CALCULATION OF MEASUREMENT UNCERTAINTY FOR PLASTIC (ABS) MATERIAL IN FLEXURAL TESTING

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Abstract: In order to determine mechanical properties of materials several tests can be applied by using their tensile strength, lower yield stress, proof stress, impact strength, Brinell, Rockwell and surface hardness, elongation after fracture properties. Among these tests, three point flexural testing method has some advantages such as for easy preparation (production) of samples and no gripping problems comparing to tension test. Flexural tests results should be known very well. The measurement uncertainty of flexural tests should be calculated adding the all-influencing parameters during tests. In this study, the measurement uncertainty of the flexural test of ABS (Acrylonitrile Butadiene Styrene) material was determined, which is widely used as industrial plastic material in many applications.

Keywords: Uncertainty of flexural testing, three point bending test, ABS (Acrylonitrile Butadiene Styrene) material

1. INTRODUCTION

In prior to improve their product quality and become more powerful in today's competitive industrial market, significant amount of companies are making mechanical tests on the material of products for development of their properties, . Knowing mechanical properties accurately will help the producer choosing better material to meet better quality for products. This will prevented a possible damage in use and will also reduce the costs.
The flexural test is based on the application of bending force of the materials. As in many other flexural test methods, 3 point bending test method also has the same principle; material is loaded to find the relationship between load and elongation of materials. Three point bending test can be called shortly flexural test measures the force required to bend a beam under 3 point loading conditions.
Uncertainty and accuracy of measurement results have a vital importance for selection of material which meets the requests []. As a result of investigations is that the length between dies the most effective parameter. In this study the effect of different between the pins to the uncertainty was investigated. As result of the research project, conclusions can be drawn about the correlation of measurement uncertainty between different specimen lengths with the overall goal to achieve lower costs and higher quality in measurement [2].

2. MATERIAL AND METHOD

The flexural test method is using widely for the determination of mechanical properties of materials especially subjecting to bending force. Three point bending test has also a advantage as a flexural test that sample geometries are easy to produce and there are no gripping problems as can occur in tensile tests [3]. In addition to these, the results can be easily calculated and the test is easy to apply.

In this experimental study sample materials were Acrylonitrile Butadiene Styrene (ABS). ABS is the most common of industrial plastics and they are generally produced by injection mouldings. Injection molded products cannot be straight in cross section, thickness at the centre of the samples measured as the smallest value of the thickness [4] The difference between the smallest h and the maximum h values were changed between 0.1 ~ 0.06 mm.
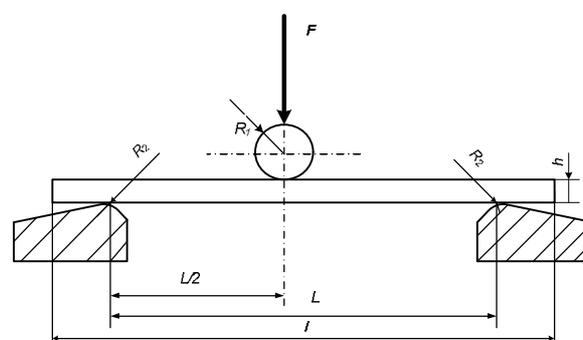

Figure 1: Test set-up according to ISO 178 [4]

Figure 2: Measurement of test sample dimensions by calliper

Figure 3: Measurement of test sample during Flexure testing

Samples	Nominal thickness, h	Width b	R1	R2	L	l
ABS-1	2.82	10	5,02	5,08	62	110
ABS-2	3,69	25	5,01	2,12	47	75

Table 2. Sample Dimensions

The thicknesses of the samples were measured from ten different random points place along the length. The thinner specimens had a length of 75 mm and a width of 25 mm. The distance between the supports, L was calculated as 48 mm, 62 mm. The crosshead speed was selected as 1 mm/min from ISO 178 [5]. Twenty different specimens were tested under same conditions to reduce uncontrolled uncertainty sources effect like inhomogeneous internal structure of molded material.

3. UNCERTAINTY ANALYSIS

In the calculation step repetitive measurements were performed. In order to determine combined uncertainty of test results of material firstly the calibration uncertainties of the testing machine used to measurement of tensile force and caliper was used for measurement of dimensions of tested specimens were taken into account. Then, the standard deviation of the uncertainty of a tensile strength measurement is calculated in the 20 test results. Combined standard uncertainty sum of the squares of the uncertainty estimates multiplied by the squares of their corresponding sensitivity coefficients is used to determine combined standard uncertainty u_c according to the standard.

$$u_c = \sqrt{\sum c_i^2 u_i^2}$$

u_i : uncertainty contributors

c_i : sensitivity coefficients

The sensitivity coefficient c_i of the input quantity x_i was given by which expresses mathematically how much f changes was given an infinitesimal change in x_i [6,7].

$$c_i = \frac{\partial f}{\partial c_i} \tag{1}$$

The data taken from experiments were used in order to get uncertainty. Firstly bending modulus was calculated according to formula for 3 point bending test according to Fig.1 :

$$E_{b3} = \frac{l_1^3 (F_2 - F_2)}{4bt^3 (a_2 - a_1)} \tag{2}$$

$$\sigma_f = \frac{3Fl}{8bh^2} \tag{3}$$

l:the lenght between outer dies,mm

b: width of the specimen,mm

t: thickness of the speciment,mm

F_2-F1: difference of load-deflection curve, N

a_1-a_2: deflection at the center of load lenght

$$\sigma_f = \frac{1.5 \cdot F \cdot L}{b \cdot h^2} \qquad (4)$$

In equation (4), the flexural stress (σ_f) was calculated using applied force (F), length between two support point (L) and sample dimensions (b and h).

Partial derivates of equation (2) and equation (4) were taken according to each parameters given in formulas, sensitivity coefficients c_F, c_l, c_b, c_h, c_t, c_a, c_F, c_L, c_b and c_h were calculated easily. The measurement uncertainties of (U_{Eb3}) and ($U\sigma_f$) was calculated as given equation (5) and equation (6).

$$u_{E_{b3}} = \sqrt{c_F^2 u_F^2 + c_l^2 u_l^2 + c_b^2 u_b^2 + c_h^2 u_h^2 + c_t^2 u_t^2 + c_a^2 u_a^2} \qquad (5)$$

$$u_{\sigma_f} = \sqrt{c_F^2 u_F^2 + c_L^2 u_L^2 + c_b^2 u_b^2 + c_h^2 u_h^2} \qquad (6)$$

c_F : Sensitivity coefficient for applied force measurement
c_A : Sensitivity coefficient for cross-section measurement of test bar
u_F : Measurement uncertainty of applied force taken directly from calibration certificate of material testing machine
u_A : Measurement uncertainty of cross-section of the test bar

Measurement uncertainties u_F, u_l, u_b, u_h, u_t, u_a, u_F, u_L, u_b and u_h was calculated using directly measured test results.

In some measurment, statistical method can also be used for obtained test results. The test data covers the influencing parameters. The standard deviation of test data gives the standard uncertainty of testing (u_{test}) as a combined uncertainty of the above error sources (7):

$$u_{test} = \frac{s_{test}}{\sqrt{n_{test}}} \qquad (7)$$

S_{test} : standard deviation of the test results of five test bars for tensile strength,
n_{test} : number of test results for tested bars

$$s_{test} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X}_{test})^2}{n_{test} - 1}} \qquad (8)$$

X_i : value of the flexural strength measurement
$\overline{X}_{test}$: Average of the flexural strength measurement

With these values combined measurement uncertainty was computed by using flexural strength ($u_{\sigma f}$) and test uncertainty (u_{test}). The calculation of measurement uncertainty for flexural testing as shown in below;

$$U_{combined} = \sqrt{u_{\sigma_f}^2 + u_{test}^2} \qquad (9)$$

There are many uncertainty sources like;

- Definition of the characteristics,
- Measuring procedure. The method of gripping the test piece and axiality of the application of the force, deflection errors (Figure 4),
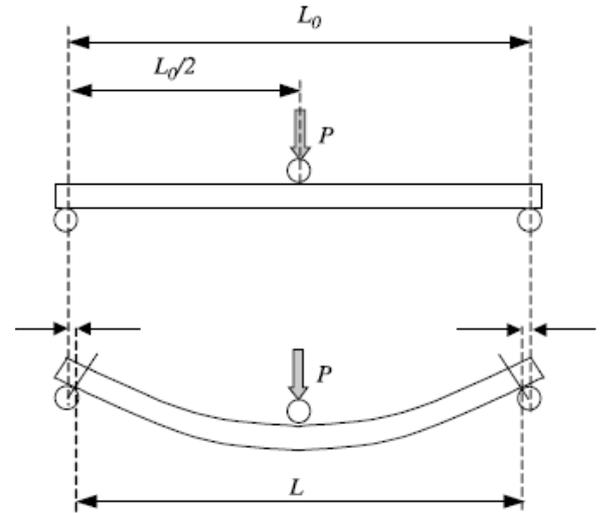

Figure 4: Effect of deflection to the computed lenght

	C_F, [$1/mm^2$]	C_A, [N^2/mm^4]	C_{ac}, [mm]	u_σ [N/mm^2]	u_F, [N]	u_A, [mm^2]	u_{Ac} [mm^2]	u_{test} [N/mm^2]	U_{exp} [N/mm^2]
ABS-1	0,00004	-0,32	34,1	2, 24	47,5	20,3	0,021	1,87	2,72
ABS-2	0,000031	-0,30	34,1	2,10	35,2	35,4	0,021	1,41	2,53

Table 3. Calculations of sensitivity coefficients and uncertainties for the samples

- Physical constants,
- Software and calculations of the tensile properties,
- Metrologist,
- Measurement environment like test temperature and loading rates in successive stages of tests,
- Software and calculations,
- Measuring object and reference element. The material in homogeneity that exists even within a single processed batch obtained from a single melt of material. The testing machine characteristics.

Including all of the uncertainty components as seen in Figure 2 means a really strength measurement output. At the same time, including these all components mean more tasks and heavier numerical computation at the formulation step. To make this computation easier expanded uncertainty is used. Estimated expanded uncertainty (U_{exp}) was calculated as;
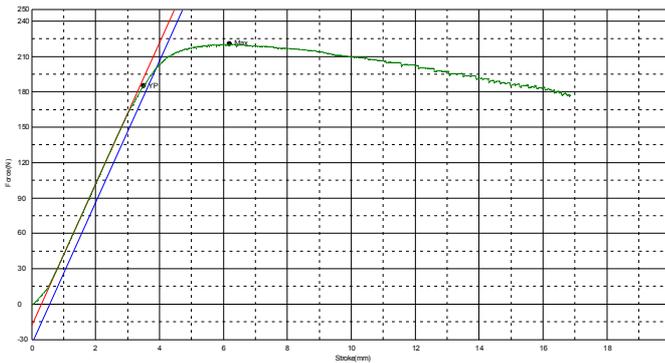
$$U_{exp} = k \times U_{combined} \qquad (10)$$

Figure 5: Strain-Stress curves for ABS-2 obtained from experiment

Experiments were made for two different geometries to investigate the effects of length to the uncertainty. A small difference was noticed for these different samples. Shimadzu AG-IC Floor Type tensile test equipment with 50 kN capacity was used in mechanical properties laboratory. For the testing specimen geometries1kN capacity load cell was used. Deflections of points were recorded by two cameras. To provide a reference length for the cameras a calibration bar was used.
Some values were directly taken from machine programme. (Figure 5). U_F is directly taken from calibration certificate of material testing machine and $U_{c-cert.}$ was also taken from the calibration certificate of the calliper.
The average thickness of the shorter samples (ABS-1) was 2,82 mm, the average width is 10 mm, the average maximum force is 3052,27 N and the average tensile strength is 103,2564 N/mm2. The tensile strength and uncertainty in the result of tensile test are shown 103,2564 N/mm^2 ± 2.72 N/mm^2 (Table 3).
The average thickness of the longer samples was 3,69 mm, the average width is 25 mm, the average maximum force is 2651,81 N and the average tensile strength is 179,609

N/mm^2. The tensile strength and uncertainty in the result of tensile test are shown 179,609 N/mm^2 ± 2.32 N/mm^2 (Table 3).

4. CONCLUSION

An analysis of the uncertainty sources incorporated during measurements of the flexure strength of the ABS material has been performed. Although not all sources of uncertainty have been investigated in detail, calculable sources such as dimensions of tested bars, cross-section, uncertainty of calipers and applied forces and so on are added into measurement uncertainty of flexure strength results. Examples illustrate the importance of uncertainty sources relevant to the variability of the parameters measured from a series of tests bars in same group of ABS material. According to the prior studies [8] this study assumes that the error terms don't depend on the material properties or load span used. Thickness and length of the specimen were determined to be the most effective uncertainty sources.
The relationship between the measurement uncertainty and uncertainty components for different lengths were identified, which would help either reduce the measurement cost or improve the measurement productivity. These results also will provide the user and producers to select better material for safety and life of their product.

5. REFERENCES

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