SOME PHYSICAL PROPERTIES OF RESIN CONCRETES

R. BARES (1) & J. NAVRATIL (2)

In their reports at previous conferences the authors have presented some results of their resin concrete research. On the whole, the questions of technological character have been dealt with and the greatest attention has been paid to furane resin concretes. In the present contribution some other physical properties will be dealt with, mainly those of furane resin concretes, so as they have been found out during the last years at the Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences.

An important factor for the structural exploitation of resin concretes is represented by their elasticity as a sum of stress-strain relations under various conditions – the compositions, the influences of environment – during a short-term mechanical loading. The resin concrete is composed of solid particles with a relatively high modulus of elasticity and of a binder, including an amount of closed or open voids containing free water and gases. The elasticity of resin concretes is thus a result of not only mechanical deformation of individual components, but also of the effective interaction between them, in which the physical and the physico-chemical phenomena play a remarkable role, namely with regard to the environment. The modulus of elasticity of the only binder is of a minor order than the one of the aggregate. It leads to a considerable redistribution of stresses in the structure when mechanically loaded and to the generation of important grip states – the triaxial state of stress – of the binder. Herewith becomes more important also the change of the binder modulus of elasticity with the value of stress, influencing considerably the deformation of the whole system : on the beginning, at minor stresses, the bonding agents get deformed in an elastic manner, later on the plastic deformation joints ; the complicated state of stress is beginning thereby to play a still greater role, resulting from the binder grip, increasing its modulus. Gradually, with a further loading, the mechanical destruction of the binder or of its contact zone with the aggregate takes place, and the modulus is decreasing down to a total material fracture.

The fundamental property of the solids elastic behaviour is the time stability of their stress-strain relation under constant external conditions. Some materials

---

(1) PH.D., Sen. Research Officer, Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences, Prague, Czechoslovakia.

(2) Research Officer, Building Research Institute of the Czech Technical University in Prague, Czechoslovakia.

are showing their stability in limited time intervals only. There is a common rule that the material deformation under the constant external stress, changes with the time as well as the stress in bodies with a constant deformation. Such processes happen to play an extra role with plastics. In systems, where some phase is formed by the plastic, e.g. in resin concretes, the manifestation of such processes is stronger and, therefore, less negligeable than with traditional materials. For the structural exploitation of resin concretes, i.e. for the elements exposed for a long time to either load or temperature, there furthermore becomes necessary to follow up and to become acquainted with the relations between stress, strain, temperature and time. It necessitates simultaneously, the knowledge of the mixture composition, the material curing, its age, etc., influences the mentioned relations. The authors are believing that some of their observations introduced hereafter may constitute an aid for the formation of the opinion concerning the said relations.

The influence of the volume amount of both solid phases in the system (the mixture composition) upon the form of the stress-strain diagram of the furfurol-furfural resin concrete (berol) is represented in figure 1 (3). The mixtures 1 and 2, being up to the first zone (of discontinuous porosity) are separated in a very distinct mode from the other mixtures in the third zone (of continuous porosity). Attention is paid to the development of the volume deformation ϵ_v calculated from the well-known formula $\epsilon_v = \epsilon_{long} + 2\,\epsilon_{lat}$ by substitution of the measured longitudinal ϵ_{long} and lateral ϵ_{lat} deformations, as well as to the course of Poisson's ratio μ : the curves correlation for individual mixtures is of interest. There is to be seen that the mixture 2 happens to be already in the second – intermediate – zone, in the beginning of which the state of stress of the system as well as its deformation are developing quite differently, than in both boundary zones, i.e. the first and the third one. About a relative stress $\frac{\sigma}{\kappa} = 0.6 - 0.7$, the volume reduction with the compression stops, the volume, on the contrary, is beginning to magnify and just before the fracture the same gets even considerably increased in comparison to the initial one.

Similar relations have been obtained also by further experiments with the furfurol-furfural resin concrete (fig. 2 (4) and fig. 3 (5)).

From those the form of the stress-strain diagram of the material may be the following mathematical formula :

$$\sigma = E_0\,\epsilon - (E_0\,\epsilon_{lim} - \kappa)\left(\frac{\epsilon}{\epsilon_{lim}}\right)^{\frac{5}{4}}$$

where E_0 is the initial modulus of elasticity of the system, ϵ_{lim} and κ are the limit values of strain and compressive stress. In figure 4 (6) the theoretical forms of stress-strain diagrams calculated according to the above formula with those found out by the experiments are compared for some cases ; the coincidence of both is apparently good.

It is necessary, thence, to note that a similar form as that for compressive

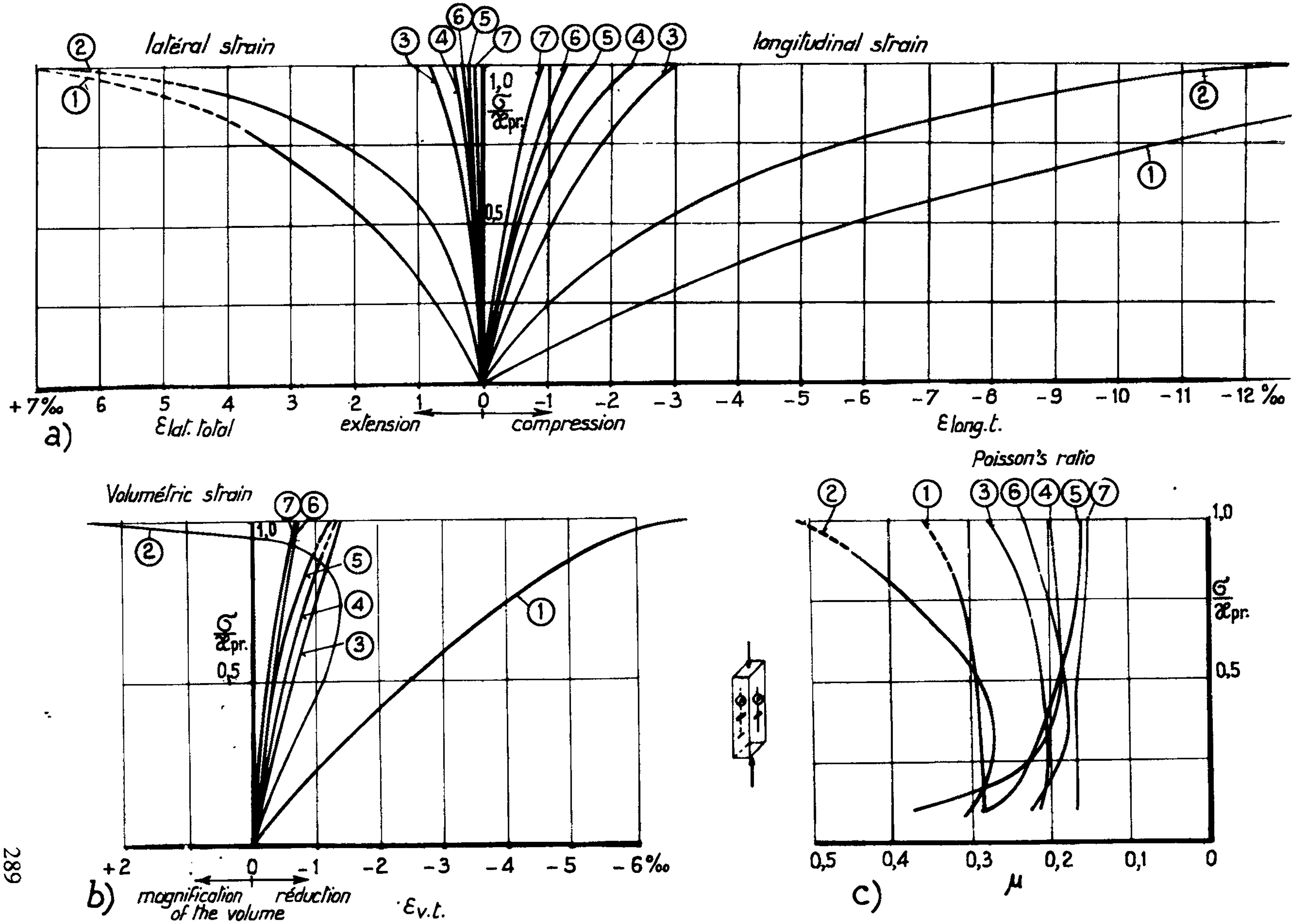

Fig. 1 a, b, c — Longitudinal, lateral, volume strains and Poisson's ratio of the furfurol-furfural resin côncrete (berol) in the dependence on relative stress up to the fracture.

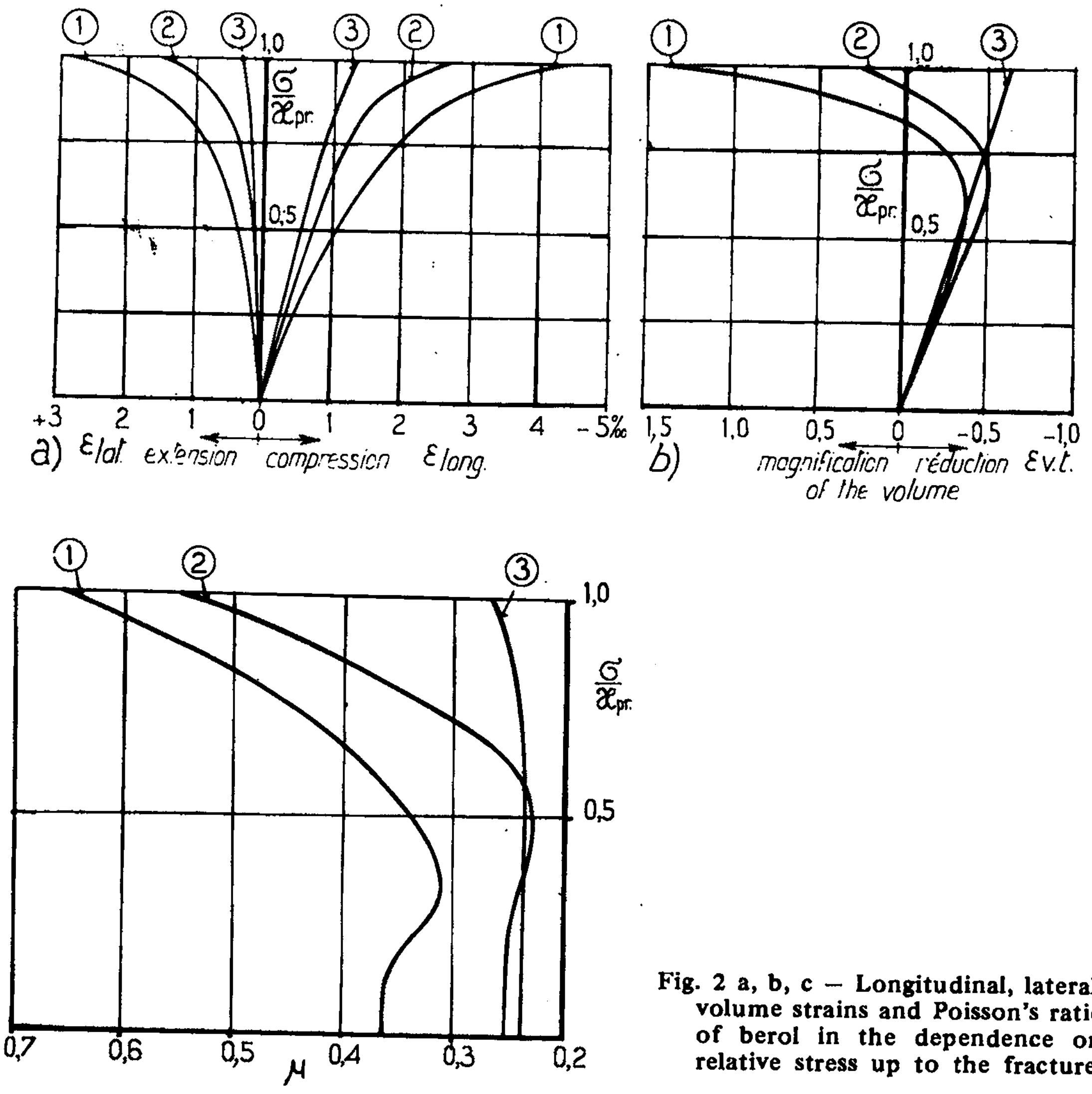

Fig. 2 a, b, c – Longitudinal, lateral, volume strains and Poisson's ratio of berol in the dependence on relative stress up to the fracture.

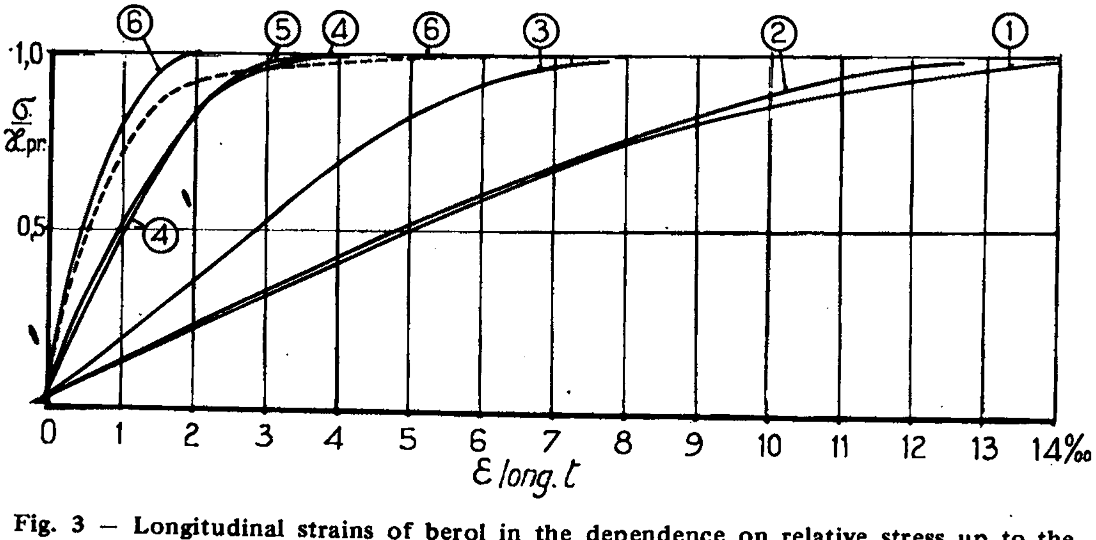

Fig. 3 – Longitudinal strains of berol in the dependence on relative stress up to the fracture.

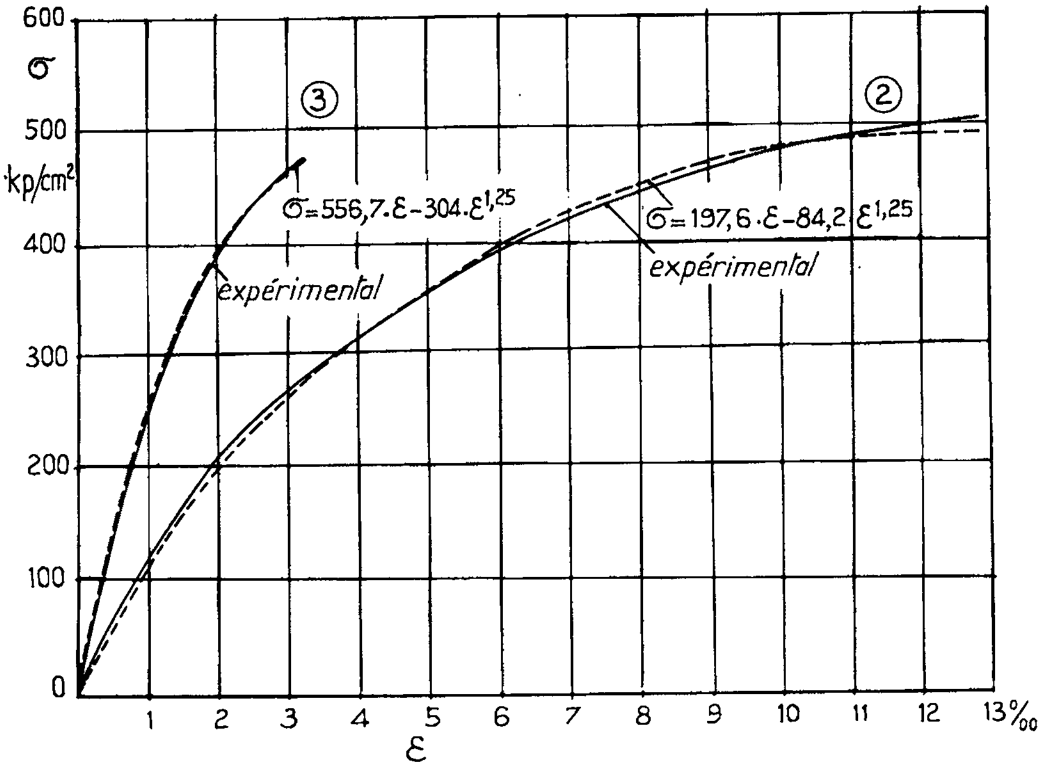

Fig. 4 – Comparison of the experimental and theoretical stress-strain diagrams of berol.

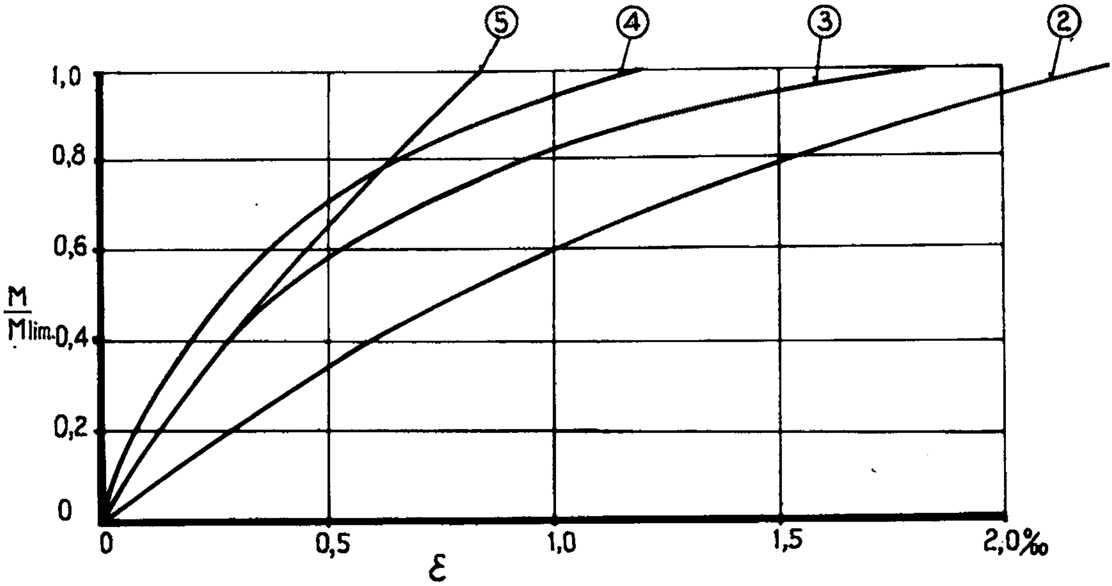

Fig. 5 – Tension strain in the outermost fiber of berol beams in the dependence on relative bending moment.

stress shows also the stress-strain diagram for tensile or flexural stress, as it is presented in figure 5 (6).

The important material characteristic – the modulus of elasticity – depends, first of all (not, however, in a simple manner) on the mixture composition. The typical relation of the moduli of elasticity (7) and of compressibility (8) to the mixture composition is shown in figure 6 (5). It is of interest that as regards the form, a similar relation is obtained by the following up of the elasticity modulus with strength, as presented in figure 7 (3).

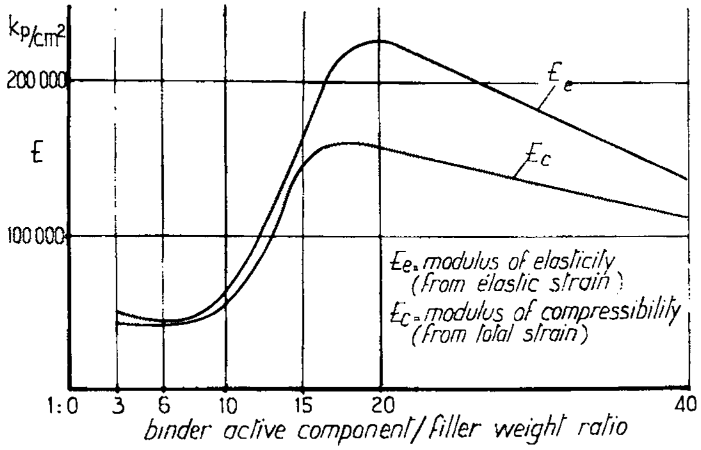

Fig. 6 – Change of the modulus of elasticity and compressibility of berol under the stress with mixture composition.

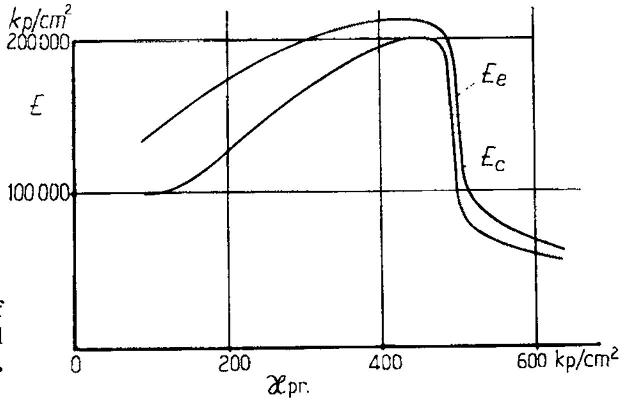

Fig. 7 – Dependence of the modulus of elasticity and compressibility of berol under the stress at prism strength.

The limit strains are important characteristics, too. In figure 8, the variation of as well longitudinal as lateral limit strains with mixture composition at compressive and tensile stresses is shown during different experiments. A main change of rate takes place in the intermediate - second zone. Figure 9 introduces then the development of the boundary strain with a prism strength. It is possible to find out that the character of curves is analogous to the preceding figure.

From the schematic summary of results in figure 10, it is evident that the important break on the limit strain course takes place around 4 % in the relation to the strength, as well as to the mixture composition. A simultaneous comparison of the limit strain and of the strength, ev. of elasticity modulus relations to the mixture composition shows thence a break on the first curve taking place

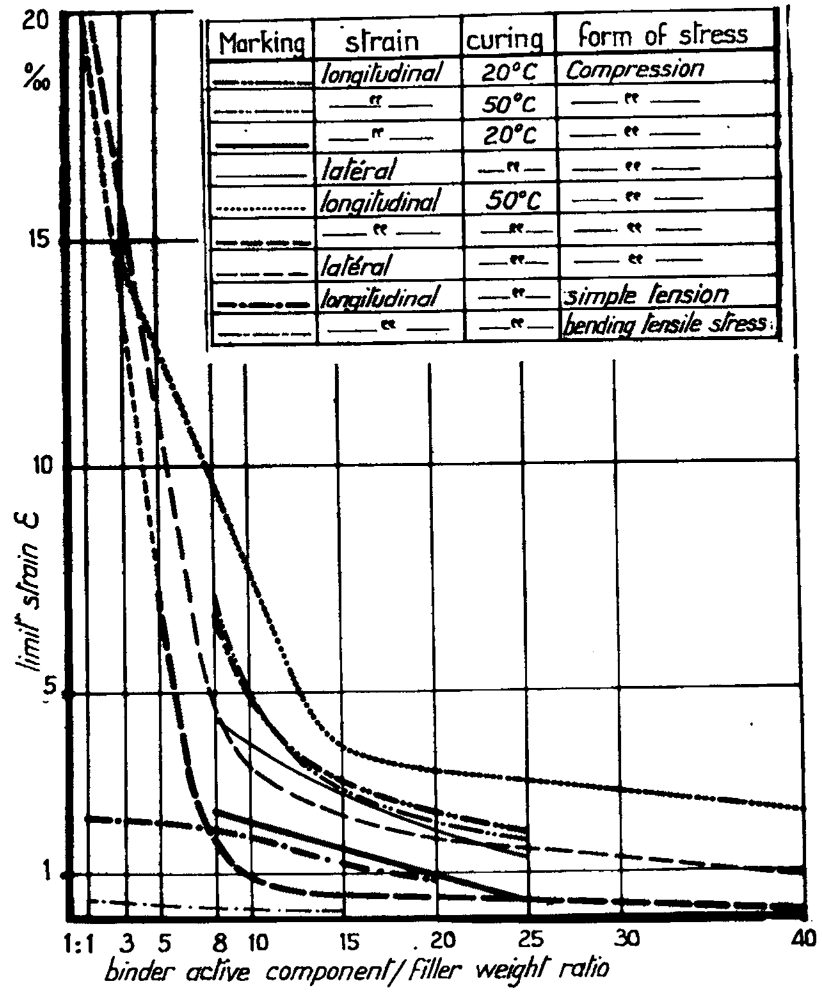

Fig. 8 – Limit strain of berol plotted against mixture composition.

at the second curve maximum, i.e. in the beginning of the third interval. That furnishes, without doubt, convincing backgrounds not only for the mutual connection of all phenomena under consideration, but chiefly their common dependence on the same fundamental influences. Besides, the comparison of both relations of limit strain with the relation of strength to mixture composition leads to the existence of some variable with strong influence on strength (or elasticity modulus) and a negligeable one on the limit strain. From results and discussions already published (1) there follows that the variable mentioned

---

(1) BARES R., NAVRATIL J., BERKA L., JAVORNICKY J., *Practical Application of Synthetic Constructive Material as a Result of Exact definition of Material Properties.* International symposium on the research and reception tests of synthetic material for construction. RILEM. Liège, June 1964.

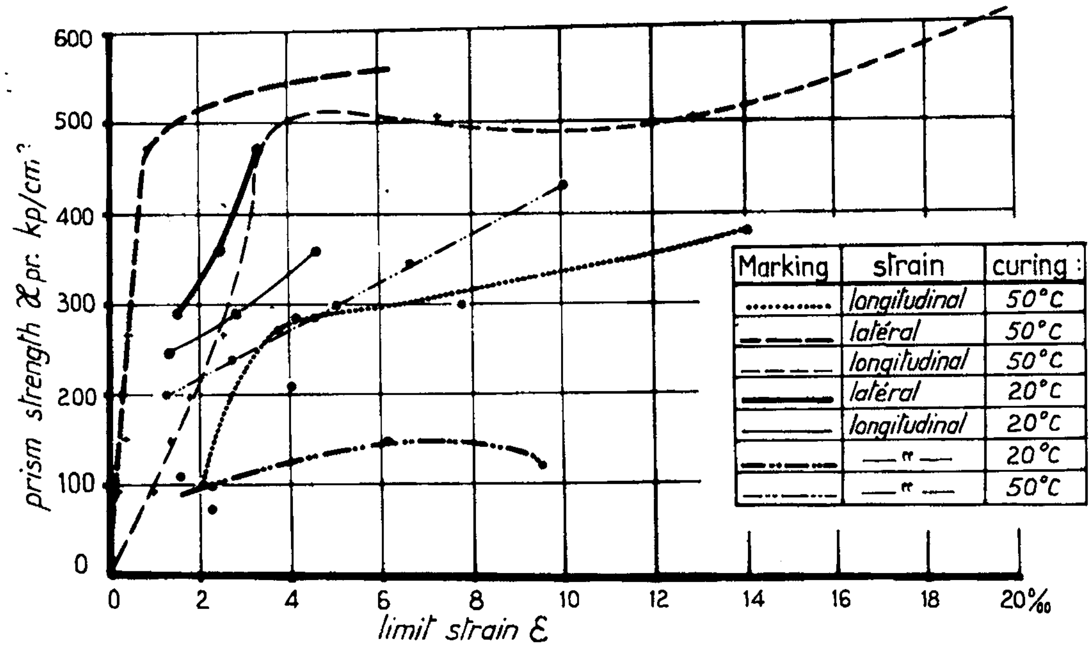

Fig. 9 – Limit strain-compression strength relation of berol

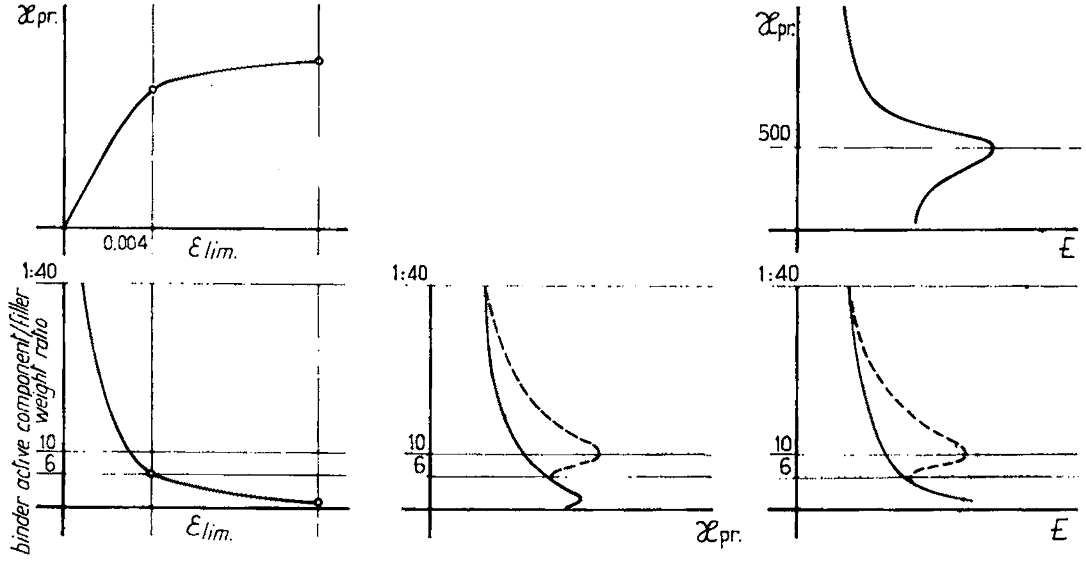

Fig. 10 – Schematic comparison of some properties of resin concretes.

would be, obviously, the humidity or the degree of saturation by water vapour (in the second and third zone) of the resin concrete.

Up to now a polycondensate resin concrete has been dealt with, the furfurol-furfural one. Another type of such resin concrete, practically applicable under moderate environmental conditions only, is the phenol-formaldehyde one. Its stress-strain diagrams and the limit strain change with the composition and the strength are shown in figures 11 (9) and 12 (9). From the further

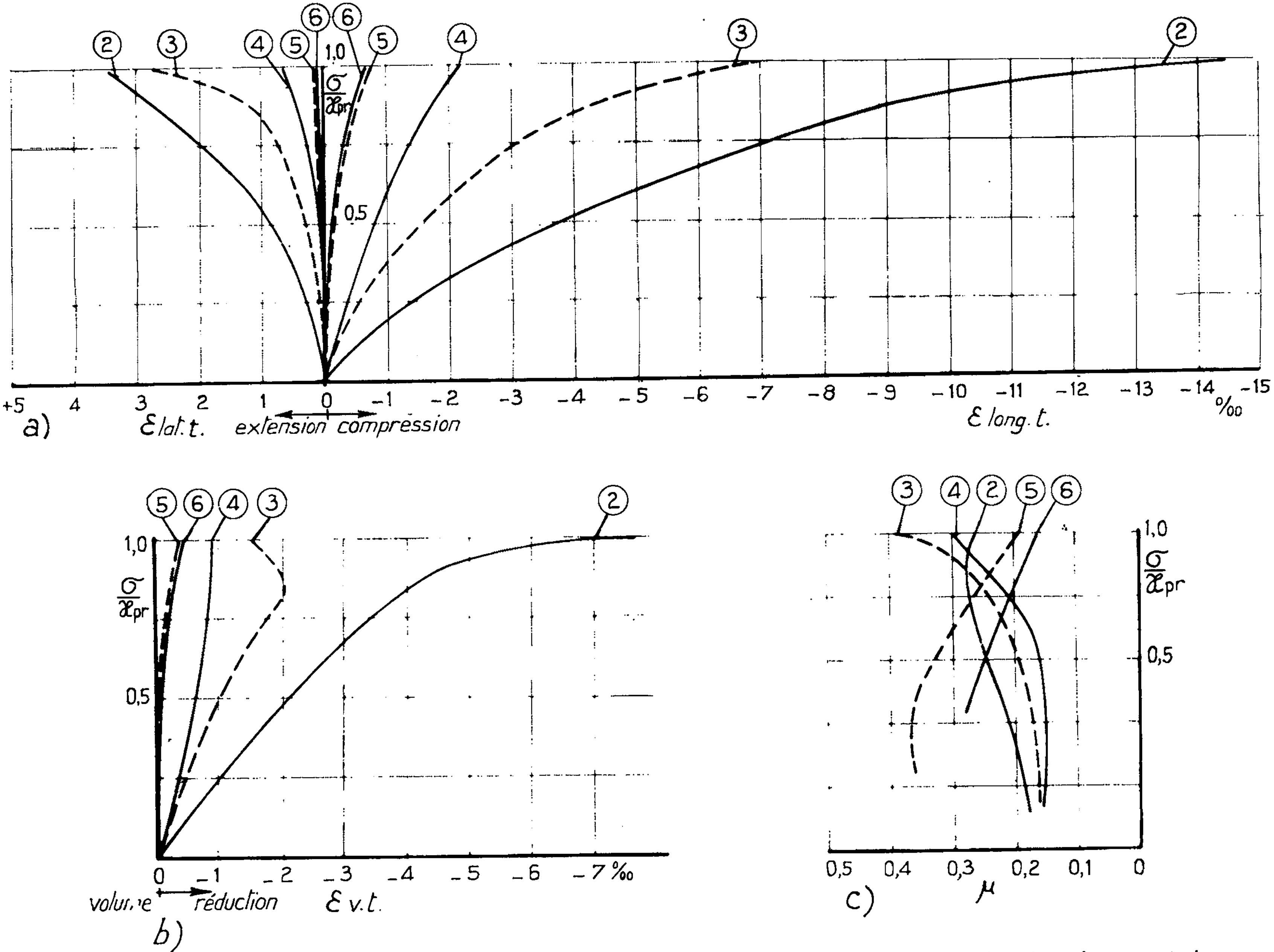

Fig. 11 a, b, c – Longitudinal, lateral, volume strains and Poisson's ratio of the phenol-formaldehyde resin concrete in the dependence on relative stress up to the fracture.

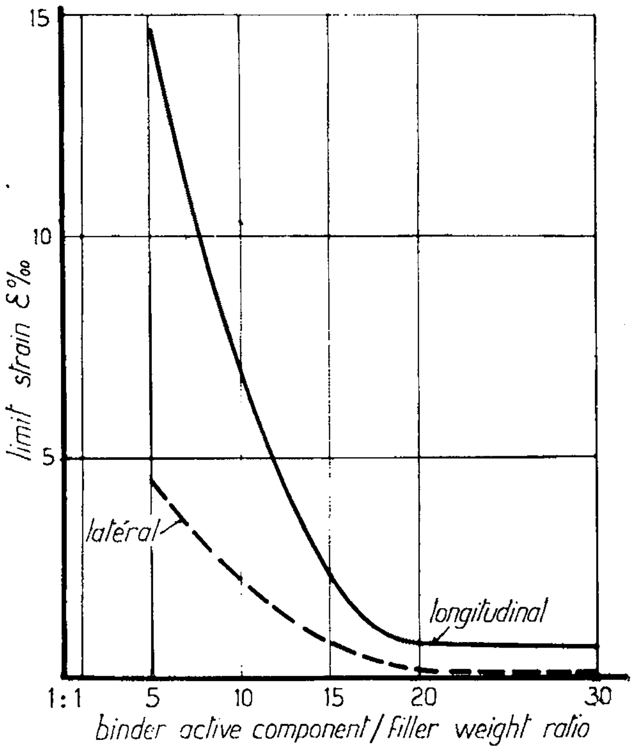

Fig. 12 a – Limit strain xof phenol-formaldehyde resin concrete plotted against mixture composition.

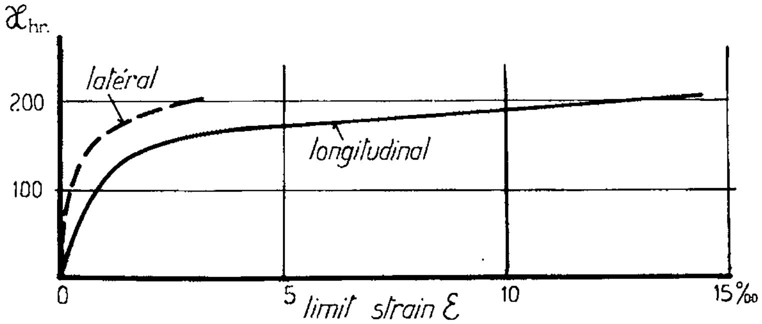

Fig. 12 b – Limit strain-compression strength relation of the phenol-formaldehyde resin concrete

important group, polymer resin concretes, are worth noticing the two most spread at least : the epoxide resin concrete and the polyester one. Figures 13 (10) and 14 (11) illustrate the relative longitudinal and volume changes of them with loading up to the fracture. Figures 15 (10) and 16 (11) compare the courses of the relations of limit strains for both resin concretes to their composition and strength.

As has already been remarked, the deformation properties of the material under long-term loading are not less important than the deformation characteristics under a short-term one. As to time, of course, it is much more pretentious to obtain all the necessary experimental data. Existing results show the creep of resin concretes under mechanical loading to be essentially greater than that of traditional building materials. Coming up to expectations, the unfavourable

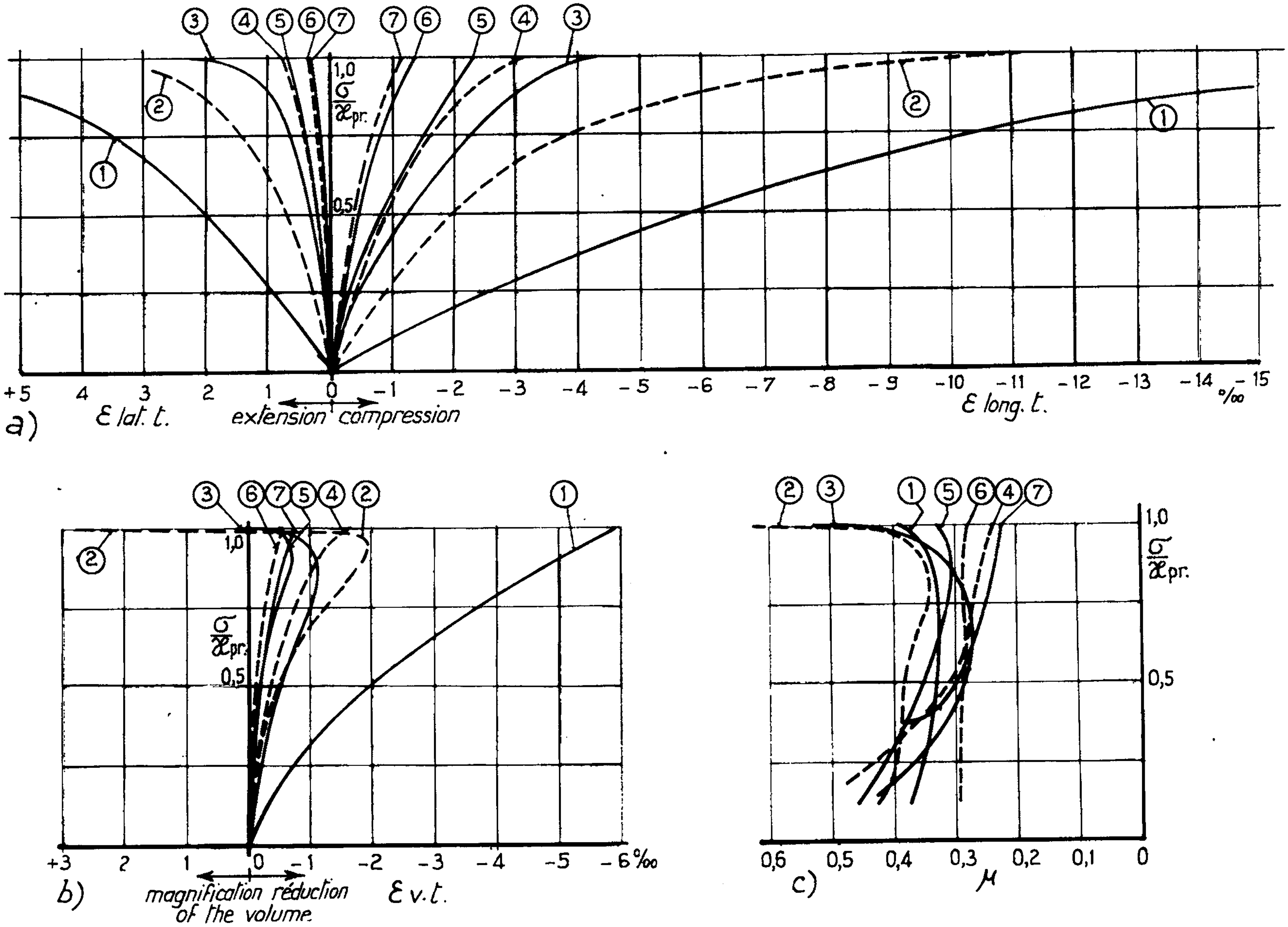

Fig. 13 a,b,c – Longitudinal, lateral, volume strains and Poisson's ratio of the epoxide resin concrete in the dependence on relative stress up to the fracture.

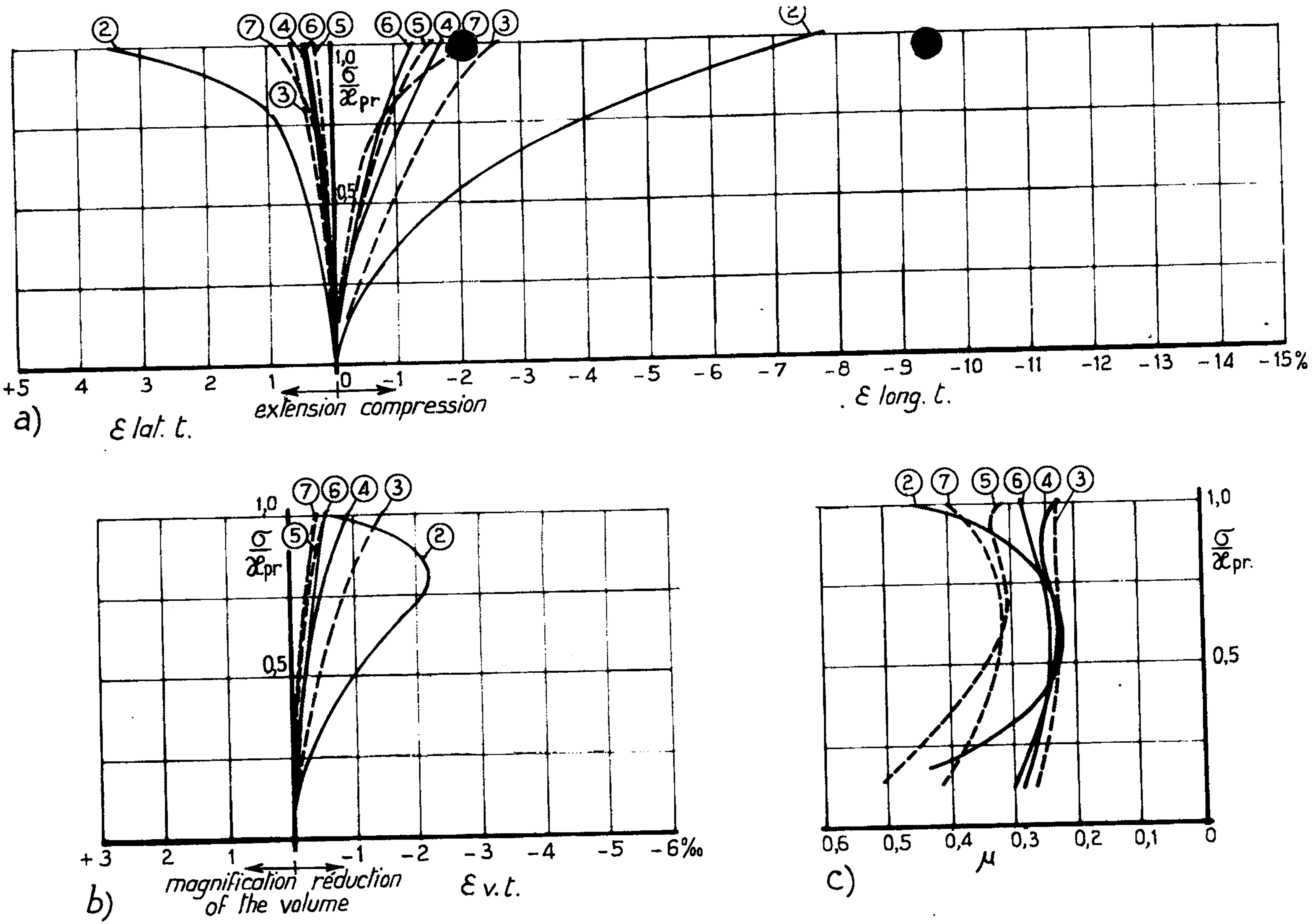

Fig. 14 a, b, c – Longitudinal, lateral, volume strains and Poisson's ratio of the polyester resin concrete in the dependence on relative stress up to the fracture.

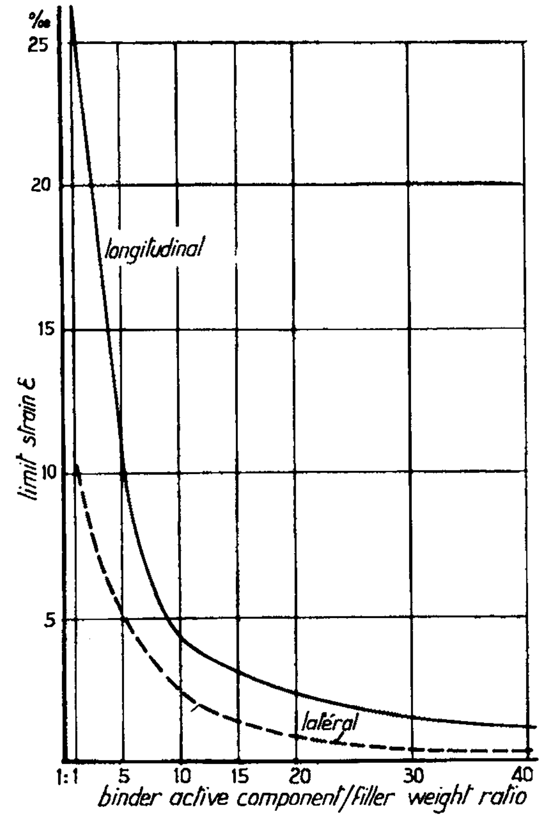

Fig. 15 a – Limit strains of the epoxide resin concrete plotted against the mixture composition.

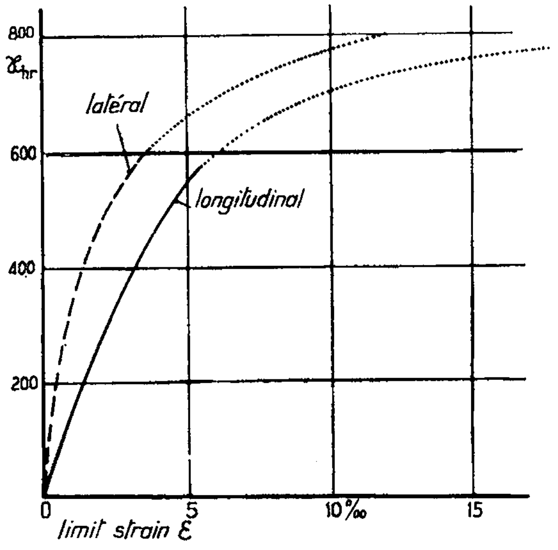

Fig. 15 b – Limit strain compression strength relation of the epoxide resin concrete.

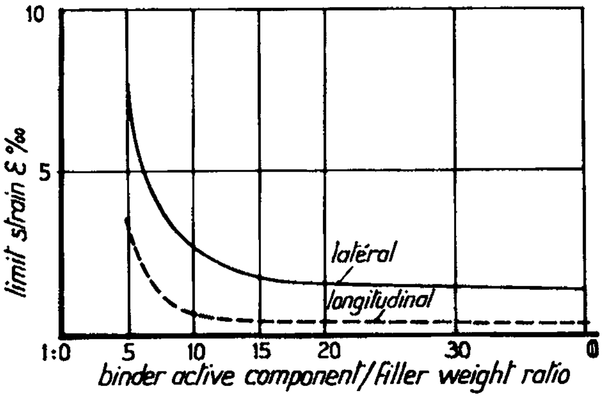

Fig. 16 a – Limit strains of the polyester resin concrete plotted against the mixture composition.

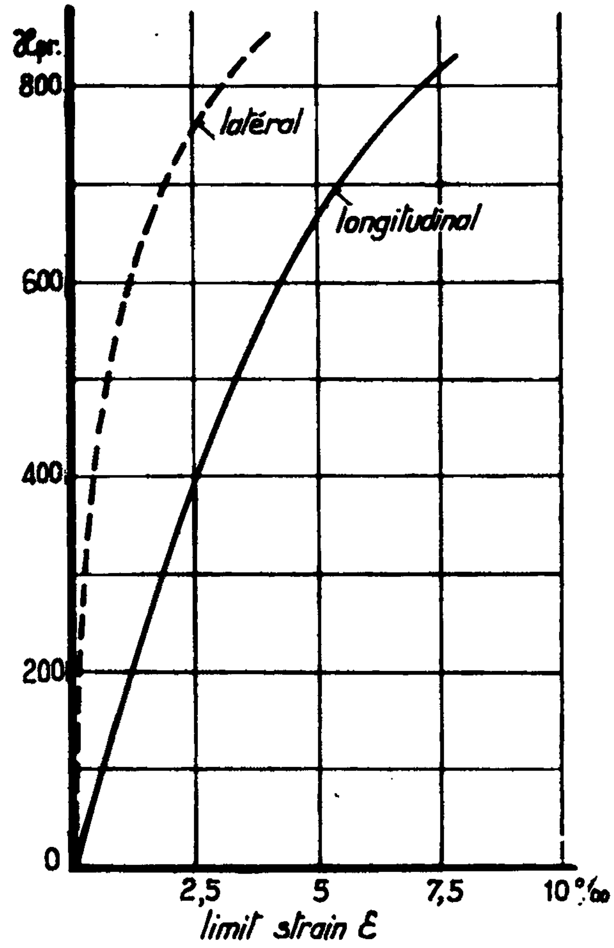

Fig. 16 b – Limit strain compression strength relation of the polyester resin concrete.

character of the one solid phase of the system – of the plastic – is playing an efficient role in this instance. It is not possible, obviously, to count for a perpetual loading of the structural elements from resin concretes higher than up to 30-40 % of their short-term strength. The creep of resin concretes namely, is going over in cyclic periods of rest and acceleration, as presented e.g. in figure 17 (12) for the long-term flexural tests of the furfurol-furfural resin concrete. It is evident that only with bodies, the load of which is minor to 40 % of strength, the rest up to the stop of the creep takes place. It looks like the long-term strength would not rise over 50 % of its short-term value, neither with some special technological interventions, as illustrated in figure 18 (12). This is necessary to remember while designing the structural elements of resin concrete. Although in the application for the preparation of resin concretes under consideration thermosetting resins are preferred, their creep at various temperatures differs as demonstrated e.g. in figure 19 (13) for furfurol-furfural resin concrete with a weight composition of bonding agent to aggregate of 1 : 10. It is rather interesting that the minimum deflection happens as the temperature of 60°C, at which sample curing took place. With exception of negative temperatures, – 10°C in the present case, the deflections are the greater, the more different is the medium temperature, below or beyond the curing one.

For understanding of the primary state of internal stress – prestressing – of resin concretes, it is necessary even from the view point of their practical applicability, to know their hardening volume changes. The hardening reaction is exothermic in general. From the beginning of the polycondensation or polymerisation of the bonding agent in the material there is a heat produced, accelerating the further process on the one hand and causing the body dilatation – the increase of its volume – on the other. At the same time, as the bond net – the macromolecular structure of the binder – is developing, it reduces its volume and consequently the body shrinkage takes place. The whole phenomenon results thereafter as the system dilatation at first, starting with the hardening and decelerating then until the contrary tendency dominates in the system shrinkage. It depends on the mixture composition, on environmental conditions, and to the highest degree, however, on free heat capacities inside the body and on its surface, how early both influences appear, when their crossing breaks the rate of the longitudinal change in time curve, and finally, what effect results in comparison to the initial state : whether an increase or a reduction of the system volume. Figure 20 (3) presents a typical course of longitudinal changes by the hardening of furfurol-furfural resin concrete at elevated temperature (beginning with the exposition to this temperature). A prevailing influence of the mixture composition, i.e. of the bonding agent-aggregate ratio on the resulting longitudinal changes. Figure 21 (3) demonstrates the typical course of final longitudinal changes after the resin concrete hardening in the dependence on the mixture composition. With the mixture of 1:1 a shrinkage has been observed, with that of 1:5 a dilatation of an equivalent order, with a mixture of 1:10 a shrinkage once more, and with

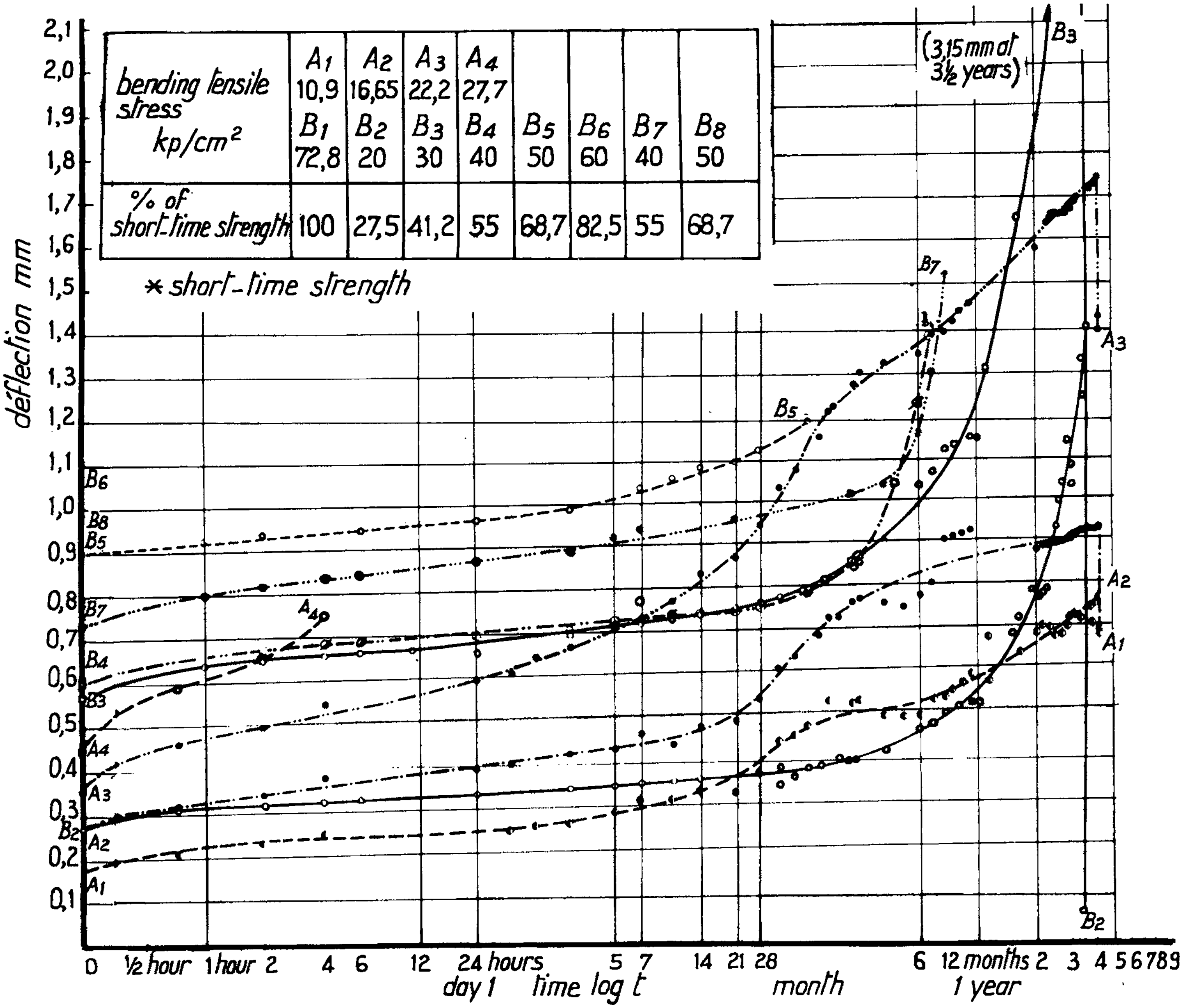

Fig. 17 – Deflections of berol beam plotted against time.

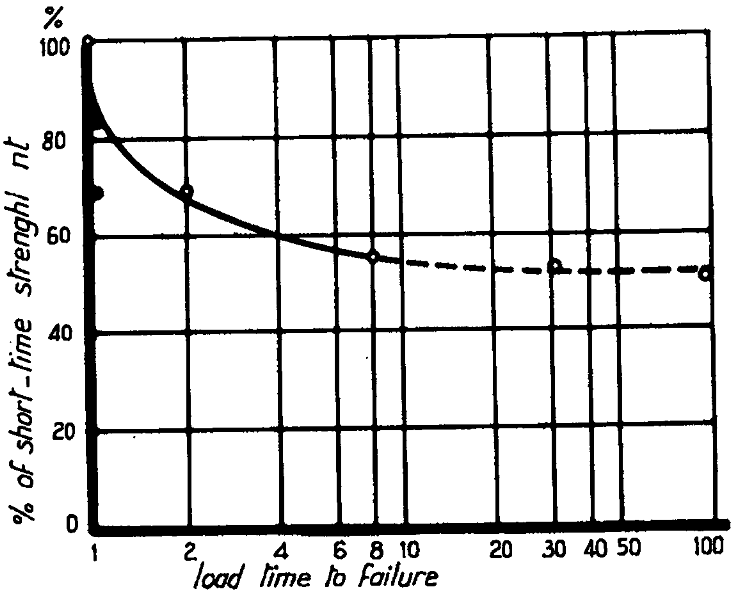

Fig. 18 – Change of berol flexural tensile strength with the loading period.

mixtures the dilatation again. Referring to the curve of the relation, for instance of the tensile strength (or of the elasticity modulus of the resin concrete to the mixture composition (see figure 9) it is possible to state in figure 22 a similar course of longitudinal changes after its hardening at elevated temperature with analogous maxima on the same coordinates. The common argument for both material characteristics may be just its internal state of stress only, originating with the hardening and influencing then even the deformation under the external loading and finally the strength, too. It should be emphasized that only a thorough study of the spontaneous as well as provoked internal state of stress in the structure of a non-homogeneous body, the study of the change of that state of stress with time, of its causes and results, may elucidate in an objective manner all the complicated problems of the observed phenomena.

The relation course of the thermal expansion coefficient to the mixture composition is in the case of the furfurol-furfural resin concrete similar to the course of the same limit strain dependence. A sudden change of the rate takes place again in the second zone – an intermediate one between the discontinuous and continuous porosity – as shown in figure 23 (3-14). The humidity influence on the environment manifests itself pronouncedly with mixtures in the third zone – that of the continuous porosity. The higher is, at the same time, the temperature of environment, the greater is the influence of its humidity change : decisive is thus the vapour tension. A perceptible change in rate on the curve of relative longitudinal change-environmental humidity takes place around 80 % RH, as follows, e.g. from figure 24 (15) for various mixtures at the temperature of 40°C. The comparison of absolute values of longitunal changes with the humidity and with the temperature shows the equivalence of both kinds of them.

By the humidity change the same effect may be reached with some continuous porosity mixtures, as by the temperature change of up to 60°C. The

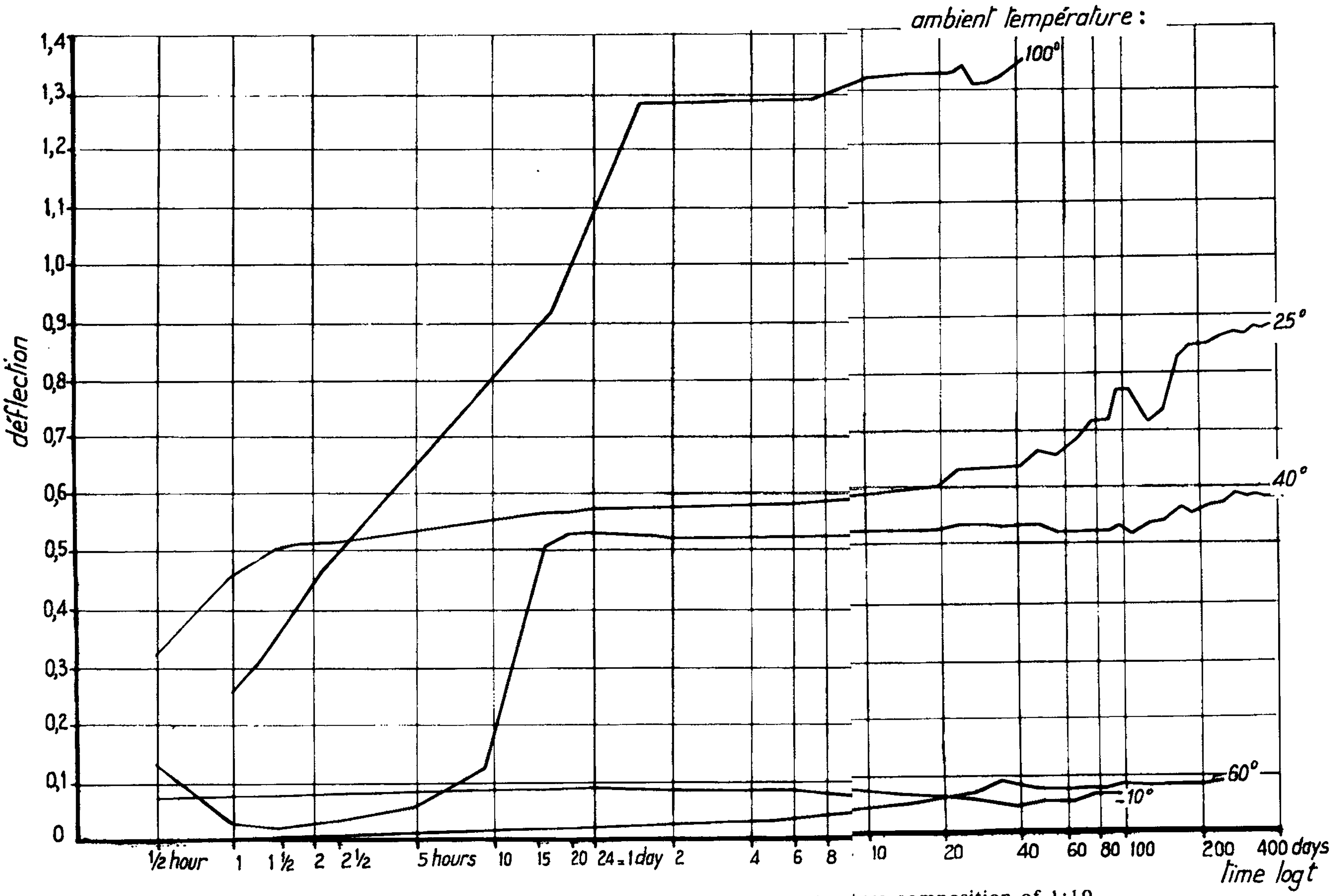

Fig. 19 – Change of berol deflections with time for the mixtuture composition of 1:10.

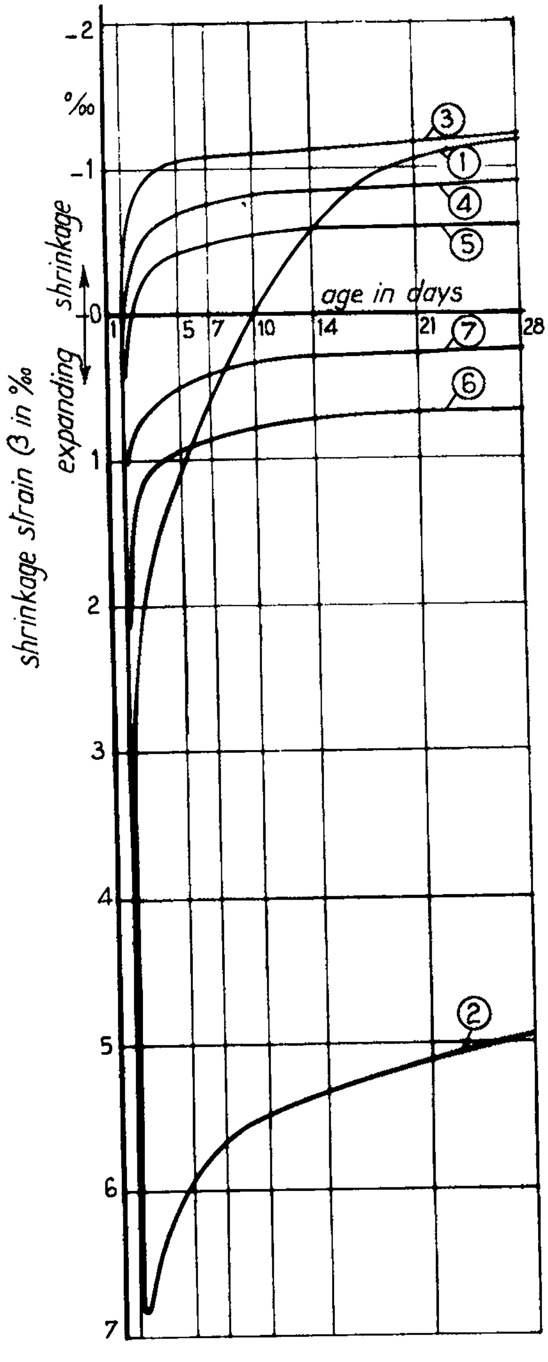

Fig. 20 – Development of longitudinal changes by hardening of berol.

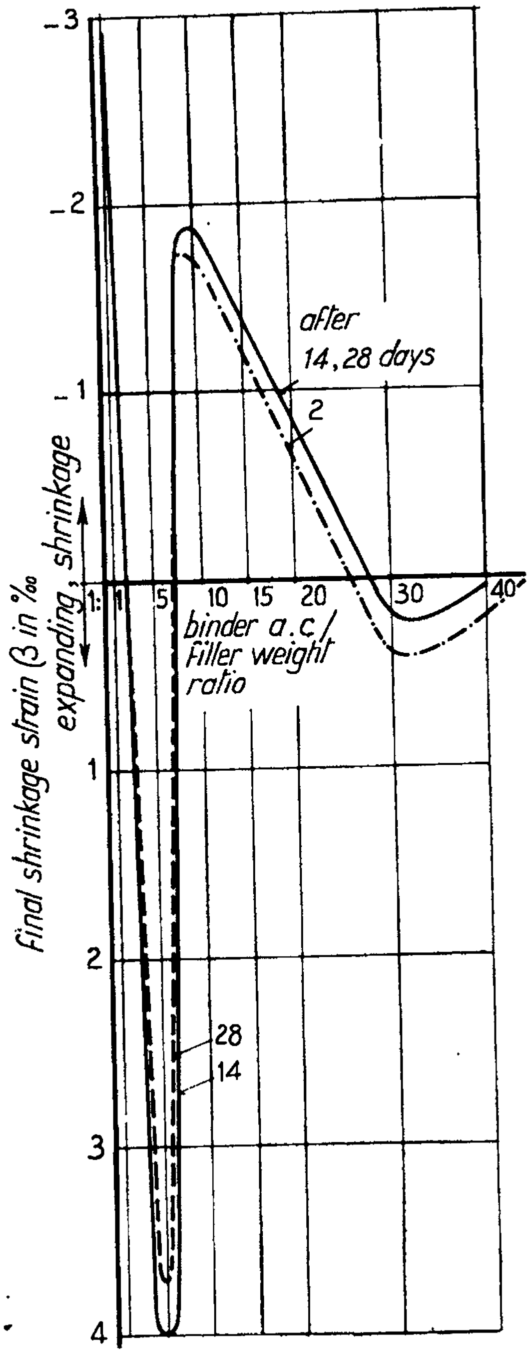

Fig. 21 – Development of longitudinal changes by hardening of berol.

absorptive power even and the resistance to freezing cycles as well as the durability of the resin concretes, in general are controlled by the same rules. As to a mixture in the first up to the second zone, the variation of external conditions does not influence any system properties substantially. On the contrary, in the third zone – in the one of continuous porosity – with the change of some external conditions change also the material properties reflecting so the physical activity of the liquid in the voids of the system.

An important factor for the structural application of resin concretes, is, no doubt, representing their bond to the reinforcement. As regards some of them with a high degree of adhesion (for instance the epoxide one), even the above bond to a considerable degree may be expected. With other, namely the polycondensate resin concretes, doubts may arise about the bond value. In the case of the acidic catalysts, use there should be ascertained, particularly, their long-term influence on the reinforcement. For the bond determination pull-out tests have been performed with the size of samples of 10 x 10 x 40 cm. For all the resin concretes under examination a fully satisfying bond resistance has been stated. The average value of bond e.g. when the furfurol-furfural resin applied, attains some 12-18 cm^2, according to the mixture kind and the reinforcement diameter. The long-term observation (up to five years) of reinforcement inside the bodies from resin concrete is proving a minimum corrosion due to hardener acidity – if hardener used have not been overdosed – so that it cannot be in any case decisive for the life time of the structural element in question.

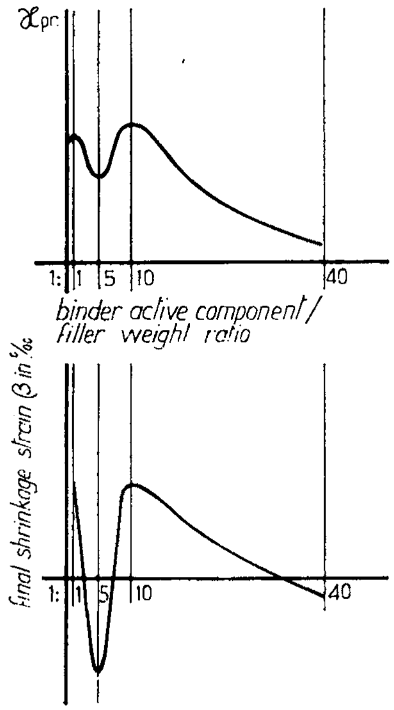

Fig. 22 – Schematic comparison of some resin concrete properties.

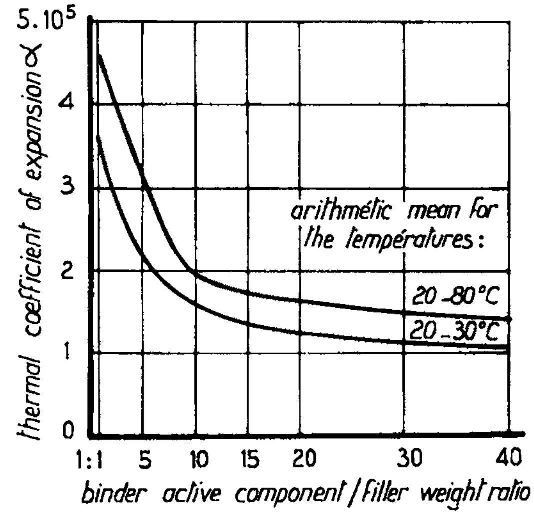

Fig. 23 – Change of berol thermal coefficient of expansion with the mixture composition.

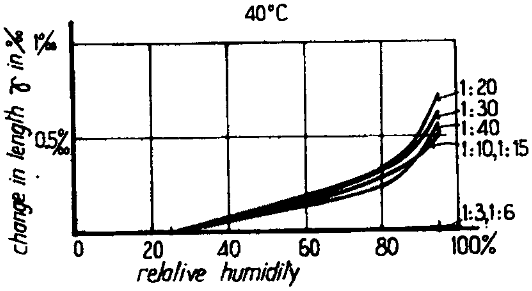

Fig. 24 – Influence of change of relative humidity upon berol longitudinal changes.

A number of further experiments, which cannot be described in the present article (16), has proved, without doubt, the ability of resin concretes to become building materials of manifold application possibilities and with great durability. The exploitation of them, of course, has to start with a knowledge of their fundamental properties, of the relations and influencing conditions for the individual kinds of resin concretes as well as for resin concretes in general representing the certain class of very non-homogeneous materials.

NOTES

(3) *Mixture composition :* 10 parts by weight of furfurol resin, 1 part by weight (further just wt.pt.) of furfural, 4 wt.pt. of catalyst, sand up to 7 mm in 10-50-100-150-200 -300-400 wt.pt. (mixtures number 1, 2, 3, ... 7) ; Curing during hardening : 50°C, 20 % if relative humidity (28 d) ; Age at test time : 28 days ; Sample size : 4x4x16 cm ; Stressing mode : by continuous compression up to the fracture.
Stressing mode : by continuous compression up to the fracture.

(4) *Mixture composition :* 10 wt.pt. of furfurol resin, 2 wt.pt. of furfural, 4 wt.pt. of catalyst, sand up to 25 mm 80-150-200 wt.pt. (mixture number 1, 2, 3) ; Curing during hardening : 20°C, 60-90 % R.H. ; Age at test time : 1,5 year ; Sample size 10x10x50 Stressing mode : continuous compression up to fracture.

(5) *Mixture composition :* furfurol resin 10 wt.pt. furfural 2 wt.pt., catalyst 4 wt.pt. sand up to 25 mm 30-60-100-150-200-400 wt.pt., (mixture number 1, 2, 3, ... 6) ; Curing during hardening : 50°C, 20 % R.H. (14 days) ; Age at test time : 1 year ; Sample size : 10x10x30 cm ; Stressing mode : continuous compressing up to the fracture.

(6) *Mixture composition :* furfurol resin 10 wt.pt., furfural 1 wt.pt., catalyst 4 wt.pt., sand up to 7 mm 10-50-100-120-150-200 (mixture number 1, 2, 3, ... 6) ; Curing in hardening : 50°C, 17-20 % R.H. (14 days) ; Age at test time : 2 months, Sample size 4x4x16 ; stressing mode : continuous bending up to fracture (loaded by two loads in span thirds).

(7) From elastic strain.

(8) From total strain.

(9) *Mixture composition :* phenol-formaldehyde polycondensate in acetone solution 10 wt.pt. catalyst p-toluene sulphonamide acid, 50 % aqueous solutions-2,5 wt.pt., sand up to 7 mm 50-100-150-200-300 wt.pt., (mixture n° 2, 3, 4, 5, 6) ; curing in hardening; test time age, sample size and stressing mode same as ad (3).

(10) *Mixture composition :* epoxide resin (Epoxide groups equivalent 100 g of resin = 0.3 ; the resin contains 5 % by weight of dibutylphthalate) 10 wt.pt., catalyst-diethylenetriamine 0.7 wt.pt. sand up to 7 mm 10-50-100-150-200-300-400 wt.pt., (mixture n° 1, 2, 3, ... 7) ; curing in hardening, test time age, sample size and stressing mode are the same as ad (3).

(11) *Mixture composition :* polyester resin (unsaturated polystyrene content 70 %, styrene 30 %) 10 wt.pt., catalyst (methycyclohexanoneperoxide) 0.3 wt.pt. accelerant (cobaltnaphthenatein solution with styrene in proportion by weight 1:40) 0,15 wt.pt. ; curing in hardening, age at test time, sample size and stressing mode are the same as ad (3).

(12) *Mixture composition :* furylalcohol 10 wt.pt., furfural 2 wt.pt. catalyst 2 wt.pt., catalyst 3 wt.pt., sand up to 25 mm, 150 wt.pt. ; curing in hardening : 50-60°C, 30 % R.H. ; Age at test time : 14 days ; Sample size : 10x10x80 cm ; Stressing mode : by bending (loaded by two loads at span thirds).

(13) *Mixture composition :* furylalcohol 10 wt.pt., furfural lwt.pt. calatyst 4 wt.pt., sand up to 4 mm 100 wt.pt. ; curing in hardening : 50-60°C, 20 % R.H. ; age at test time : 14 days ; sample size : 2x2x10 cm ; stressing mode : by bending (one load in the centre of the span).

(14) After 24 hours of hardening at normal temperature of 20°C the samples have been unmolded and deposited in a medium having a temperature of 50°C.

(15) *Mixture composition :* furfurol resin 10 wt.pt., furfural 1 wt.pt., catalyst 3 wt.pt., sand up to 7 mm 30-60-100-150-200-300-400 wt.pt., (mixture number 1, 2, 3, ... 7) ; curing in hardening : 50°C, 20% RH. ; test time age 14 days ; sample size : 4x4x16 cm ; test temperature : 40°C.

(16) E.g. the resin concrete bond to concrete, long-term bond of resin concretes of the reinforcement, the resin concrete resistance to various media, etc.