatable if all the conditions are fulfilled. However, a comparison between results evaluated by different editions of the same standard brings some differences.

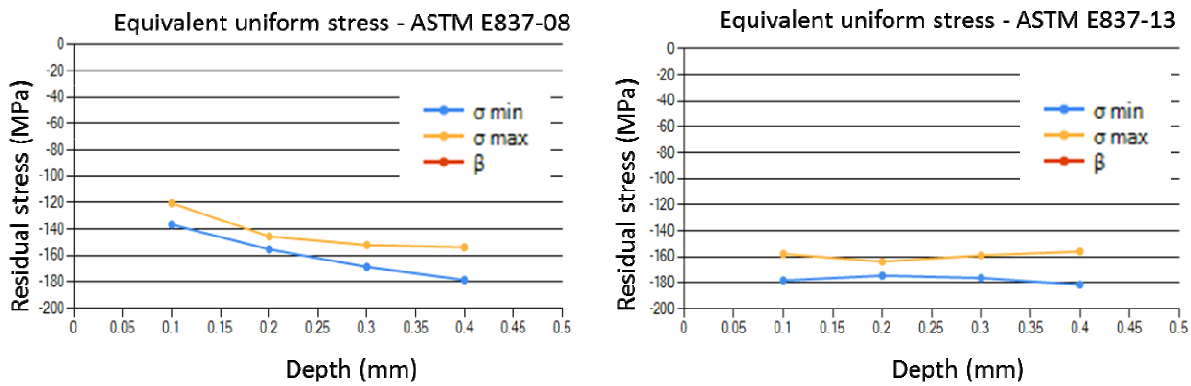

Fig. 1. Residual stress evaluated by the equivalent uniform stress method using the ASTM E837-08 and E837-13 standards editions.

A comparison between the residual stress evaluation by the equivalent uniform stress (EUS) method using a previous ASTM E837-08 [4] edition and current ASTM E837-13a [5] editions is showed in Fig.1. The residual stress in the depth 0.1 mm is -120/-140 MPa and falls up to about -160/-180 MPa in the depth 0.4 mm by the E837-08 edition. Evaluation of the same relieved strain data made by the E837-13 edition brings values -160/-180 MPa, which is almost constant up to depth 0.4 mm. The input data - relieved strain interpolation, evaluation steps or material properties - were the same in both the cases. Thus, the evaluation differences presented in the Fig.1 are only caused by the differences in calibration coefficients, which are defined by the ASTM E837-08 and E837-13 standards.

The comparison of the residual stress evaluation by the EUS and Integral methods according to the ASTM E837-13 standard is in Fig. 2. The shapes of the curves differ as can be expected according to the different evaluation procedures. However, with regard to the EUS and Integral evaluation methods principles, the first value of the evaluation in the depth 0.1 should be the same for both the evaluation procedures. In this case, the residual in the depth 0.1 mm is -160/-180 MPa by the EUS method and -140/-160 MPa by the Integral method.

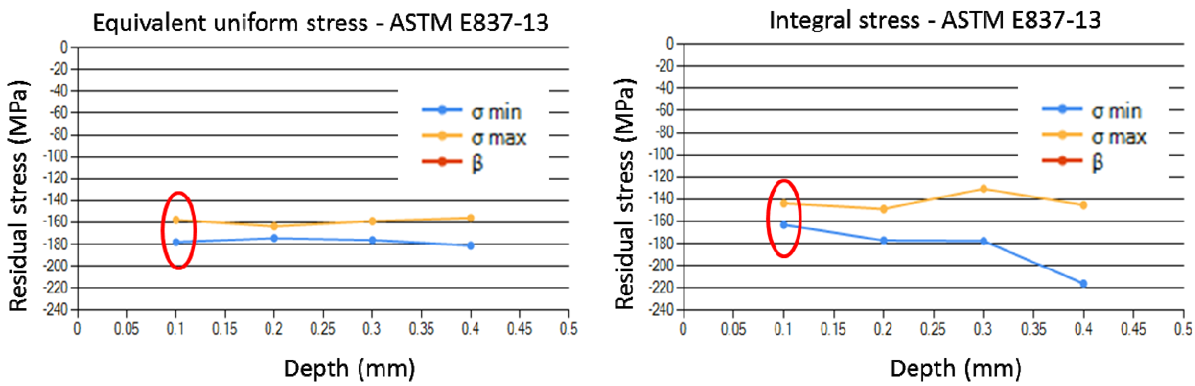

Fig. 2. Residual stress evaluated by the equivalent uniform stress method and the Integral method using the ASTM E837-13 standard editions.

It was found that these differences resulted from calibration coefficients definition in the ASTM standards. If consistent calibration coefficients for both the method are used, the evaluation results correspond to the above assumptions. This is demonstrated in Fig. 3, where the same relieved strains data were evaluated by the EUS and Integral method using the user-defined calibration coefficients determined by a numerical simulation.

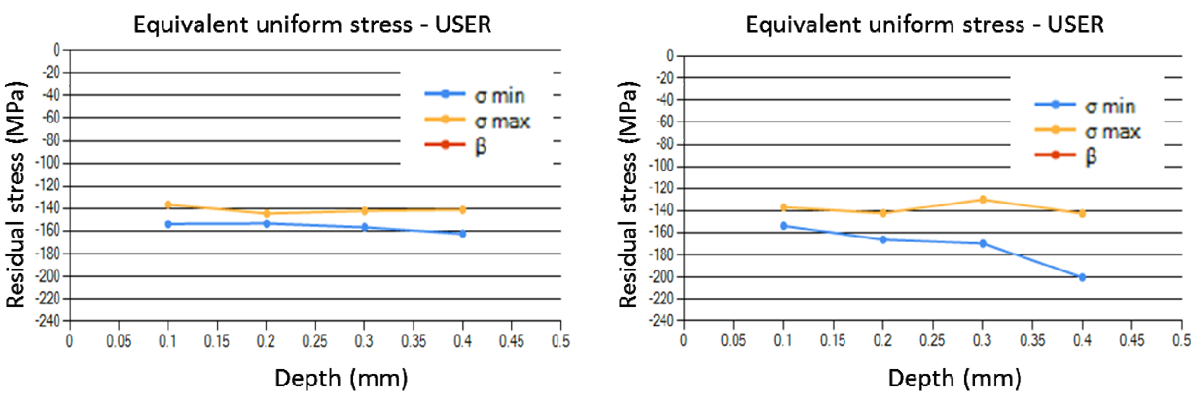

Fig. 3. Residual stress evaluated by the equivalent uniform stress method and the Integral method using the user-computed calibration coefficients.

The presented facts revealed some measurement accuracy uncertainty, which are caused solely by evaluation procedure, even if it is standardized. As it was shown in this contribution, the residual stress evaluation results can differ even if the input data (relieved strain, material properties etc.) and evaluation procedure are the same. The hole drilling residual stress evaluation results should be therefore accompanied by information about input parameters, evaluation method, calibration coefficients used (the standard edition or a user computed coefficients) so that the results are comparable.

Additional uncertainty can bring the measured data and calibration matrices processing, which is not fully described in the ASTM standard and which can influence the results significantly. It can be critical namely in the case of Integral method calibration matrices processing, where two-dimensional interpolation of triangular matrices must be used.

Conclusions

As the hole-drilling is a widely used method for residual stress determination, it brings a lot of opportunities for the method analysis and critical appraisal of the method. It contributes to its improving and achieving more accurate and reliable results. This contribution is not focused on uncertainties in general, but on the evaluation procedure only. From the examples presented in this contribution follows that the results are fully comparable only if the same evaluation methodology is used. It includes for example specification of the used ASTM standard edition or data processing and interpolation procedure.

However, the differences are not critical and all the presented procedures are usable in most of cases. Although some problems were shown, the hole-drilling measurement method is still one of the most reliable residual stress determination methods. In addition, the presence of the ASTM standard brings a lot of benefits, as the most of the measurement procedure and evaluation steps are defined in this standard.

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