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# EVALUATION OF TENSILE TEST FOR SPECIFIC POLYMER

V. Machalla[1], K. Frydrýšek[2], V. Mostýn[3], J. Suder[4]

**Abstract:** Presented article deals with realization and evaluation of the tensile tests. The tensile tests are used for determining of material properties of thin polymers (plastic) films that are used for manufacturing windows. These plastic films are placed between plates glasses and reflects thermal energy back (insulation). From measurements, Young′s moduli, fracture limits, force-displacement relationships and engineering and logarithmic stress-strain relationships were evaluated. The results were approximated by two straight lines and by suitable chosen functions. The obtained data can be used for analytical, numerical and stochastic modelling of problems connected with manufacturing.

**Keywords:** thin insulation film; tensile test; plastics; evaluation and approximation.

## 1 Introduction

Energy savings is very discussing topic in nowadays. The aim is to reduce energy losses (i.e. insulation) for mechanical devices and for buildings. For example, if a windows seal is bad, there is a large loss of thermal energy through window. One possible way of insulating windows is to place the suitable insulating film, between the insulation glasses; see Fig. 1. This special insulation film made of plastics reflects thermal energy back to interior.

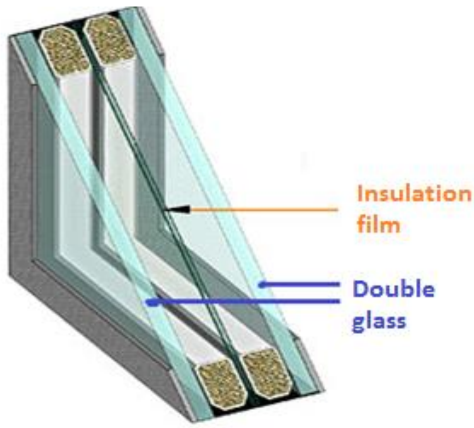


*Fig. 1: Section window with an insulation film*

This article deals with the realization and evaluation of the tensile tests of thin plastic films. The aim of this test finds out material parameters of the insulation film [1], [2]. The acquired results will be applied in analytical/numerical/stochastic modelling connected with quality/design improving of double and triple-glazed windows.

However, there is a lack of literature focused on tensile tests of thin films, for example see [3]. Hence, the presented results are unique.

[1] Vojtěch Machalla; Department of Applied Mechanics, Faculty of Mechanical Engineering, VŠB-TU-Ostrava, 17. Listopadu 15/2127, 708 33 Ostrava-Poruba, Czech Republic; vojtech.machalla@vsb.cz
[2] Karel Frydrýšek; Department of Applied Mechanics, Faculty of Mechanical Engineering, VŠB-TU-Ostrava, 17. Listopadu 15/2127, 708 33 Ostrava-Poruba, Czech Republic; karel.frydrysek@vsb.cz
[3] Vladimír Mostýn; Department of Robotics, Faculty of Mechanical Engineering, VŠB-TU-Ostrava, 17. Listopadu 15/2127, 708 33 Ostrava-Poruba, Czech Republic; vladimir.mostyn@vsb.cz
[4] Jiří Suder; Department of Robotics, Faculty of Mechanical Engineering, VŠB-TU-Ostrava, 17. Listopadu 15/2127, 708 33 Ostrava-Poruba, Czech Republic; jiri.suder@vsb.cz

## 2 Measurement description

For the measurements, see Fig. 2, ten specimens (tapes of thin plastic film) with length 150 mm and width b = 25 mm were created; see Fig 3. The thickness of specimens t = 0.005 mm was measured several times before each test with a micrometer.

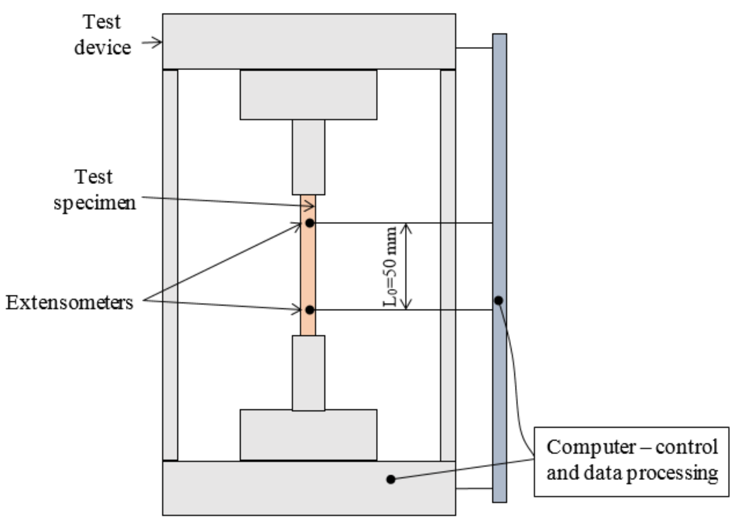


*Fig. 2: Measurement scheme*

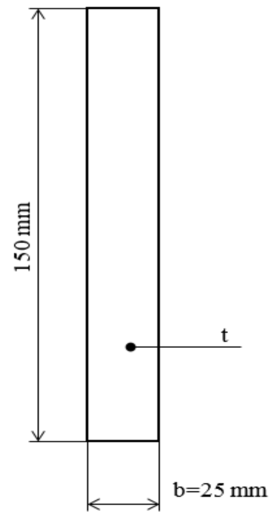


*Fig. 3: Dimensions of specimen*

The specimens were clamped into testing device (TestometricM500/50CT), see Fig. 4, and subjected to tensile tests in the research laboratory (Department of Applied Mechanics, Faculty of Mechanical Engineering, VSB – Technical University of Ostrava). Then, the specimens are loading with tensile forces $F$ [N] until the material breaks (fracture limit); see Fig. 4. During the test, the force $F$ acting on the specimen and longitudinal extension (displacement $\Delta_L$ [mm]) of specimen were recorded. Initial distances between two extensometers (i.e. original length) $L_0$ = 50 mm. Other parameters were calculated such as [4], [5].

Engineering Stress $$\sigma_{eng} = \frac{F}{b\,t}\ \text{[MPa]}, \tag{1}$$

Engineering Strain $$\varepsilon_{eng} = \frac{\Delta_L}{L_0} = \frac{L-L_0}{L_0}\ \text{[-]} \quad \text{or} \quad \frac{L-L_0}{L_0}\cdot 100\ [\%], \tag{2}$$

True Stress $$\sigma_{true} = (1+\varepsilon_{eng})\sigma_{eng}\ \text{[MPa]}, \tag{3}$$

True Strain $$\varepsilon_{true} = \ln(1+\varepsilon_{eng})\ \text{[-]}, \tag{4}$$

where $L$ [mm] is a length specimen after deformation.

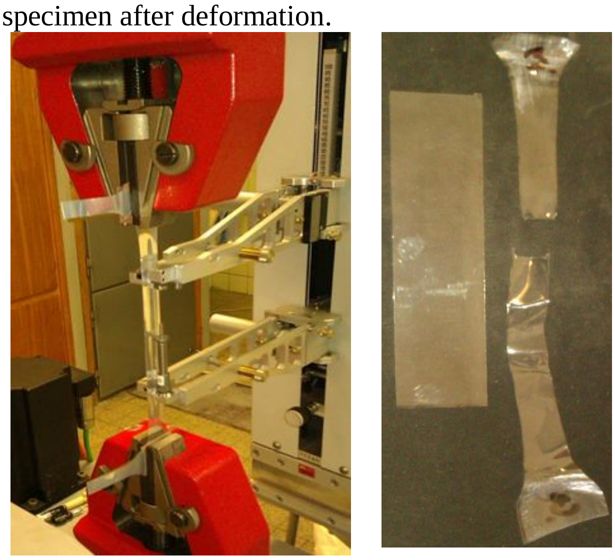

*Fig. 4: Measurements and fracture of specimen*

## 3 Results

Dependencies of $\sigma_{eng}$ on $\varepsilon_{eng}$ in graph, from some selected measurements are shown in Fig. 5, Approximately, the dependencies were similar to the value 600 MPa (i.e. kind of Yield Limit).

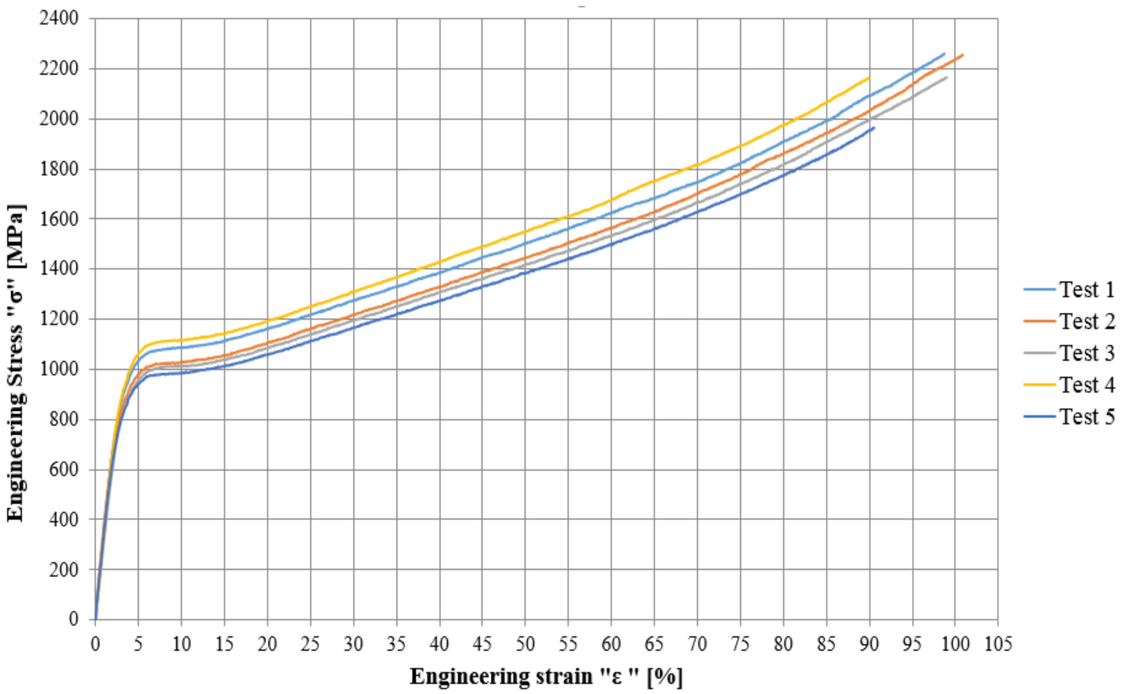


*Fig. 5: Graph (5 chosen tests) – Dependencies of Engineering Stress on Engineering Strain*

As an illustration of evaluation, the specimen 2 was selected; see Fig. 6. Hence, the maximum Engineering Stress (i.e. fracture limit) $\sigma_{eng\,max} = 2256$ MPa and the specimen was pulled up by maximum Engineering Strain $\varepsilon_{eng\,max}$ =101%. The results of all chosen tests are presented in Tab. 1.

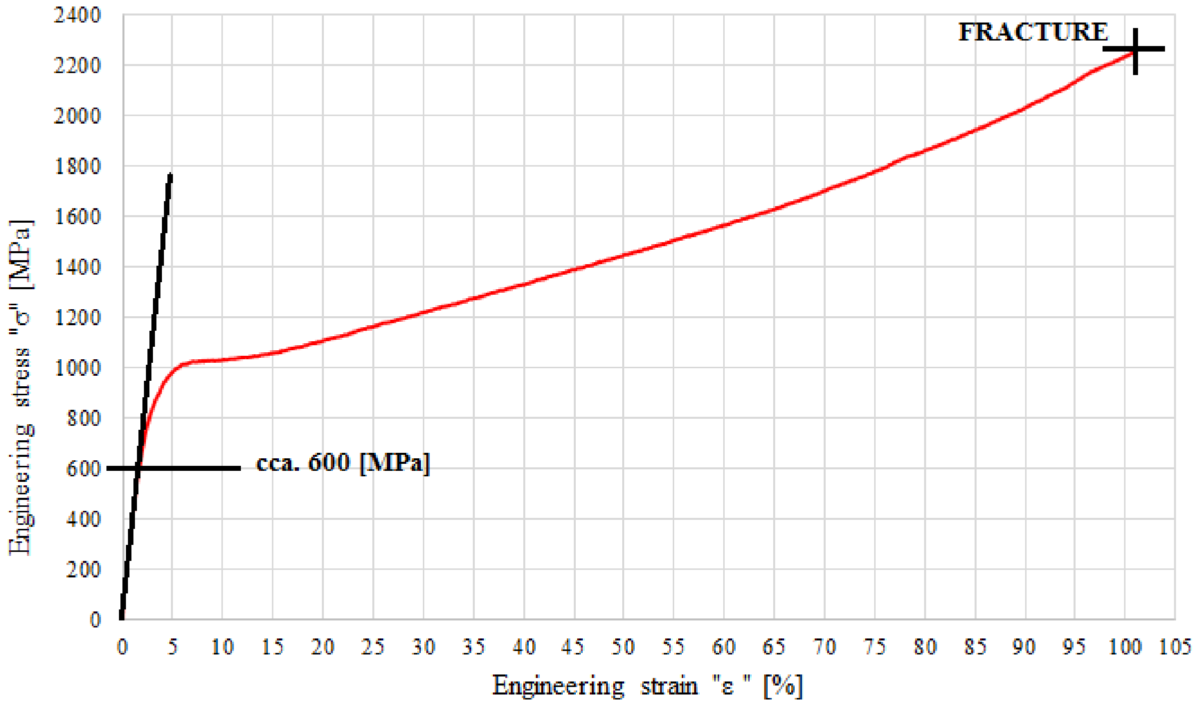


*Fig. 6: Graph - Dependence of Engineering Stress on Engineering Strain (test 2)*

| Linear area | | | | Non-linear area – Fracture character | | | |
|---|---|---|---|---|---|---|---|
| ***Number of test:*** | **$E$ [MPa]:** | **Validity to $\sigma_{eng}$ [MPa]:** | **$\varepsilon_{eng}$ [-] at 600 [MPa]** | **$\sigma_{eng\ max}$ [MPa]** | **$\sigma_{true\ max}$ [MPa]** | **$\varepsilon_{eng\ max}$ [-]** | **$\varepsilon_{true\ max}$ [-]** |
| ***1.*** | 38319 | 600 | 0.0157 | 2259 | 4490 | 0.988 | 0.687 |
| ***2.*** | 40000 | 600 | 0.0150 | 2256 | 4531 | 1.01 | 0.697 |
| ***3.*** | 33179 | 600 | 0.0181 | 2165 | 4310 | 0.99 | 0.688 |
| ***4.*** | 38035 | 600 | 0.0158 | 2164 | 4112 | 0.899 | 0.64 |
| ***5.*** | 37042 | 600 | 0.0162 | 1963 | 3740 | 0.905 | 0.645 |
| ***Mean values*** | 37315 | 600 | 0.0162 | 2161 | 4236 | 0.958 | 0.671 |
| ***Stochastic definitions*** | $37315^{+2685}_{-4136}$ | 600 | $0.0162^{+0.0019}_{-0.0012}$ | $2161^{+98}_{-198}$ | $4236^{+295}_{-496}$ | $0.958^{+0.052}_{-0.059}$ | $0.671^{+0.026}_{-0.031}$ |

*Table 1: Evaluation of chosen measurements*

Young's moduli $E$ [MPa] can be determined from the first parts graphs in Fig. 5 and 6, from the area where the dependencies of stresses on strains are predominantly linear; see Fig. 7. These dependencies can be approximated by a straight line with beginning at point [0, 0] in the interval (0, 600) MPa. Therefore, $E = tan(\alpha)$.

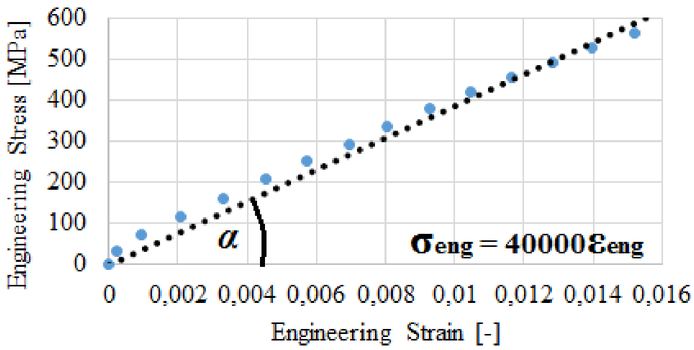


*Fig. 7: Graph – Dependence of Stress on Strain – linearized region (test 2)*

Practical applications of results are connected with the need for function approximations. Two approximations are presented.

**Approximations 1.** – bilinear models approximated by two straight lines (i.e. $\sigma_{eng} = 40000\varepsilon_{eng}$ & $\sigma_{eng} = 1311\varepsilon_{eng} + 830$) which have their intersection at point [2.145313×10$^{-2}$, 858.125 MPa]; see Fig 8.

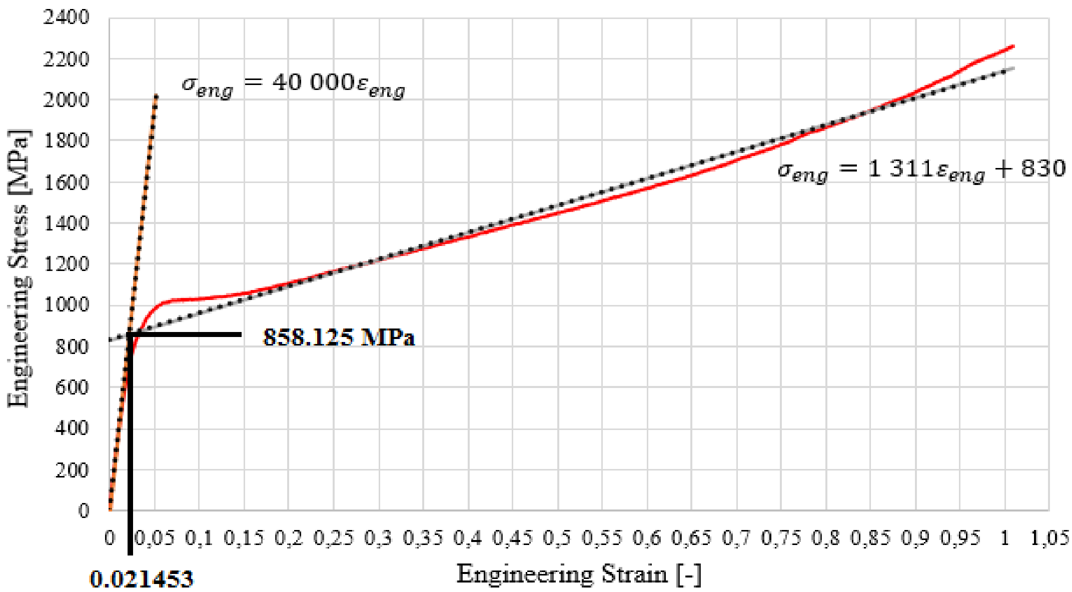


*Fig. 8: Graph Dependence of Engineering Stress on Engineering Strain, approximation by two straight lines (test 2)*

**Approximations 2.** – Approximations by combination of linear and nonlinear functions

$$\sigma_{eng} = A\varepsilon_{eng} + Barctan(C\varepsilon_{eng}) + D(e^{E\varepsilon_{eng}} - 1), \quad (5)$$

see Fig. 9 and Tab. 2, where A, B, D [MPa], C, E [-] are regression coefficients acquired by Matlab sw. Approximations 2 give more accuracy results but nonlinear dependencies.

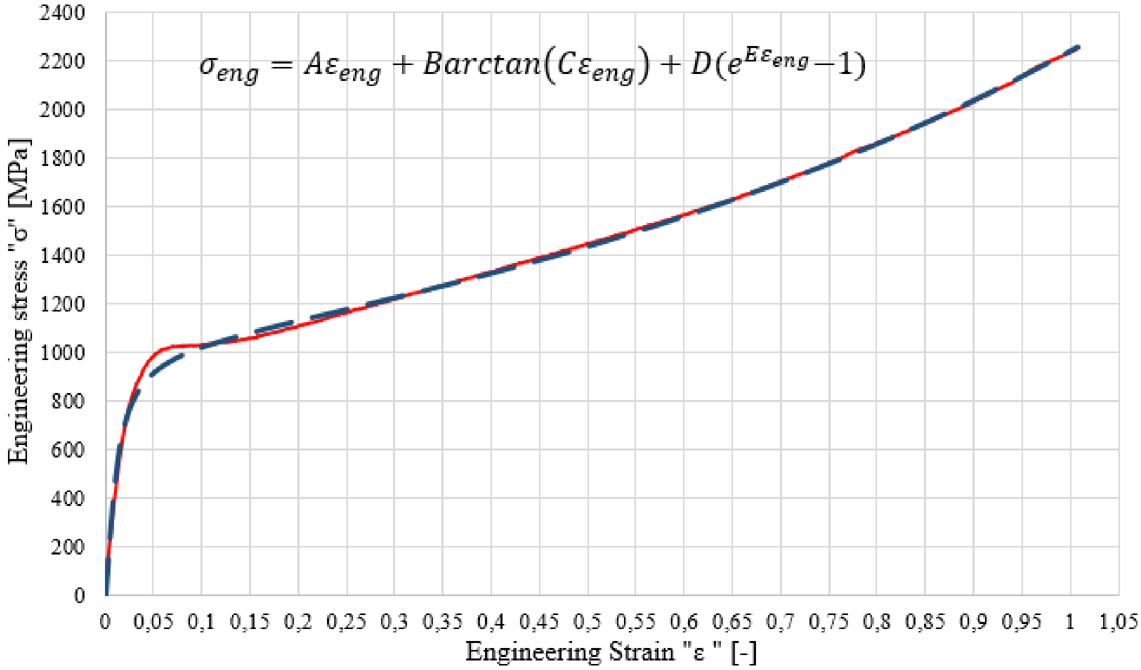


*Fig. 9: Graph Dependence of Engineering Stress on Engineering Strain, approximation by combination of function (test 2)*

| ***Number of Test*** | ***Coefficients of approximation*** | | | | |
|---|---|---|---|---|---|
| | **A [MPa]** | **B [MPa]** | **C [-]** | **D [MPa]** | **E [-]** |
| ***1.*** | -941.3 | 709.9 | 78.79 | 1912 | 0.7452 |
| ***2.*** | -821.9 | 664.4 | 87.4 | 1745 | 0.77 |
| ***3.*** | -1118 | 662.5 | 75.16 | 2298 | 0.6879 |
| ***4.*** | -1357 | 728.5 | 78.05 | 2988 | 0.6235 |
| ***5.*** | -1014 | 637.9 | 86.26 | 2220 | 0.6774 |
| ***Mean values*** | -1050 | 680 | 81 | 2232 | 0.701 |
| ***Min*** | -1357 | 637.9 | 75.16 | 1745 | 0.6235 |
| ***Max*** | -821.9 | 728.5 | 87.4 | 2988 | 0.77 |
| ***Stochastic definitions*** | $-1050^{+228.1}_{-307}$ | $680^{+48.5}_{-42.1}$ | $81^{+6.4}_{-5.84}$ | $2232^{+756}_{-487}$ | $0.701^{+0.069}_{-0.0775}$ |

*Table 2: Evaluate data from approximation*

Equation (5) (i.e. function $\sigma_{eng} = f(\varepsilon_{eng})$) can be easily converted into a function $\sigma_{true} = g(\varepsilon_{true})$ via equations (2-4). Thus

$$\left.\begin{aligned} \sigma_{true} &= (\varepsilon_{eng} + 1)\sigma_{eng} = \sigma_{eng} e^{\varepsilon_{true}} = \\ &= e^{\varepsilon_{true}}\left(A(e^{\varepsilon_{true}} - 1) + Barctan[C(e^{\varepsilon_{true}} - 1)] + D\left[e^{E(e^{\varepsilon_{true}} - 1)} - 1\right]\right) \end{aligned}\right\} \quad (6)$$

Equation (5) and (6) can be expressed in stochastic way, see last 2 rows of Tab. 1 and Fig.10.

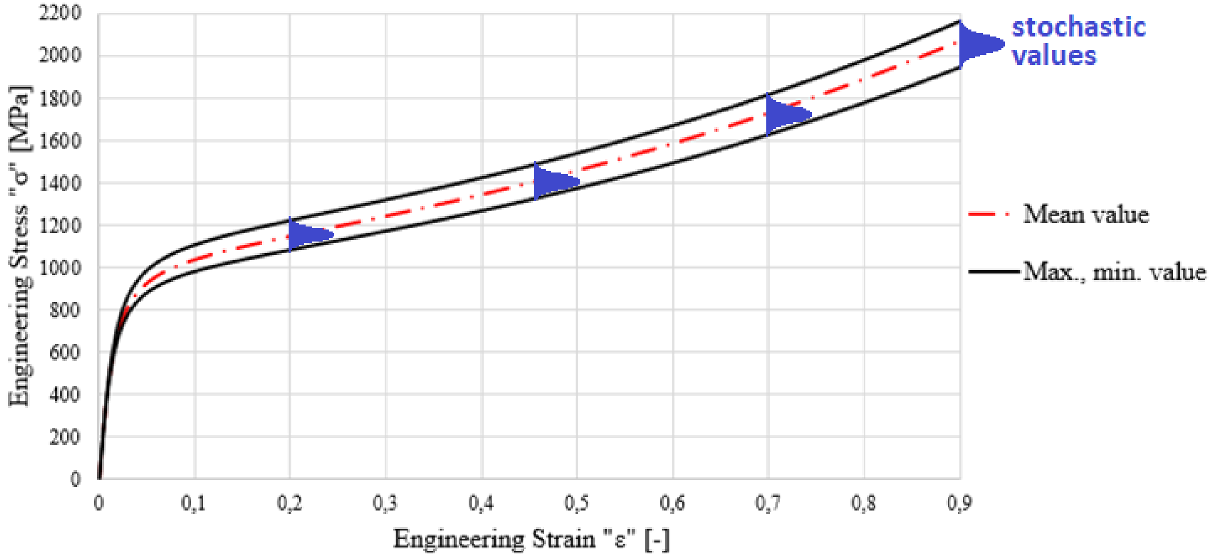


*Fig. 10: Graph Dependence of Engineering Stress on Engineering Strain, approximation by combination of function with max., min and mean value*

## 4 Conclusion

Tensile tests of insulation plastic thin film were performed and evaluated (i.e. Young′s moduli, fracture limits engineering stresses and strains, true stresses and strains etc.). Young′s modulus of the insulation film is $37315^{+2685}_{-4136}$ MPa applicable to proportional/yield limit 600 MPa.

Two approximations were proposed (i.e. at first, bilinear regression and at second, regression via combination of chosen functions). The second approximation is better but nonlinear. Hence, stochastic material dependence was proposed for future analytical and numerical modelling and designing based on small and large deformation approaches.

There is a lack of information about material equations for thin plastic films. Therefore, the presented results are unique.

Practical aspects are application of the data in designing of windows with some insulation films (i.e. cooperation with industry; to reduce energy losses). Therefore, all results (namely information about material) could not be published in this paper due to confidentiality reasons.

### Acknowledgement

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