Evaluation of Residual Stresses using ASTM E837-20

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Abstract: Procedures given in new issue of ASTM E837-20 standard for measurement of hole-drilling method including the comparison with the older standard versions and discussion of new issue benefits are described in this article. Comparison is also made on experimentally obtained residual stress data from railway axle.

Keywords: residual stresses; hole-drilling method; ASTM-E837.

1 Introduction

The new revision of ASTM E837-20 standard for residual stress measurement using hole-drilling method issued in the year 2020 with successive improving of evaluating procedures dated from first issue from the year 1981 (one step measurement), followed with multiple power series method (2001) and ending with the integral through profile method [2] (2008, 2013). The residual stresses are evaluated here from strains relieved by hole-drilling using large triangular matrices $\bar{\boldsymbol{a}}$, $\bar{\boldsymbol{b}}$. In the last standard version [1], the matrices were expressed for 20 equal drilling steps $0.01D$ up to the practical depth $0.2D$ (rosette type A and B, D is the mean rosette type diameter) i.e. only for specific hole diameter and hole depths with lower testing convenience [4].

2 Theory

In the new standard version the generalization of matrix coefficients are made with fifth order polynomial interpolation using two sets of calibration constants C_i. Using these constants first three cumulative calibration matrices $\hat{\boldsymbol{a}}$, $\hat{\boldsymbol{b}}$ have to be calculated for given three hole diameters, used drilling depths and workpiece thickness W. The reason for this is that the cumulative functions on which the integral method is based [2] are more suitable for coefficients interpolations. Then the mean cumulative matrix is calculated from these three matrixes for both coefficients. The final calibration matrices $\bar{\boldsymbol{a}}$, $\bar{\boldsymbol{b}}$ are obtained with numerical differentiation of these cumulative functions as differences of matrix values in each row. This access makes it possible to choose arbitrary hole diameters and drilling steps. The number of steps can be even in the range of 15 to 40 for rosette type A and B, the depth steps may not to be equal. The maximum drilling depth is specified as the minimum of $0.2D$ or $0.6W$, thus the deepest residual stress profile is 2 mm using the largest 1/8 in rosette.

Another benefit of the new standard is the possibility to measure the residual stresses in the intermediate workpiece thickness going from $0.25W$ to $0.6W$, which was not defined in the older standard issues. New set of constants were also defined for homogenous stress field.

The demand for the accuracy of the drilling set-up is approximately the same in both standard issues.

The evaluation procedure for residual stress profile from measured relieved strains using calculated matrices $\bar{\boldsymbol{a}}$, $\bar{\boldsymbol{b}}$ is performed as for the integral as for the power series and as for throw hole methods in the same way for both last and new standard issues.

The new standard is based on the work, published in [3]. The correction of drilling hole misalignment and the correction to elastic-plastic stress state are again not included to the standard.

3 Implementation

One set of measurement on surface hardened axle was performed using apparatus SINT RESTAN (Fig. 1), 1/8 inch rosette HBM RY61-3.2/120S, and the electric motor head with n = 20 000 rpm) in 22 drilling steps from 0.1 mm up to 2.2 mm (Fig. 2). Data seems to be very smooth.

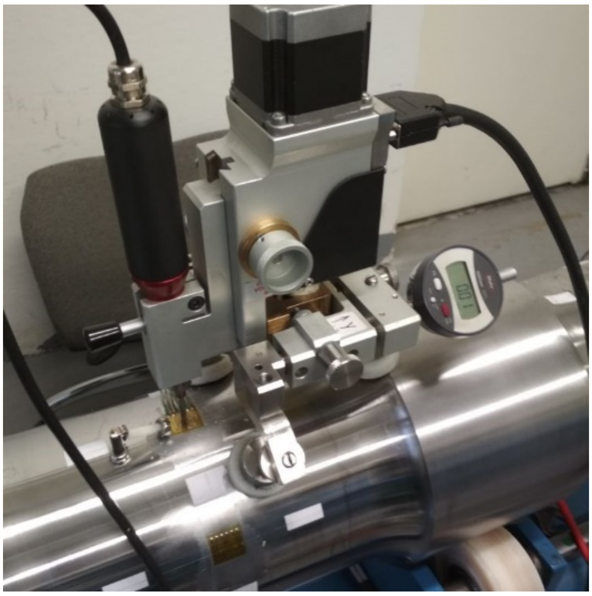

Fig. 1: Hole-drilling device HBM Restan with electric motor head.

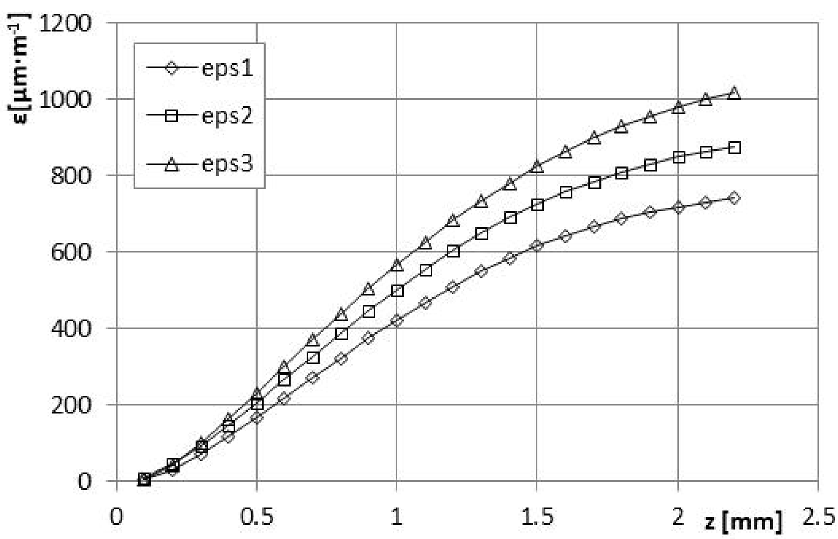

Fig. 2: Measured raw strains without interpolation.

The evaluation was made according to both last issues of standard ASTM E837 and also with constants from original integral method [2]; differential Kockelmann's and SINT HDM method were also added for comparison. Results of both principal stresses including the angle of the maximum principal stress are given in Fig. 3. Both ASTM -13a, ASTM-20 and integral method give comparable stress depth histories. HDM method does not provide so detailed distribution of residual stress with the depth but also the maximum principal values are comparable. Substantially different lower stresses were obtained with the differential method, which we do not recommend for this type of measurement.

The absolute values of stresses evaluated with ASTM E837-20 in comparison with the older issue were at the most of 6% higher.

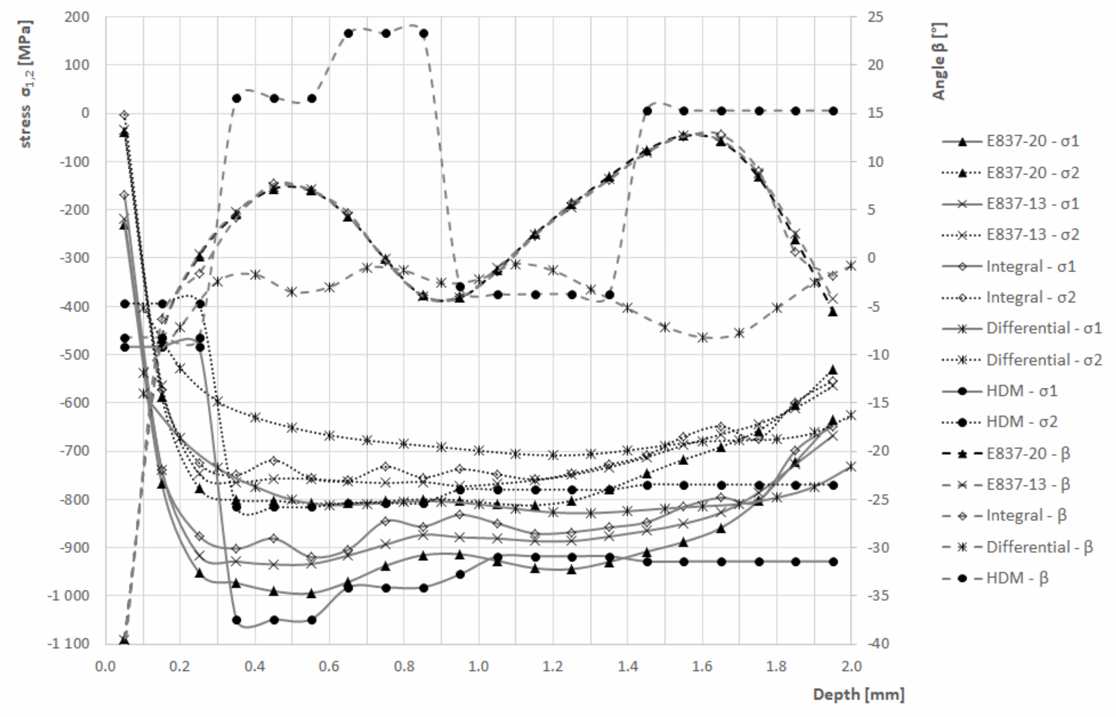

Fig. 3: Comparison of residual stress evaluation with various methods using the software SINT Eval including both ASTM E837-13 and E837-20 issues.

The difference between evaluated principal stresses according ASTM E837-13a and E837-20 is given in Fig. 4. It changes from negative to positive values and may be a mistake of polynomial interpolation in the new standard.

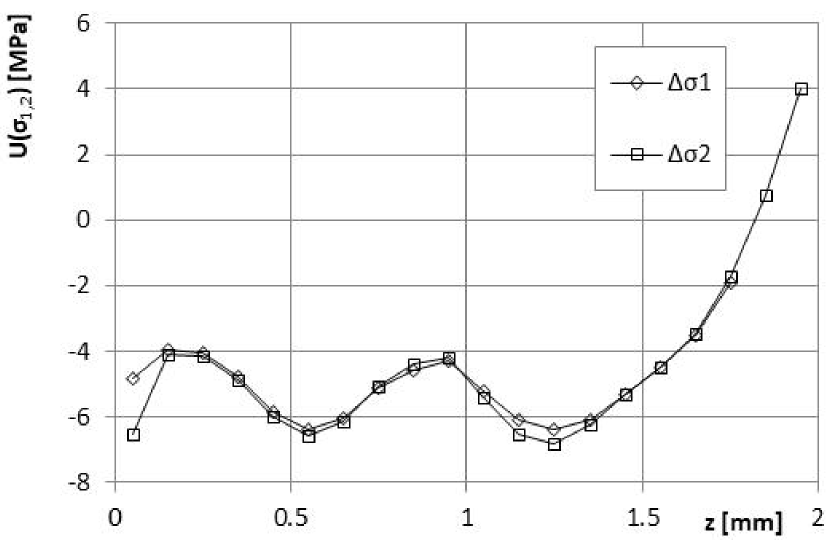

Fig. 4: The difference of evaluated principal residual stresses using ASTM E837-13 related to the new standard: older stresses are lower at the surface and higher in the maximal depth.

The residual stress evaluation from relieved strains was performed using software SINT Eval. It includes very good estimation of the uncertainty for several hole-drilling methods used for non-homogenous residual stress profile evaluation. The evaluation of residual stress uncertainty was made for both ASTM -13a and ASTM-20 methods. The results are given in Fig. 5 in form of upper tolerance intervals for both minimum and maximum principal stresses.

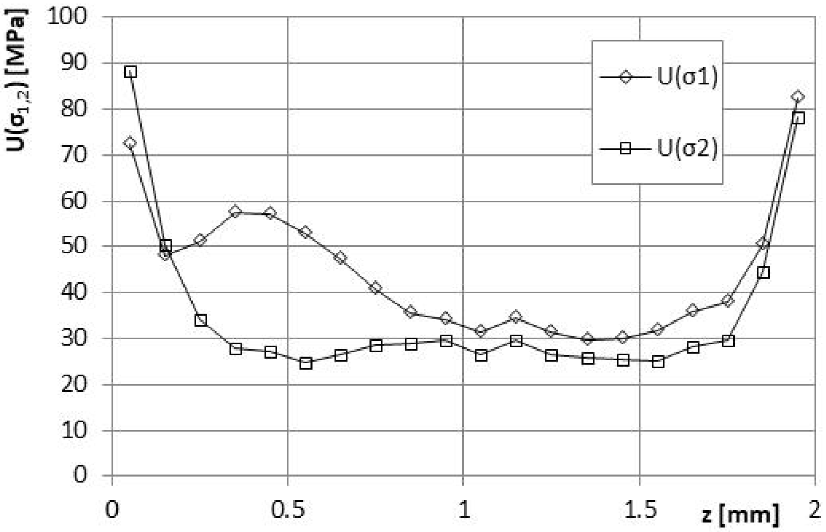

Fig. 5: Distribution of absolute uncertainties of calculated residual principal stresses through the depth is the same for both ASTM E837-13a and E837-20 standards.

4 Conclusion

The matrices in ASTM E837-13a standard issue were obtained from the old FEA model whereas new given constants are based on much more detailed finite element mesh; new calibration constants are about 2–3% higher (i.e. calculated stresses are lower). On the other hand, there rises some small error in computed stresses using interpolation procedures specified in the new standard. The effect of these differences can lead to much more higher differences in computed residual stresses especially in the case of noisy data up to 10 %, which is a generally valid criterion.

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