Materials Physics and Mechanics. 2022;49(1): 153-159
Conference materials
http://dx.doi.org/10.18149/MPM.4912022_11

Influence of temperature and load on mechanical properties of unirradiated and irradiated plexiglass

A.I. Kupchishin[1,2]✉, B.G. Taipova[1], M.N. Niyazov[1], D.C. Utepova[1], V.M. Lisitsyn[3], B.A. Tronin[1]

[1]Abai Kazakh National Pedagogical University, Dostyk, 13, Almaty, Kazakhstan

[2]Al-Farabi Kazakh National University, 71 Al-Farabi Ave., Almaty, Kazakhstan

[3]Tomsk National Research Polytechnical University, Tomsk, Russia

✉ ankupchishin@mail.ru

Abstract. Investigations of the mechanical, properties of unirradiated and irradiated plexiglass of various types have been carried out when tested for the flat straight bend. Exposure to temperature and radiation significantly affects the properties of the material. As a result of the research, the dependences of deformation on stress, length, and width of the specimens were obtained. The experimental curves are satisfactorily described by a linear model.

Keywords: bend, deformation, mechanical properties, plexiglass, radiation, stress

Acknowledgments. *This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP08855701).*

Citation: Kupchishin AI, Taipova BG, Niyazov MN, Utepova DC, Lisitsyn VM, Tronin BA. Influence of temperature and load on mechanical properties of unirradiated and irradiated plexiglass. *Materials Physics and Mechanics*. 2022;49(1): 153-159. DOI: 10.18149/MPM.4912022_11.

1. Introduction

Thermoplastic materials are now widely used by both the academic research community and industrial sectors due to their good physical, mechanical, thermal, and optical characteristics [1-3]. Polymer materials have several advantages over traditional products. For example, they have excellent dielectric properties, ease of use, lightness, and simplicity of manufacturing methods. Among other things, polymers have improved thermal and mechanical properties. The automotive industry has recently been focusing on polymer-based composites instead of conventional steel products. They have high rigidity and a large pressure rate than metals, the strength of which additionally depends also on the geometry and shape [4,5]. Polyethylene, polyimide, polyethylene terephthalate, polytetrafluoroethylene, polymethylmetacrylate (plexiglass), epoxy resin, etc. are used in laboratory research as well-known homogeneous model materials for experiments. In particular, they are employed in systems whose mechanical properties are critical to aircraft designers and engineers [6]. These materials also find application as candidate ones, where loading with a high deformation rate is likely in many structures [7]. The mechanical properties of composites can change at high strain rates and after irradiation with high–energy particles [8-10]. Such materials will also vary their properties with an increase in load. This makes it obligatory to take into account changes in the design and operation of structures operating in harsh conditions [11,12]. There are very few studies on the effects of temperature, irradiation, and mechanical load on polymer properties when tested in tension, compression, shear, bending and etc. This work is devoted to the comprehensive study of various types of unirradiated and irradiated plexiglass when tested for a flat straight bend.

2. Research methods

Two types of smooth and corrugated plexiglass (pyramids and stripes) were taken as the materials under study. Specimens of smooth plexiglass had thickness (h) of 1 mm and a width (b) of 5 and 10 mm and different working lengths (L) – 20, 30, 40, 50, 60, and 70 mm. For corrugated specimens, plexiglass thickness was 3 mm in the corrugations of the convex portion, the width – 5 mm, and length – 40 mm. The experiment was carried out at temperature of 20, 25, and 50°C. The relative humidity of the room was 50 %. Electron irradiation of corrugated plexiglass samples was carried out on an ELA-6 linear accelerator with an energy of 2 MeV in air. The radiation dose was 100 kGy. The thickness of the specimens was measured along the entire perimeter with a micrometer.

The experiments were carried out on a testing machine providing a uniform velocity v = 0.4 mm/s of the relative movement of the loading tip and supports, allowing measurements of the load with an error of ± 1%, and the deflection with an error of ± 2%. The impact took place at a constant rate. The specimens were loaded with one concentrated force applied in the middle of the specimen between the supports [13,14].

BI (bursting installation)-50 tensile testing machine was used for bending tests under various load conditions. It is the setup consisting of a loading device, a control panel, and rods connecting the loading device with a control panel. On the bottom of the device were a force sensor, a temperature chamber, and various supports. The test was carried out at an AC frequency of 9 Hz. Changing the frequency helps to control the speed of the loading crosshead of the installation.

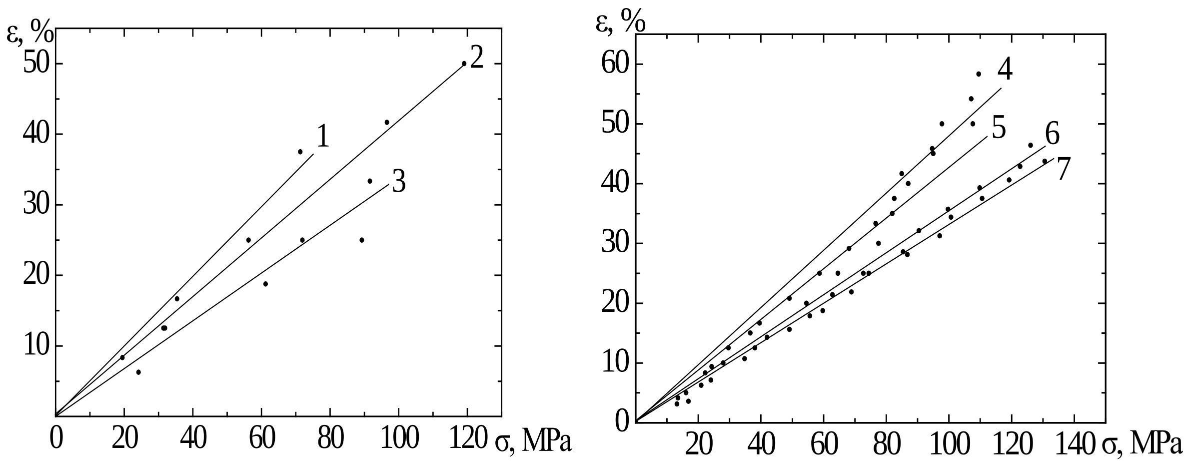
3. Results and discussion

The dependences of deformation on stress, obtained for testing samples of smooth plexiglass of various sizes under flat straight bend, are shown in Figures 1 and 2. The figured points present the experimental results, and the lines display the calculation data. The physical and mechanical properties are displayed as functions ε (σ), because the dependence of σ on ε is incorrect, since σ is an argument, and ε is a function.

Figures 1 and 2 show that the dependence of deformation on stress is adequately described by a linear model for all sizes. Moreover, the maximum deformation of the specimens, depending on the sample length and the stress, varies in the range of 35 - 60%.

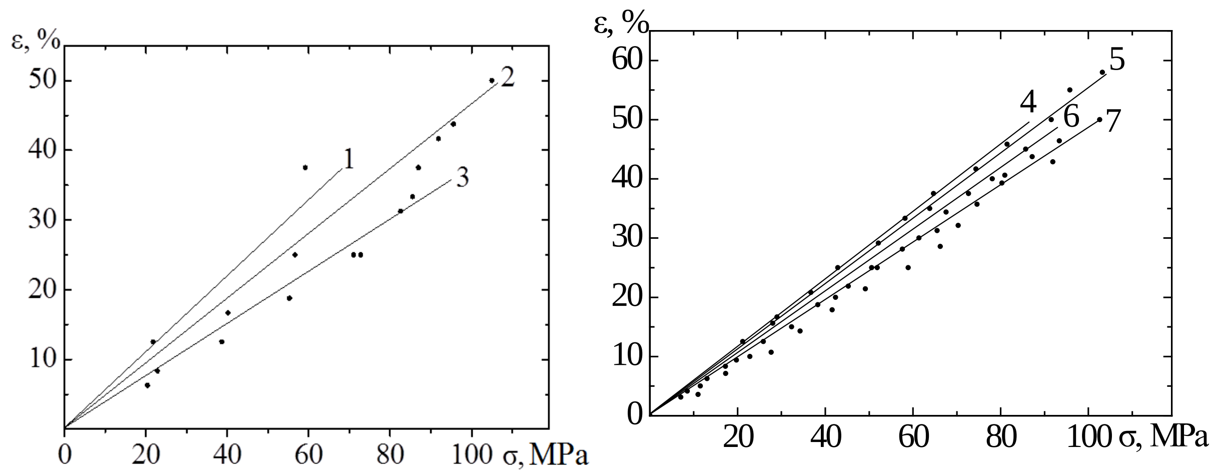
Figure 3 demonstrates the dependence of deformation on stress for unirradiated and irradiated specimens of corrugated plexiglass, in which plane bending occurs with and without taking into account the horizontal component (Fig. 3 a and b).

According to the results, when the stress increases, the relative elongation of the corrugated plexiglass specimens (both unirradiated and irradiated) grows by virtue of linear law. Furthermore, the striped-corrugated material has greater strength and a relative elongation than the pyramid-corrugated material. It can be seen that smooth plexiglass by mechanical properties is much better than corrugated (Figs. 1-4). Moreover, its strength properties are more than 5 times higher than those of corrugated plexiglass. After exposure to a dose of 100 kGy, the corrugated plexiglass specimens lose their plasticity by 20 and 40 % respectively compared to the unirradiated materials. The changes in the strength of materials after irradiation are insignificant. Visual analysis displays that the light transmittance (transparency) declines, while the specimens are painted brown.



1 – 20; 2 – 30; 3 – 40; 4 – 50; 5 – 60; 6 – 70; 7 – 80 mm
figured points – experiment; lines – calculation

Fig. 1. Dependence of strain on stress for unirradiated specimens of smooth plexiglass 5 mm wide and different lengths at 20°C (room) temperature



1 – 20; 2 – 30; 3 – 40; 4 – 50; 5 – 60; 6 – 70; 7 – 80 mm
figured points – experiment; lines – calculation

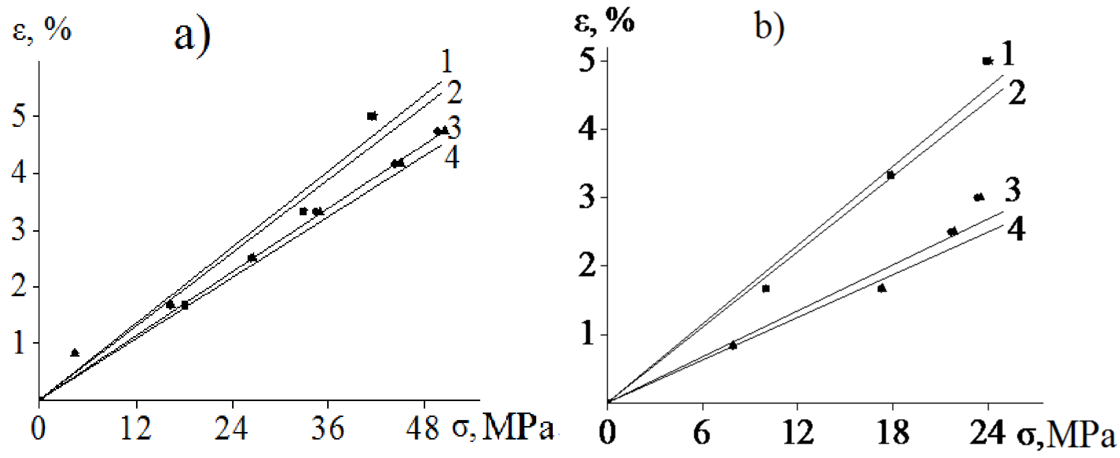
Fig. 2. Dependence of strain on stress for unirradiated specimens of smooth plexiglass 10 mm wide and different lengths at 20°C (room) temperature

The experimental data are described with good precision by a linear model, for both smooth and corrugated plexiglass of two types [15]

$$\varepsilon = k\sigma,$$

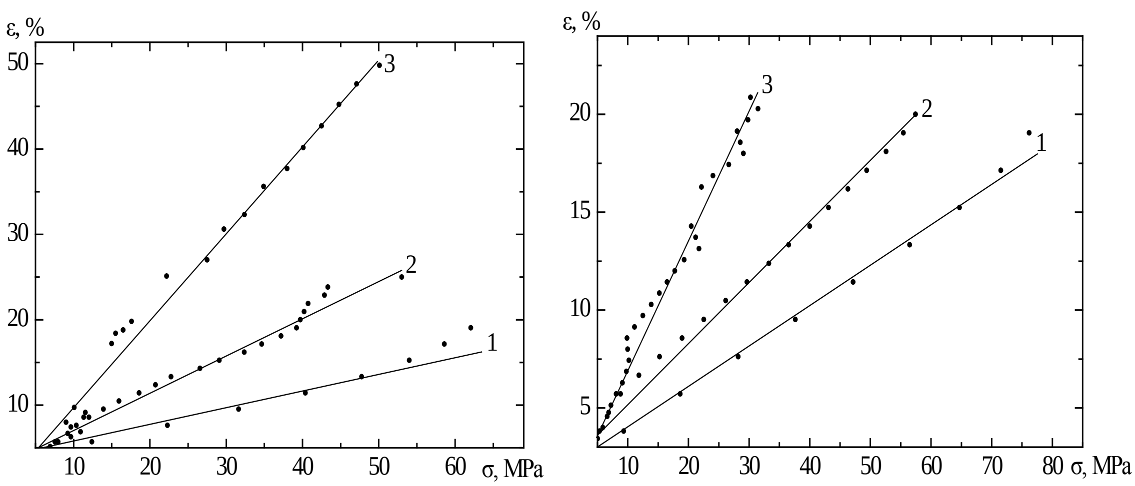
where k is the slope tangent. For unirradiated striped-corrugated glass k=0.14 and for pyramid-corrugated glass 0.2%/MPa. For irradiated materials k=0.1 and 0,13%/MPa, respectively. Figure shows that k ranges in the interval from 0.2 to 1.2%/MPa. In addition, it is the coefficient that is inverse to the modulus of elasticity, that is k=1/E.

Figure 4 illustrates the relationships between strain and stress for the plexiglass (PMMA) specimens 5 and 10 mm wide at a temperature of 25ºC. It can be seen that the curves are consistent with linear model calculations. As the width of the specimens rises, the deformation reduces. Strength characteristics also undergo considerable changes.



figured points – experiment; lines – calculation

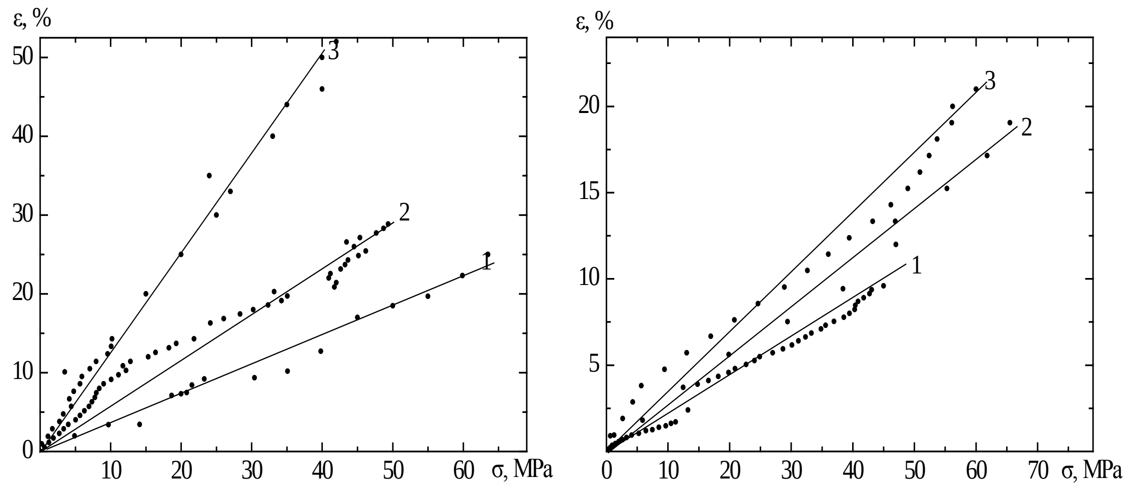
Fig. 3. Dependence of strain on stress for unirradiated (1, 2) and electron irradiated (3, 4) specimens of striped – corrugated (a) and pyramid – corrugated (b) plexiglass, with plane bending, the horizontal component is taken into account (squares and asterisks) and without taking into account (points and triangles)



1 – 20; 2 – 40; 3 – 70 mm

Fig. 4. Dependence of deformation on stress for the plexiglass smooth specimens of 5 mm wide (left) and 10 mm (right) for bending at a temperature of 25ºC

Figure 5 presents the dependence of deformation on stress for the plexiglass smooth specimens 5 and 10 mm wide in a temperature heating chamber. The device maintained a constant temperature of 50°C. With a further increase in temperature, the specimens begin to bend without load, which makes analyzing the material behavior difficult. It can be seen from the figures that a long sample has a greater deflection (regardless of the temperature) than a short one and breaks at a lower value of mechanical stress. With increasing the temperature, in the range of 20-50 degrees, the deformation increases by 20% for all the sizes of the material, and the strength characteristics deteriorate by 10-30%.



1 – 20; 2 – 40; 3 – 70 mm

Fig. 5. Dependence of deformation on stress for the plexiglass smooth specimens of 5 mm wide (left) and 10 mm (right) for bending at a temperature of 50°C

4. Conclusions

1. The experiments on the dependence of deformation on stress during flat straight bending testing of unirradiated and irradiated plexiglass specimens of various types in a temperature chamber have been carried out. It was found that the maximum deformation of specimens of different sizes varies in the range of 50-60%, depending on the stress, length, and width of the material.

2. It has been established that electron irradiation leads to a noticeable change in the deformation-strength characteristics of the material, manifested in a decrease in plasticity. The relative elongation of striped plexiglass after irradiation changes by 20%, and that of pyramidal – by 40%. At the same time, there is practically no change in strength.

3. With an increase in the temperature of the test specimen in the range of 20-50 degrees, an increase in deformation characteristics by 20% is observed for all sizes of the material, and the strength characteristics deteriorate by 10-30%.

4. The obtained curves of the dependence of ε on σ are satisfactorily described within the framework of a linear model.

References

1. Mousavi SS, Aliha MRM, Imani DM. On the use of edge cracked short bend beam specimen for PMMA fracture toughness testing under mixed-mode I/II. *Polymer Testing.* 2020;81: 106199.

2. Guduru RKR,. Shaik SH, Tuniki HP, Domeika A. Development of mono leaf spring with composite material and investigating its mechanical properties. *Materials Today: Proceedings.* 2020;45: 556-561.

3. Blumenthal WR, Cady CM, Lopez MF, Gray GT and Idar DJ. Influence of Temperature and Strain Rate on the Compressive Behavior of PMMA and Polycarbonate Polymers. *AIP Conference Proceedings.* 2002;620(1): 665-668.

4. Reis PNB, Gorbatikh L, Ivens J, Lomov SV. Strain-rate sensitivity and stress relaxation of hybrid self-reinforced polypropylene composites under bending loads. *Composite Structures.* 2019;209: 802-810.

5. Zhou W, Huang J, Huang W, Liu D. Dynamic fracture testing of polymethyl-methacrylate (PMMA) single-edge notched beam. *Polymer Testing.* 2020;91: 106833.

6. Kazemi M. Experimental analysis of sandwich composite beams under three-point bending with an emphasis on the layering effects of foam core. *Structures.* 2021;29: 383-391.

7. Jiang Y, Wu Q, Li Y, Peng Y, Gong J. Mechanical properties of low-temperature gaseous carburizated layer in 316L stainless steel based on nano-indentation and four-point bending tests. *Surface and Coatings Technology*. 2020;387: 125501.
8. Angelides SC, Talbot JP, Overend M. High strain-rate effects from blast loads on laminated glass: An experimental investigation of the post-fracture bending moment capacity based on time–temperature mapping of interlayer yield stress. *Construction and Building Materials*. 2021;273: 121658.
9. Qureshi Y, Tarfaoui M, Lafdi KK, Lafdi K. Development of microscale flexible nylon/Ag strain sensor wire for real-time monitoring and damage detection in composite structures subjected to three-point bend test. *Composites Science and Technology.* 2019;181: 107693.
10. Zhou J, Jiang W, Ao Y, Zeng W, Liu J, Mei J, Huang W. The three-point bending responses of carbon fiber composite sandwich beams with Y-frame cores at high and low temperatures. *Thin – Walled Structures.* 2021;162: 107595
11. Liu H, Liu J, Ding Y, Zhou J, Kong X, Harper LT, Blackman BRK, Falzon BG, Dear JP. Modelling damage in fibre-reinforced thermoplastic composite laminates subjected to three-point-bend loading. *Composite Structures.* 2020;236: 111889.
12. Cerbu C, Botis M. Numerical modeling of the Flax/Glass/Epoxy hybrid composite materials in bending. *Procedia Engineering.* 2017;181: 308-315.
13. Kupchishin AI, Niyazov MN, Voronova NA, Kirdiashkin VI, Abdukhairova AT. The effect of temperature, static load and electron beam irradiation on the deformation of linear polymers. *IOP Conf. Series: Materials Science and Engineering.* 2017;168: 1-4.
14. Kupchishin AI, Niyazov MN, Taipova BG, Khodarina NN, Shahanov KSh. The mechanical properties of the PCB and glass fiber under test on a flat straight bend. In: *Proceedings of the V International Scientific Conference "Contemporary Problems of Condensed Matter Physics, Nanotechnologies and Nanomaterials".* 2018. p.209.
15. Kupchishin AI, Taipova BG, Voronova NA. Study of the influence of filler on the mechanical properties of composites based on polyimide. *Materials Science and Engineering.* 2016;168: 012015.
16. Kupchishin AI, Taipova BG, Kupchishin AA, Kozhamkulov BA. Study on the physical and mechanical properties of composites based on polyimide and polycarbonate. *Mechanics of Composite Materials.* 2015;51(1): 115-118.

THE AUTHORS

Anatoly I. Kupchishin
e-mail: ankupchishin@mail.ru
ORCID: 0000-0002-8872-3734

Buvkhan G. Taipova
e-mail: buv_7@mail.ru
ORCID: 0000-0003-1563-7189

Marat N. Niyazov
e-mail: marat--90@mail.ru
ORCID: -

Daniya C. Utepova
e-mail: utepova_daniya@mail.ru
ORCID: -

Victor M. Lisitsyn
e-mail: lisitsyn@tpu.ru
ORCID: 0000-0002-2075-4796

Boris A. Tronin
e-mail: troninboris@mail.ru
ORCID: -