COMPARATIVE STUDY OF ALGORITHMS USED FOR AUTOMATED EVALUATION OF THE TENSILE TEST RESULTS

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Abstract

It is a common practice to use automated software tools to identify material properties values in dataset recorded during the tensile tests. Our work is a comparative study how different numerical algorithms affect resulting material properties values. We tested four different algorithms on fifteen dataset while datasets covered all the most common metal force-deformation characteristics. Two algorithms can be considered as validated according to the standard while two others need some minor modifications. We expect that after these modifications also the two algorithms will meet evaluation requirements. Effect of using different validated algorithms is relatively small but still it needs to be considered as a source of uncertainties in entire physical test and evaluation chain.

Keywords: tensile test, automated results evaluation

1. INTRODUCTION

Recently the computer controlled automatic testing systems are mostly used for material testing. These systems include computer controlled stand and create records of test parameters during test procedure. The software Included is also used for automatic results evaluation. This paper deals with the influence of algorithms used for tensile test results evaluation on the obtained material properties values. We introduce three algorithms we have designed and one commonly used on Chinese universities [1]. All algorithms were programmed in Visual Basic for Application and the results were compared in MS Excel. As a testing data we used data from a survey [2]. We used fifteen data sets, twelve of which were real data from the real tensile tests and three were artificial curves. At the end all results are compared and discussed.

2. ALGORITHMS

2.1 Algorithm based on curve derivation

This algorithm is based on relation between a curve derivative and a curve slope. Because we search a linear region of the force-deformation curve thus derivation in that region must be constant. Because data are usually sampled with very small time step the uncertainty between two points is increasing and thus derivative calculated for each two consecutive points tend to oscillate (see Fig. 1). There are two options how to bypass this problem. First one is to smoothen the derivative curve. The second is to compute derivative using distant points. We chose the second option and used segments with length 40 data points. The slope was still not quite constant, therefore we defined the constant region which have at least 90 % of maximum value of the slope (see Fig. 2).

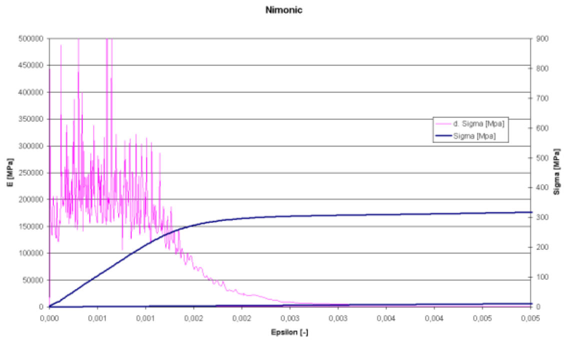

Fig. 1 Oscillations if derivative is computed for every two subsequent data points

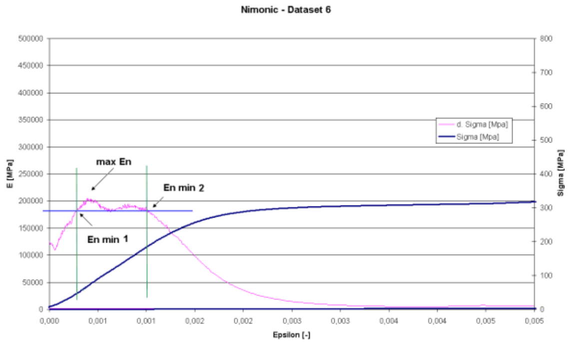

Fig. 2 Derivation curve using sectors of 40 data points

2.2 Iterative algorithm based on $R_{p0,2}$

Algorithm is based on assumptions presented in [3]. To find a slope of elastic region necessary for determining $R_{p0,2}$ we assume: linear regression in the linear region, lower limit is set to 10% $R_{p0,2}$, upper limit is set to 50% $R_{p0,2}$. Iterative algorithm uses in 0th step preset $R_{p0,2}{}^{0}$, from that value calculates lower and upper limit, from those limits slope and from the slope finally $R_{p0,2}{}^{1}$. This procedure repeats until abs($R_{p0,2}{}^{n+1}$-$R_{p0,2}{}^{n}$) < ε (defined precision). Algorithm converges usually within several iterations. For $R_{p0,2}{}^{0}$ they can be used values from interval $0.1R_m – 0.8R_m$ with minimal influence on number of iterations needed.

2.3 Algorithm based on finding segment with maximal coefficient of determination

Coefficient of determination compares real values with their estimates. It may have values between 0 and 1. For the value 1 there is a perfect correlation between the real values and the estimates for this specimen. For value equal 0 the regression equation is not able to find good estimates. The algorithm tries to find a segment with maximum coefficient of determination. To start with we use values entered by a user or we use results of other methods. On the Fig. 3 you can see the dependency between coefficient of determination for lower limit (from 20 to 120MPa) and upper limit (from 150 to 200 MPa) for dataset 6. Segment with the best coefficient of determination (0,999866) is the segment from 76 to 206 MPa.

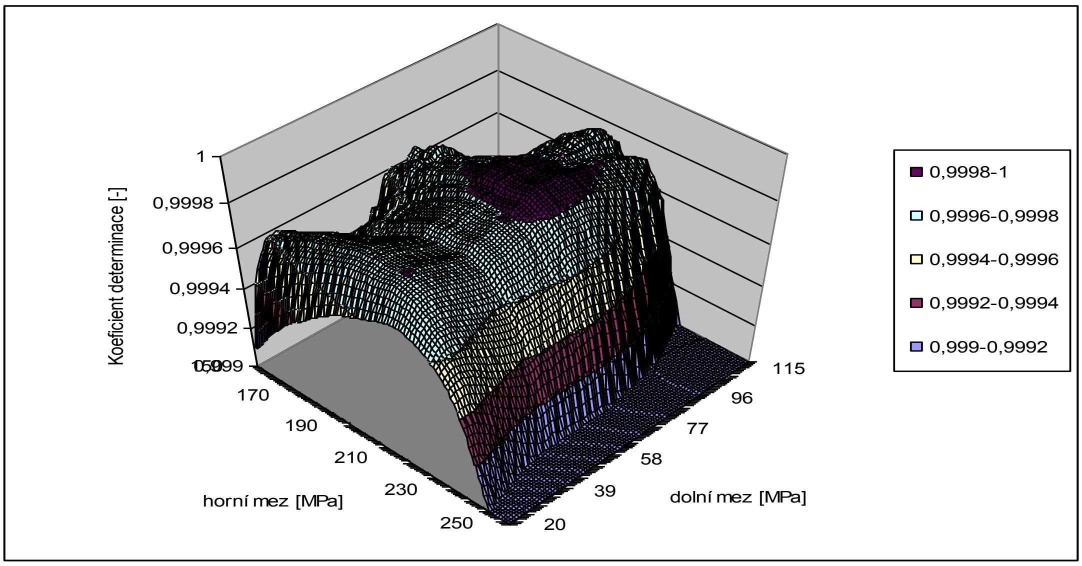

Fig. 3 Coefficient of determination for Dataset 6

2.4 Iterative method used on Chinese universities [1]

This method uses the following algorithm (see Fig 4. for details):

- In the starting part of the loading curve (F-ΔLe), where $R_{p0,2}$ is expected, the point A^0 is randomly chosen. The value $F_{p0,2}{}^0$ corresponds to this point on the load axis. It is assumed it represents the load on yield point $F_{p0,2}$.
- Two point B_1 and D_1 are defined at values 0.1 $F_{p0,2}{}^0$ and 0.5 $F_{p0,2}{}^0$ respectively and straight line is put between them.
- At the point C, which corresponds to 0.2% elongation, a line is constructed parallel to the line B^1D^1. That line intersects the load curve at point A^1.
- In case $A^1 = A^0$, $F_{p0,2}{}^0$ is the load on the yield point $F_{p0.2}$, which is the value we looked for. Otherwise the entire procedure repeats with new value $F_{p0.2}{}^1$ derived from A^1.
- Iterations continue until A^n=A^{n-1}. Then F^n is the load $F_{p0.2}$ at the yield point we looked for and the slope of the B_nD_n represents Young's modulus of elasticity.

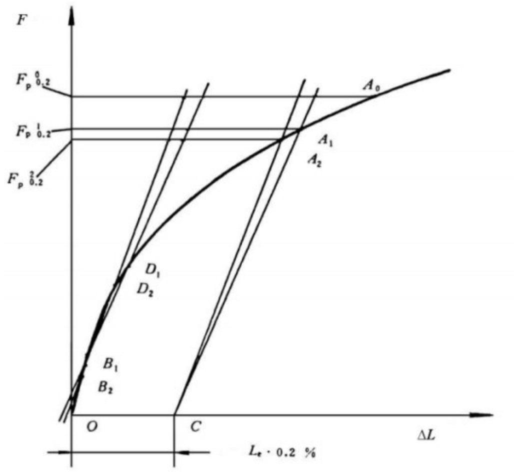

Fig. 4 Iterative method used to find yield point [1]

This iterative method is easily utilized particularly in automated test systems. In addition to yield point, if we use an extensometer it is also applicable for the determination of a ductility. Together with the appropriate extensometer it significantly contributes in eliminating the differences in the results of the measurements.

3. ALGORITHM VERIFICATION

All algorithms were programmed in Visual Basic for Applications, modules for data loading and reporting were added. The final program analyzes all data files in a given directory with all algorithms and it creates the report table.

We used the data files from project TENSTAND EU [2] as a source data for this survey. The data are ASCII files with force-elongation curves with different material characteristics and they are freely available for a software validation. The standard [4] states that in case of validation using predefined data files of known material the results should be within the limits presented in Table 1.

Table 1 - The maximum allowed differences between the results obtained by computer and the results obtained manually

Parameter	Average deviation D		Standard deviation s	
	relative	absolute	relative	absolute
Rp0.2	≤ 0.5%	2 MPa	≤ 0.35%	2 MPa
Rp1	≤ 0.5%	2 MPa	≤ 0.35%	2 MPa
ReH	≤ 1%	4 MPa	≤ 0.35%	2 MPa
ReL	≤ 0.5%	2 MPa	≤ 0.35%	2 MPa
Rm	≤ 0.5%	2 MPa	≤ 0.35%	2 MPa
A	-	≤ 2%	-	≤ 2%

All algorithms were tested on 15 datasets, 12 of them are real data measured on real specimens and 3 are artificially generated curves. Complete report table with all data for all dataset covers three complete A4 pages, therefore it is not present in this paper (but it is available upon request). A brief summary of the results for each algorithm follows.

3.1 Algorithm based on curve derivation

In three cases the difference in yield point value $R_{p0.2}$ was ≥ 0.5% from CTV[1]. It shows the algorithm failed in these cases. Further analysis revealed the cause to be unexpected derivative behaviour probably during grips tightening around specimen that led to extreme value of derivative. Due to the fact the algorithm use 90% of maximum derivative value to define linear part of the curve the result is not satisfying. Based on the results we cannot considered this algorithm as validated. On the other hand is it highly probable that after some small changes in the algorithm to overcome such problems, the method will be able to pass a process of validation.

3.2 Iterative algorithm based on Rp0,2

Relative difference of the yield point value $R_{p0.2}$ was in all cases less than 0.5%. For 11 datasets it was equal to CTV. After deep study this algorithm can be considered as validated for a data without any disturbances.

3.3 Algorithm based on finding segment with maximal coefficient of determination

This algorithm needs a starting point around which it tries to find required values. For our tests we choose 20% $R_{p0.2}$ for the middle lower value of the segment, 75% of $R_{p0.2}$ for upper middle value of the segment and delta to be 20% $R_{p0.2.}$ These values were chosen so that the minimal segment would be from 40% to 55% of $R_{p0.2}$. For all datasets the relative difference was ≤ 0.5% from CTV, therefore the algorithm can be considered as validated for data without disturbances. In few cases the algorithm reached interval limits without finding maximal coefficient of determination. From this reason changes in algorithm allowing the segment boundaries to move would increase a usability of this method.

[1] CTV = conventionally true value. The value that is attributed to the particular quantity and accepted, sometimes by convention, as the value with uncertainty which is satisfactory for the purpose [4]. It specifies the interval in which the right value is present with certain probability. In our case these are values agreed in study [2] – Table 9: Agreed values for the Premium Quality ASCII dataset (no smoothing applied)

3.4 Iterative method used on Chinese universities

Relative difference from CTV at yield point was more than 0.5% in two cases. In one case is is probably because of disturbances are present in the analyzed data. This method has some difficulties based on the following:

1. It does not eliminate pre-stress in the specimen (while the other methods do)
2. Algorithm uses bisector method, which is not ideal for data with disturbances.

Most of the differences were similar to the method described in chapter 2.2. This algorithm cannot be considered as validated as it is. It is however highly probable that after some small changes it can pass the validation process.

CONCLUSION

Three algorithms were introduced and one was taken from the literature. Software for algorithms validation was prepared and all four algorithms were tested on fifteen dataset. Two algorithms were considered as validated and two others were studied further. Changes in these two algorithms were suggested and it is highly probable that after the changes both algorithms will pass the validation process. The report table shows all the differences between resulted values achieved by all algorithms for different materials (different datasets). For data without disturbances all methods resulted mostly in difference less than 0.5MPa in yield point value. Therefore we can say none of these algorithms have significant effect on resulting material properties values.

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