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Measuring Material Properties of Metal Foils Using Bulge Test Method

Josef Káňa*, Bohuslav Mašek, Kateřina Rubešová

University of West Bohemia. Research Centre of Forming Technology – FORTECH, Pilsen, 306 14, Czech Republic

Abstract

Testing device and testing method for determination of material properties of very thin metal foils (up to 0.05 mm of thickness) using modified bulge test method were introduces in previous works. The paper describes recent development of both the device and the methodology which further improve given concept. The design of the whole device was all remade, pressure measurement was significantly improved, new control and evaluation software was introduced. The method for laser measurement on glossy surfaces is presented. The method is an outcome of problems we faced during measurement using a laser system on glossy surfaces as it is almost impossible to obtain proper data on highly glossy surfaces for further post-processing. Our measurement outcomes are presented and discussed on specimens made of several different materials - Al, Cu, FeNi alloy. Finally we recognize specific limitations of the presented methodology.

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Keywords: metal foils; laser; bulge test; material properties; LabVIEW

1. Introduction

A need for a precise, an easy and a quick (on production site) method of getting material properties of very thin metal foils in recent years comes from the industry as a result of increased usage of thin metal foils. These are also used in more advanced applications where knowledge of exact material properties is required. In the [1] new method and testing device for such measurement were introduced. Method is based on commonly used [2,4,5,7] bulge test method with several modifications. First modification is the use of air as pressurizing medium instead of mostly

* Corresponding author. Tel.: +420 377 632 312; fax: +420 377 638 052.
E-mail address: jkana@rti.zcu.cz

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used oil or water. The second one is use of laser for specimen displacement measurement. Both, the method and the testing device were thoroughly tested and based on that many improvements were introduced. Furthermore we describe the improvements and also we present preliminary outcomes of the testing.

2. Hardware improvements

The design of the testing device changed significantly from the one introduced in [1]. The new design (see Fig. 1) is more compact and sturdy. The Fig. 1 shows an actual design and a safety cover that is opened. On the right from the specimen holder there is a scant plate which protects a pressure sensor and a power source installed behind it. The safety cover is necessary especially in case of testing stronger specimens; i.e. FeNi 0.05mm thick foil (the strongest tested) tears apart and pieces can be found several meters away from the testing area if no cover is used.

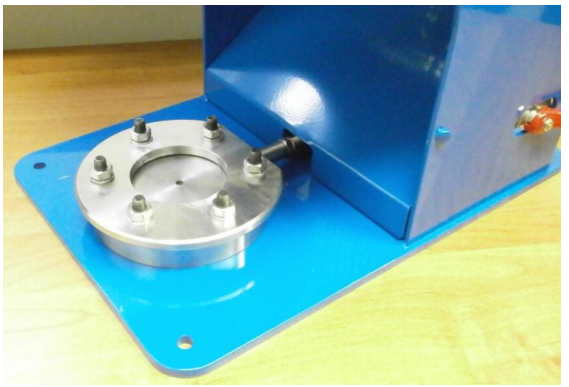

Fig. 1. Detail of the flange for specimen holding.

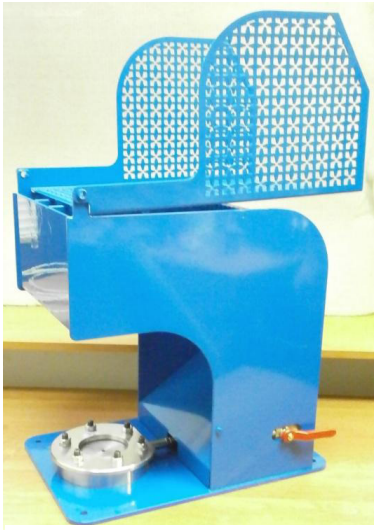

Fig. 2. Testing device.

Pressure system was redesigned in two ways – a piping system and a pressure sensor. The pressure sensor was moved as close to the flange holder as possible and the flow control needle valve was moved behind it (see Fig. 3). Fig. 3 shows how the pressure sensor is connected to the main line using T-shape connector. At the back of the Fig. 3 there is a visible power source for the laser sensor, which is installed in the upper part of the device.

Fig. 3. Pressure piping system.

The hole in the lower part of the flange where pressured air enters area under tested specimen was enlarged. The reason was to minimize the pressure losses in that part of the system. The concept where the hole was very small to limit pressure jump after opening main valve proved wrong. The small hole brought pressure losses and therefore values of pressure measured by the pressure sensor and real values of the pressure applied on the specimen were different. The other improvement was based on the change of the pressure sensor. The original pressure sensor had an analog-digital transducer built in. Communication with PC running control software uses serial line, that proved to be too slow and resulted in minimum 40ms time between sending the command asking an actual pressure value and obtaining that value for further processing. Because the pressure value applied on the specimen at the moment of the rupture is critical for the calculation of the material properties. Not only its precise value is very important, but also the fact that the value is taken at an exact moment of the rupture. Therefore new analog pressure sensor was installed to allow the measurement at maximum laser sensor frequency 100Hz.

3. Control software

Control software was newly programmed in LabVIEW because it was faster to develop measuring and post-processing applications.

The algorithm reads simultaneously values from the pressure sensor and data from the laser. Data from the laser consist of two vectors of length 640 (as used linear laser is able to measure a line consisting of 640 points). In the first vector there are x-values of measured points while the second one includes z-values. Those two vectors give 2D position of the surface points of the measured specimen. The points are interpolated by a curve and the height of the specimen dome (point with highest difference between starting and last value in z- axis) and the specimen cross-section length (use for ductility evaluation) are calculated. Material properties are then calculated using well known formulas [6]. Tensile strength by formula for maximum stress at the moment of the crack $\sigma=(P*a^2)/(4*h*t)$, where P stands for a pressure applied to the specimen at the moment of the crack, a stands for a radius of the specimen, h stands for a height of the dome at the moment of the crack and t is thickness of the foil after the test. Thickness of the foil after the test is measured as close to the crack as possible in several places and then the average is used as resulting value. Ductility is calculated $(L-L_0)/L_0$, where L_0 is specimen diameter and L is length of the cross-section of the dome at the moment of the crack.

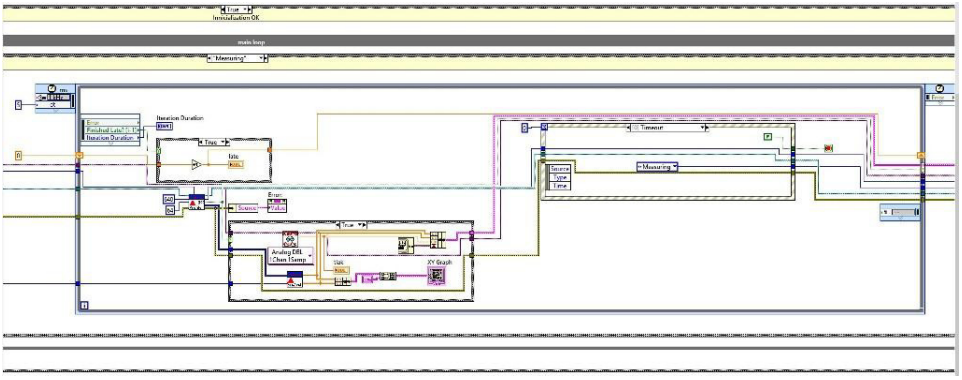

Fig. 4. Part of the LabView code – main data acquisition loop.

First version of the control software calculated all parameters and results right away during the measurement. The main problem with this approach was that the line interpolation and then searching for a moment of rupture was too time consuming. Also automatic search for crack event was not very accurate because ruptures have different shapes and can occur away from the line the laser is measuring. Therefore measuring and material properties calculations were split into two separate processes. All data are measured until a significant pressure drop occurs. It stops data acquisition.

Then post-processing part starts. Operator can manually list all measured data and can identify data set before rupture occurred. Material properties are calculated for every data set, and the operator chooses the right one by checking up both specimen cross-section shape and changes in pressure value.

4. Laser measurements on glossy surfaces

A disadvantage of using laser for distance measurements fully showed up during the device and algorithm testing. The displacement measurements with laser are both very precise and fast but it can be very difficult to achieve good results on glossy surfaces. Such surfaces are very common on thin foils where surfaces act like mirrors very often (see Fig. 6, Fig. 8, Fig. 10). Reflections of glossy surfaces prevent good evaluation of the point, where laser hits measured surface and therefore prevent to obtain good results. This can be overcome by making the surface matt in mechanical way or by applying matt color on the surface. None of the usual methods can be used for very thin foils as it would result in a significantly affected test results. After testing many ideas how to overcome this problem a use of chalk in spray proved to be a good solution. The chalk in spray is commonly used in defectoscopy for identifying surface cracks. Its application is fast and makes matt, non solid layer which does not affect measured material properties as it is not solid. The chalk layer is very suitable for laser measurement. It is easy to remove it after the test in case the specimen would undergo a further analysis.

5. Results

On the figures Fig. 5 to Fig. 11 tested samples made of different materials are presented. It is easy to see that on the soft materials like aluminum only a small rupture develops.

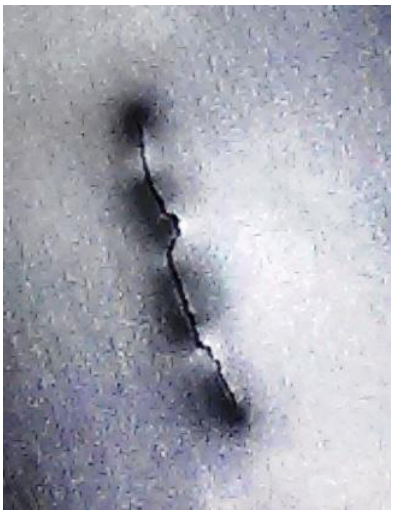

Fig. 5. Al 0.013 mm, crack detail.

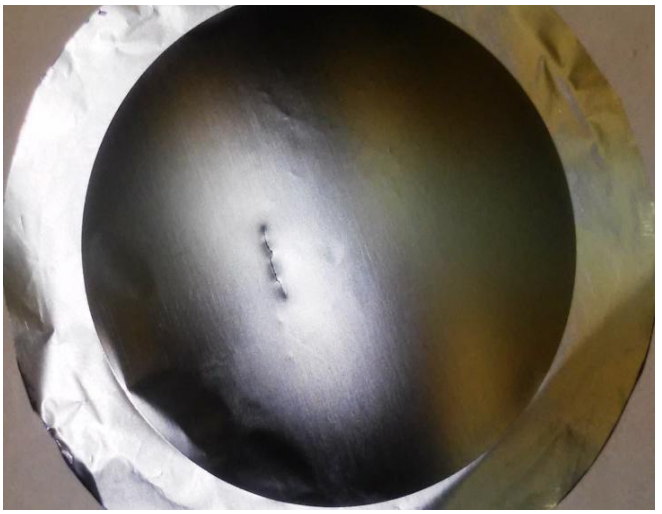

Fig. 6. Al 0.013 mm.

It looks like as a short and relatively straight line. In case a thicker foil is tested, the rupture becomes longer and one end splits to a V-shape – see Fig. 7. Also small damages in material are visible, see Fig. 8. They develop mostly in one direction due to orthotropic material properties based on foil production technology.

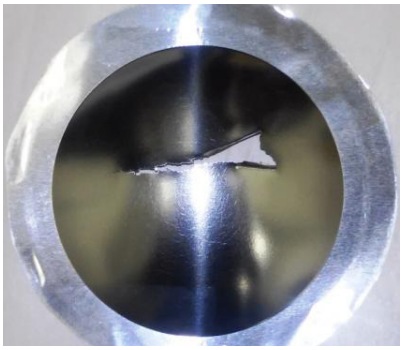

Fig. 7. Al 0.05 mm.

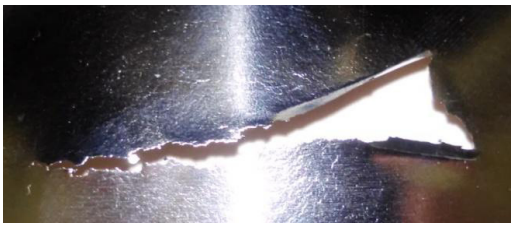

Fig. 8. Al 0.05 mm, crack detail.

Copper samples showed very different rupture shape. It is oval tear as shown on Fig. 9. Detail of the crack is also smoother than in case of aluminum foils, see Fig. 10. Very likely it is caused by different foil production technology. Only the electrolytically produced copper foils were tested and a further study is needed.

Fig. 9. Cu 0.035mm.

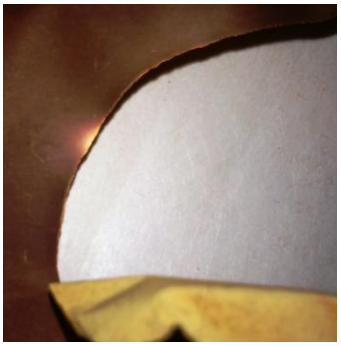

Fig. 10. Cu 0.035mm, crack detail.

The last tested material was FeNi alloy foil 0.05 mm thick. With this material testing device limits were reaches as maximum pressures had risen up to 1 MPa. Foil specimen is torn apart (see Fig. 12); and the pieces can be dangerous for device operator. Therefore the use of safety cover is absolutely necessary. Also specimen after the test is damaged. It basically explodes and hits testing device walls with very high speed. Resulted cracks in the specimens are very rough, see Fig. 11 and again they develop along line parallel to orthotropic material properties as they are results of a production technology.

Further study of measured material properties will be done and a comparison with tensile test method is planned as well. There are problems we expect in preparation the tensile test for such thin foils because the method described in the paper was developed to overcome difficulties the classic tensile test has with measuring very thin foils. The use of a high speed camera for capturing crack propagation and a numerical model could help to find out whether the results are comparable and whether a proper study could be done. No study of testing metal foils with similar thickness was found. Most academic papers that were found focus on thicker specimen materials or use micro samples for testing on the other hand.

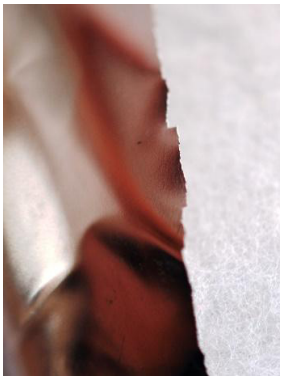

Fig. 12. FeNi alloy 0.05mm, crack detail.

Fig. 11. FeNi alloy 0.05mm.

Maximum possible specimen thickness for the device depends on material properties of the specimen and can be estimated based on formula $\sigma=(P*a^2)/(4*h*t)$, see [6] for more details.

One of the most critical parts of the whole testing process is a pressure measurement because the pressure value is needed at the exact moment the tear occurs. This can be improved by introducing even more precise pressure sensor and by acquiring data with higher rates. The second critical part is thickness measurement. The tested materials are very thin; therefore thickness measurement must be done very precisely. Errors less than 0.001 mm should be reached.

Conclusion

Presented methodology and testing device for determination of very thin material foil proved to be suitable for desired usage. Both the methodology and the testing device were examined and outcomes obtained from several different materials pointed out at different behavior of the material (shape of the crack and the way it changes with foil thickness). Problems with laser measurements on glossy surfaces were solved. The use of chalk to matt the surface can be used in many other applications where it is necessary, and even for a laser measurement of mirrors for instance.

The method is limited by a maximum pressure up to 1MPa as there are reasons of safety as well as specimens are torn in such a high pressures that they are too damaged (wrapped) to undergo further analysis. The limitation does not have technical or theoretical reasons but safety and practical ones.

Acknowledgements

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