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Photoelastic Properties of Materials Based on Compositions of Epoxy Resins and Epoxidized Oligoesters

The solution of various problems by means of method of photoelasticity requires having, at one's disposal, model materials of various moduli of elasticity. It also requires the possibility of regulating the mechanical and optical properties. For this purpose, were used epoxy resins, plasticized internally by means of components the presence of which leads to weakening of interaction between macromolecules of the polymer.

Materials of low Young's moduli have been obtained in the form of epoxidized oligoesters based on saturated aliphatic dicarboxylic acids and glycols, containing aliphatic segments and ether groups which cause an increase in elasticity [1]. The first stage resulted in obtaining hydroxyl-terminated oligoesters which were subsequently subjected to a reaction with epichlorohydrin introducing epoxy groups into oligoester molecules. The epoxidized oligoesters thus obtained are active plasticizers of epoxy resins. Compositions of epoxy resins mixed with varying quantities of epoxidized oligoesters produced birefringent materials of various mechanical and optical properties. The compositions of photoelastic materials differ in respect of Young's moduli, glass transition temperature and fringe values, depending upon the chemical composition and proportion of the in-

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gredients. The following materials were obtained: two series of compositions consisting of the epoxy resin Araldit FRL /30% epoxy group/ and of epoxidized oligo(ethylene glycol adipate)/28,5% epoxy group/ or of epoxidized oligo(diethylene glycol adipate)/22,8% epoxy group/. The composition of these materials is to be found in Table 1.

TABLE 1. The Photoelastic Compositions

Material	Per cent composition by weight			Triethylene-tetramine
	Epoxidized oligoester		Araldit FRL	Parts by weight
EP0	epoxidized oligo(ethylene glycol adipate)	100	-	14,1
EP1		80	20	13,3
EP2		60	40	12,5
EP3		40	60	11,6
EP4		20	80	10,8
EP5		-	100	10,0
D0	epoxidized oligo(diethylene glycol adipate)	100	-	11,2
D1		80	20	11,0
D2		60	40	10,7
D3		40	60	10,5
D4		20	80	10,2

The photoelastic compositions were cured with triethylenetetramine at room temperature in the manner used for epoxy resins.

The Effect of Curing Time and the Structure of the Compositions on Mechanical and Photoelastic Properties

Mechanical and photoelastic properties of materials were examined under the conditions of a simple state of stress: uniaxial tension of samples.

The materials, containing epoxidized oligo(ethylene glycol adipate), were tested after varying periods of curing time at room temperature - up to 70 days. Figures 1 and 2 show dependence of Young's modulus E and fringe value K on the epoxidized oligo(ethylene glycol adipate) content in the composition. Initially, a considerable change of properties can be observed. Subsequently, changes are slower but even after 70 days of curing at room temperature the properties of resins are not fully established. In order to obtain more stable properties of samples and to accelerate the curing process, samples were exposed to room temperature for 24 hours and up then the temperature was raised to 55°C for 3 days.

The dependences of the value E and K of compositions containing epoxidized oligo(diethylene glycol adipate) on epoxidized oligoester content are presented in Fig. 3.

Depending on the kind and quantity of components of respective compositions were obtained materials from rubberlike materials to materials with Young's moduli of the order of $10^9 \frac{N}{m^2}$. The shapes of curves of E and K as referred to component content are similar. Only for large content of epoxidized oligoesters the curves are different. Young's modulus changes monotonically and fringe value attains minimum which indicates maximum optical sensitivity at this point. This is caused by an increased optical sensitivity of epoxy resins. The plots prov[illegible]at for small and large content of epoxidized oligoesters in a composition the changes of E and K are insignificant. However, considerable changes can be observed in case of compositions containing 50-70% of epoxidized oligoesters based on ethylene glycol and 40-60% of epoxidized oligoesters based on diethylene glycol.

Glass Transition Temperature of Examined Materials

Mechanical properties of polymers in a broad temperature range are most fully characterized by the thermomechanical curve, which presents the effect of temperature on strain under constant load. Thermomechanical curves for compositions containing epoxidized oligo(ethylene glycol adipate) are presented in Fig. 4 and those for compositions containing epoxidized oligo(diethylene glycol adipate) - in Fig. 5. The glass transition temperature T_g of the examined materials corresponds in diagrams to the point of lowest temperature where the curve inflection starts.

Figure 6 shows the effect of epoxidized oligoester content in a composition on glass transition temperature. Materials with epoxidized oligo(ethylene glycol adipate)content have higher T_g than materials with the same content of epoxidized oligo(diethylene glycol adipate). Glass transition temperature of materials containing 60% epoxidized oligo(ethylene glycol adipate) and 56% epoxidized oligo(diethylene glycol adipate) is 25°C. Consequently, the materials with similar chemical composition will be characterized by large mechanical and optical creep because at glass transition temperature strong relaxation processes appear.

Testing of Strain and Birefringence of Materials as a Function of Loading Time

The mechanical and optical creep tests were carried out under gradual loading of specimens. Loading increments were equal. Time intervals of constant load were also equal /15 minutes each/. At this stage of testing, after applying a load, the mechanical and optical creep is the greatest.

Photoelastic materials EP0 and D0 do not mechanical and optical creep /see Fig. 7/. Materials EP1 and D1 exhibit very

small creep /see Fig. 8/. Strain and optical effects practically do not change in constant loading time. When calibrating materials EP3 /see Fig. 9/ and EP4 /see Fig.10/, strain and fringe order increase with time under constant load. They approach an equilibrium value at a diminishing rate. Material EP2, which contains 60% epoxidized oligoester / Fig.11/, exhibits largest creep. It demonstrates non-linear viscoelastic behaviour.

Conclusions

An analysis of the results of the examination of properties of materials leads to the following conclusions:

1. The properties of photoelastic compositions containing synthetized epoxidized oligoesters are dependent on the kind and content of the respective ingredients of the composition:

a/ modulus of elasticity E and fringe value K vary considerably depending on the content of epoxidized oligoester in the composition,

b/ materials based on epoxidized oligo(diethylene glycol adipate) have lower Young's moduli than materials based on epoxidized oligo(ethylene glycol adipate).

2. Materials containing 80% to 100% of epoxidized oligoesters e.g. EPO,DO,EP1 are all in high-elastic state. These are their characteristics:

a/ low Young's moduli $3{,}4 \cdot 10^6 \frac{N}{m^2}$ /DO/ and $4{,}8 \cdot 10^6 \frac{N}{m^2}$ /EPO/ and fringe value $0{,}4 \cdot 10^3 \div 0{,}9 \cdot 10^3 \frac{N}{m. \text{ fringe order}}$,

b/ they exhibit no mechanical and optical creep or very insignificant creep only,

c/ Young's moduli and fringe values are practically constant for the examined range of time and stress.

3. Materials with small content of epoxidized oligoesters of the range 20% e.g. EP4, D4 are in glassy state. these are their characteristics:

a/ Young's moduli of the range $4 \cdot 10^9 \frac{N}{m^2}$ and fringe value of the range $1{,}4 \cdot 10^4 \frac{N}{m \cdot \text{fringe order}}$,

b/ Mechanical and optical creep is small. The values of the creep rate decrease monotonically with an increase of stress time,

c/ the decrease in the values of Young's moduli and of fringe values under constant loading and with the increasing stresses has been observed.

4. The materials containing 50-70% of epoxidized oligo(ethylene glycol adipate) and 40-60% of epoxidized oligo(diethylene glycol adipate) are between glassy and high-elastic states. The properties of the above mentioned materials are as follows:

a/ Young's moduli of these materials range from $8 \cdot 10^7$ to $2 \cdot 10^9 \frac{N}{m^2}$ and fringe values range from $1{,}5 \cdot 10^3$ to $1 \cdot 10^4 \frac{N}{m \cdot \text{fringe order}}$,

b/ they exhibit large mechanical and optical creep,

c/ moduli of elasticity and fringe values diminish with time of constant stress or with the increase of stresses.

Materials obtained in the course of this research, due to a considerable variety of properties, enable the solution of many important problems by means of the photoelastic method. Materials of a proper mechanical and optical characteristic should be selected for specific purposes.

The materials of both low /$10^6 \frac{N}{m^2}$/ and high /$10^9 \frac{N}{m^2}$/ Young's moduli characterized by small creep can be applied to solve problems of elasticity e.g. in testing of various structural elements or in model investigations of heavy objects.

Materials of Young's moduli of the range of $5 \cdot 10^7 \div 2 \cdot 10^9 \frac{N}{m^2}$ possess mechanical and optical properties which are, to a large extent, time-dependent. They can be used in experimental model research of rock masses in projects in which time effects should be taken into account.

References:

1. Wolna M., Słowikowska I., " Otrzymywanie epoksydowanych oligoestrodioli na podstawie kwasu adypinowego i glikoli", 22 ,1,/1977/.

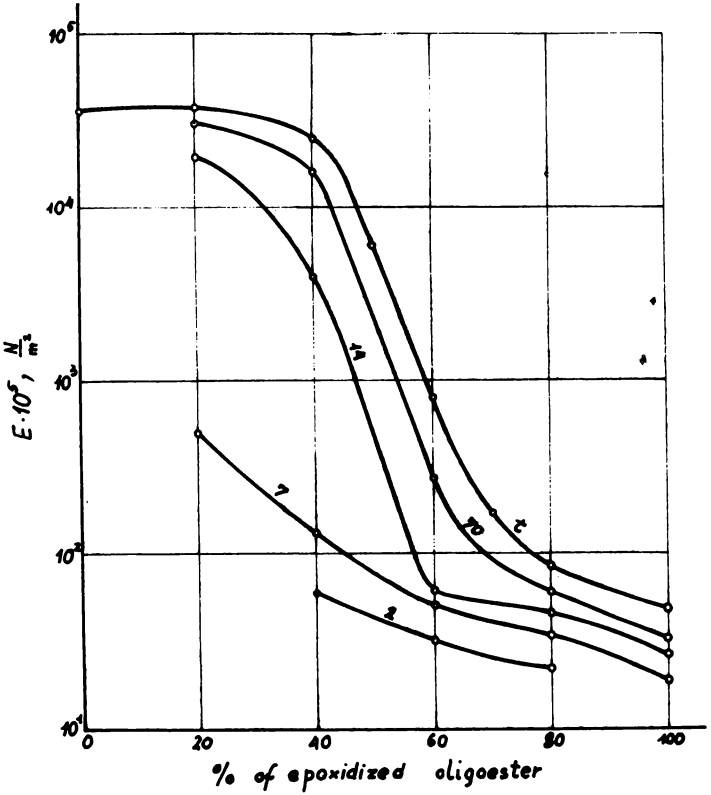

Fig.1. Young's modulus E as a function of epoxidized oligo ethylene glycol adipate content in the composition after varying periods of curing time at room temperature /2,7,14,70 days/.
t - curing for 3 days in 55°C.

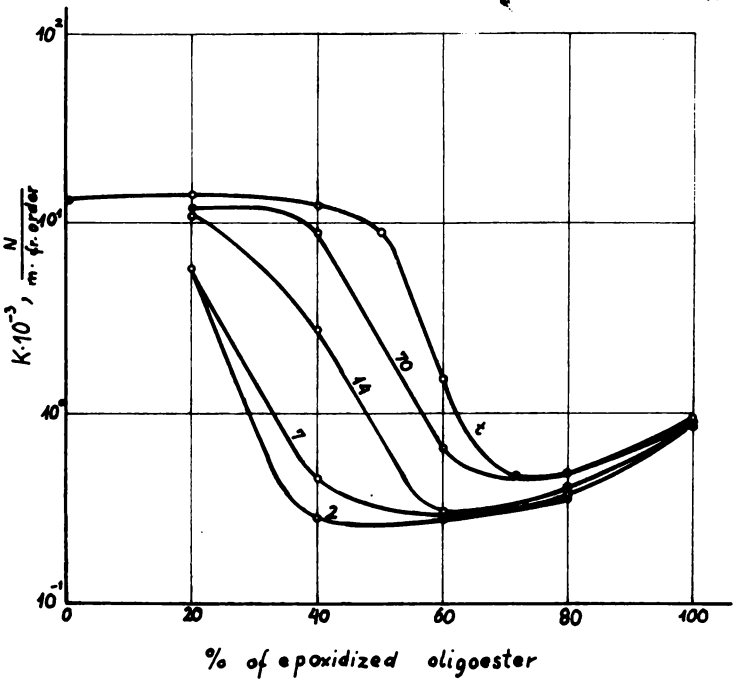

Fig.2. Fringe value K as a function of epoxidized oligo ethylene glycol adipate content in the composition after varying periods of curing time at room temperature.

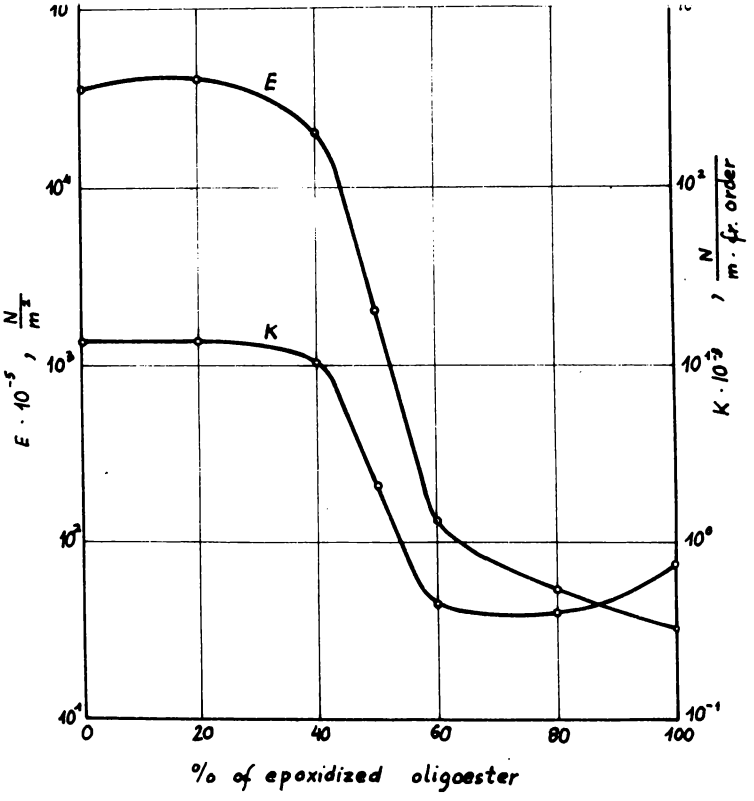

Fig.3. The dependences of the value E and K on epoxidized oligo diethylene glycol adipate content.

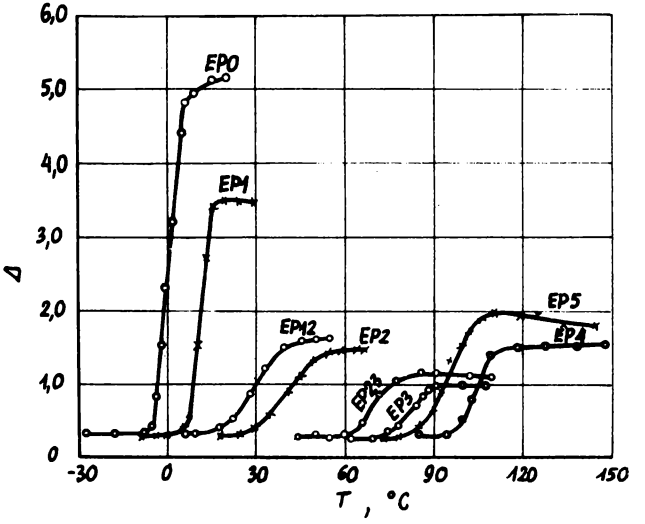

Fig.4. Thermomechanical curves for compositions containing epoxidized oligo ethylene glycol adipate.

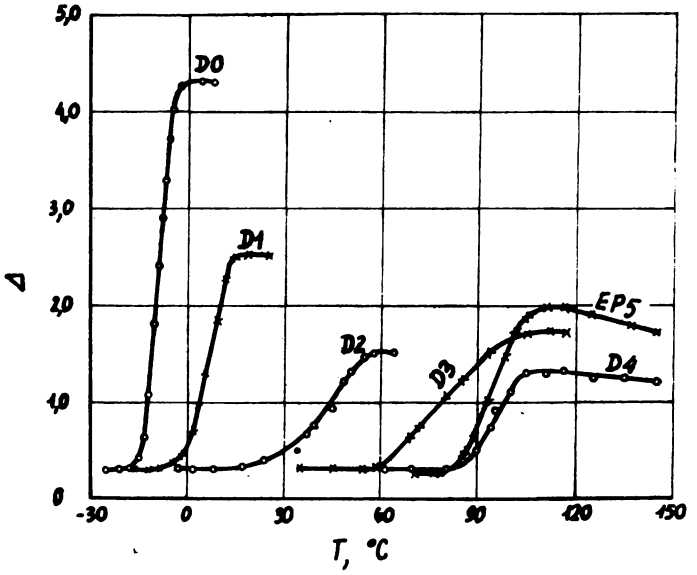

Fig:5. Thermomechanical curves for compositions containing epoxidized oligo diethylene glycol adipate .

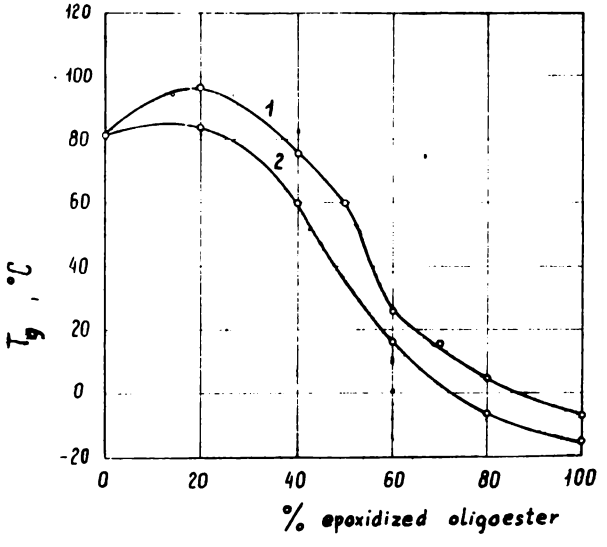

Fig.6. Effect of epoxidized oligoester content in a composition on glass transition temperature.

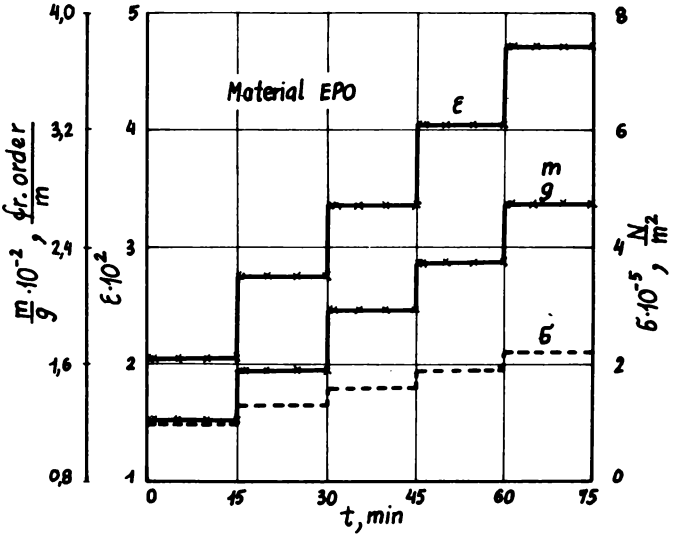

Fig.7. Mechanical and optical creep at 25°C for material EPO.

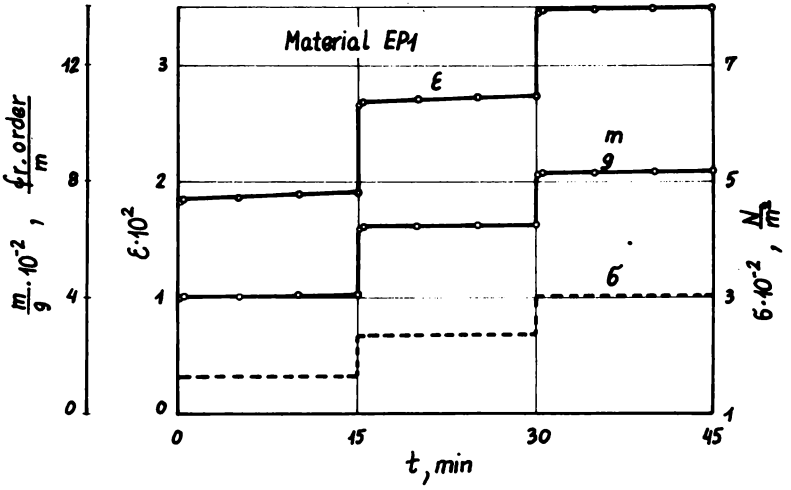

Fig.8. Mechanical and optical creep at 25°C for material EP1.

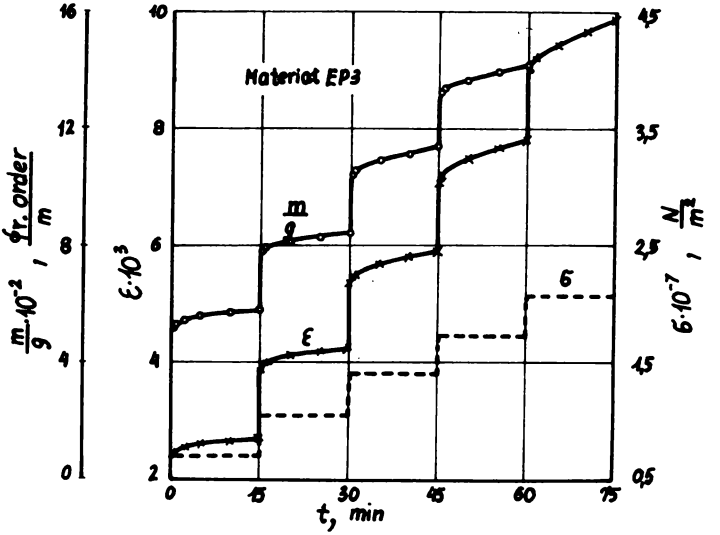

Fig.9. Mechanical and optical creep at 25°C for material EP3.

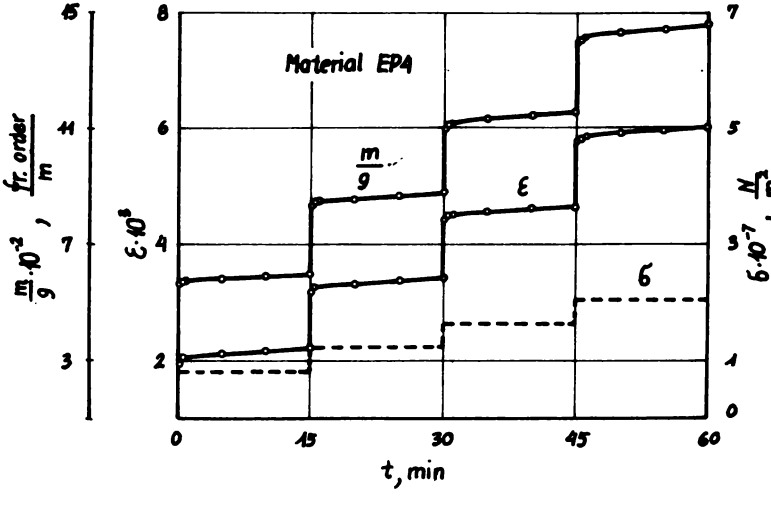

Fig.10. Mechanical and optical creep at 25°C for material EP4.

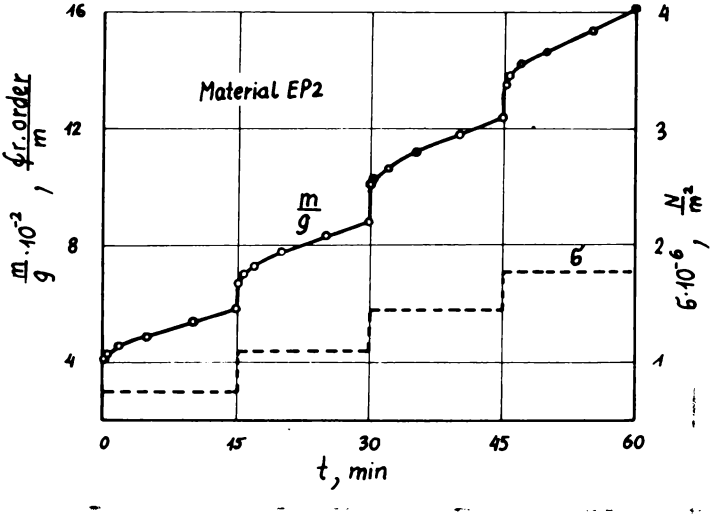

Fig.11. Optical creep at 25°C for material EP2.