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Research of electron irradiation effects upon plexiglas strain during bending test

N A Voronova¹, A I Kupchishin²³, M N Niyazov⁴, B G Taipova⁴, A T Abdukhairova⁵
¹Senior researcher, Abay Kazakh National Pedagogical University, Almaty, Kazakhstan
²Head of laboratory, Abay Kazakh National Pedagogical University
⁴Researcher, Abay Kazakh National Pedagogical University
⁵Senior researcher, Abay Kazakh National Pedagogical University
E-mail: ankupchishin@mail.ru

Abstract. Experiments on dependence of strain (ε) vs stress (σ) during bending tests of non-irradiated and irradiated (by electrons) samples of ribbed plexiglas have been carried out. Obtained curves are described satisfactory within linear model, ε grows linearly as soon as σ increases.

1. Introduction

It is commonly known that various materials have got different mechanical and technological properties, which predetermine goods quality and their machinability. The properties are diagnosed by proper tests for strain, compression, flexing, hardness, etc. Bending test for example is carried out to check jump-joints [1 –3]. The test checks plasticity of sample and its joints and material ability to take up tailor-made flexing. It can be bending static and bending impact test (dynamic) [4]. Flat symmetrical bending test is a test when all external forces applied to the material act in one plane of symmetrization [5]. Herewith bending axis of the sample is in the same plane with external forces. Bending tests are carried out for plastic and fragile materials. Strain character of fragile and plastic samples differs. If plastic material is tested for bending, it will fail to break and determine bending strength due to large deformations. Other mechanical characteristics as for example proportionality limit, yield stress can be easily determined by tests [6 – 9]. Tests are critically important for strength and stiffness checking of fragile materials because usually they are destructed due to permanent strain [10, 11]. Maximum load and maximum deflection prior destruction point are calculated. Ultimate strength is calculated at maximum load. Bending tests can be carried out by two methods: to apply single force to center of a sample between supports or to apply two forces symmetrically between supports [12, 13]. Test results depend mostly on material type, load conditions, forms and sizes of samples. Modification of properties and structure of polymer and composite materials by irradiation with various particles including electrons are of special interest [14, 15]. Herewith various defects are formed (vacancies, interstitial atoms, various clusters, broken links, new compounds, etc. [16, 17]. The work is devoted to research of stress and electron irradiation effects upon strain of ribbed plexiglas during flat bending and applying single force. So far, such research has never been carried out before.
2. Experimental procedure

We developed and prepared an experimental facility to research dependence of strain $\varepsilon$ vs stress $\sigma$. It consists of the following parts: strength sensor, indicator of clock type, tool for sample fixing, connecting wires and interface to see the data. It is installed at lower part of RU-50 rupture facility, which is a base for experiments. The facility also has a unit with loading nozzle and supports. Ribbed plexiglas of two shapes (pyramids and strips) has been taken as a test material. Thickness ($h$) of plexiglas samples is 3 mm in a convex part of ribbed material, width ($b$) is 5 mm and length is 40 mm. The smallest thickness in a concave part of ribbed material for pyramids is 1 mm, for strips is 2 mm. Research has been done at temperature 23 °C and relative humidity 50 %. Electron irradiation of samples has been carried out at linear accelerator ELA-6 with energy 2 MeV in air environment. Vacuum in the accelerator system has been maintained at level of $10^{-6}$ mm of mercury column. Samples for irradiation have been placed at distance of 40 cm from accelerator exit window. Beam current is 0.3 $\mu$A/cm$^2$, irradiation dose is $-100$ kGy. Experiments have been carried out at a testing facility, which provided uniform speed 10 mm/min, relative movement of loading nozzle and supports as well as metered load with error $\pm1$ % and bending with error $\pm2$. An arithmetical average of all measurements considered to be an experimental result; During bending test destruction due to breaking, compressing and bending stress occurs. If various types of destruction happen during samples loading, it means that obtained values of bending stress are statically heterogeneous. In this case all results shall be analyzed and ongoing processes shall be researched.

3. Results and discussion

As the result of experimental research the dependences of strain $\varepsilon$ vs stress $\sigma$ for non-irradiated and irradiated samples of ribbed plexiglas have been obtained where flat bending with regard and without regard of horizontal component occur (Figures 1a, b). Figures show experimental results, lines show calculations. Physical and mechanical properties have been reviewed in coordinates $\varepsilon$, $\sigma$. Dependence $\sigma$ vs $\varepsilon$ is physically meaningless because $\sigma$ is an argument and $\varepsilon$ is a function, which shows in [18–21].

Dependence of $\varepsilon$ vs $\sigma$ based on experimental data have calculated as follows: bending stress is calculated using the equation [22]:

$$\sigma = \frac{M}{W},$$  \hspace{1cm} (1)

where $M$ – bending moment; $W$ – sample section modulus. Herewith bending moment ($M$) is found from expression:

$$M = \frac{FL}{4},$$  \hspace{1cm} (2)

where $F$ – load; $L$ – distance between supports. Sample section modulus ($W$) is calculated using:

$$W = \frac{bh^3}{6}. $$  \hspace{1cm} (3)

Equations (1) – (3) result in:

$$\sigma = \frac{3FL}{2bh^2}. $$  \hspace{1cm} (4)

Bending stress ($\sigma_i$) with regard of horizontal component of bending moment during bending $z$ is calculated using the equation
\[
\sigma_f = \frac{3FL}{2bh^2} \left(1 + \frac{4z^2}{L^2}\right),
\]

where \( z \) – bending in the center of sample between supports.

Extension elongation is calculated as bending – sample operating length ratio \( (\varepsilon = z/L) \). Expression (5) results in:

\[
\varepsilon_f = \frac{1}{2} \sqrt{\frac{2\sigma_f bh^2}{3FL} - 1}.
\]

Results show that extension elongation of ribbed plexiglas samples (non-irradiated and irradiated) grows linearly when stress is applied incrementally. Herewith strip ribbed plexiglas has higher strength and extension elongation than pyramid ribbed plexiglas. Plexiglas irradiated with 100 kGy samples lose plasticity by 20 and 40 % comparing to non-irradiated materials respectively. Material strength does not change after irradiation. Visual analysis shows that (transparence) decreases, samples are colored to brown. Counting of horizontal component does not affect significantly upon extension elongation. Experimental data are described linearly with good accuracy:

\[
\varepsilon = \alpha \sigma,
\]

where \( \alpha \) – slope. \( \alpha = 0.14 \) for non-irradiated strip ribbed plexiglas, \( \alpha = 0.2 \) for pyramid ribbed plexiglas. \( \alpha = 0.1 \) and 0.13 for irradiated materials respectively.

![Figure 1](image-url)  
**Figure 1.** Dependence of strain vs stress for non-irradiated (1, 2) and irradiated by electrons (3, 4) strip (a) and pyramid (b) ribbed plexiglas samples during flat bending with regard of horizontal component (squares and stars) and without regard of horizontal component (dots and triangles) respectively.

### 4. Conclusions

1. Experiments in dependence of strain vs stress during flat bending tests of non-irradiated and irradiated ribbed plexiglas samples have been carried out. It is found out that irradiation leads to visible change of stress-strain behavior of material resulted in plasticity decrease. Extension elongation of irradiated strip plexiglas decreases by 20 % and of irradiated pyramid plexiglas by 40 %. Material strength does not change after irradiation.  
The obtained curves of dependence \( \varepsilon \) vs \( \sigma \) are described satisfactory within linear model.

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