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Evaluation of Performance of Industrial Floors According to their Shrinkage and Temperature Stresses

Bewertung der Gebrauchseigenschaften von Industriefußböden nach ihrem Schwindverhalten und ihren thermischen Spannungen

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SUMMARY

Polymer binders for jointless floors are supplied by producers without a detailed spesification on their deformation and rhelogical properties. Principal parameters which are substantial for the assessment of long-term durability with regard to the stress state of the flooring material were defined. Amethology and a testing apparatus RGMwere designed for the ascertainment of relative values of intrnal stresses due to hardening shrinkage and a temperature drop. Methods of ascertainment of further deformation properties were devised. The paper gives examles of data ascertained by the tests of 55 types of flooring materials, none of which has shown optimum properties. It is obvious that more attention must be afforded in the future to the set of properties of flooring materials which are decisive for long-term performance safety of their applications with regard to their stress state.

1. INTRODUCTION

The growing requirements imposed on industrial floors, together with the possibilities of application of new composite materials on synthetic resin basis /such as epoxy resins, polyester resins, etc./ have resulted in considerable expansion of application of jointless resin floors. A number of various types of resin binders, hardeners, fillers and flooring materials is available so that the application of a flooring material of required quality is not connected with any difficulties, provided certain basic knowledge.

The problem of jointless floor layers, however, consists primarily in their durability. Jointless floors are usually made of materials which show very good resistance to mechanical or chemical loads under normal circumstances; defects due to premature wear are very rare, and if they occur, they are mostly due to the choice of the material and type of floor inadequate to the actual performance loads or a gross neglect of technological principles.

The weakest link of jointless floors in respect of their durability is, in a number of cases, /even though all technological rules have been strictly observed/ their long-term adhesion to the base. After the elapse of several months, sometimes one or even several years after the flooring application, the contact zone fails, cracks arise and the floor begins to spall. These problems of cracking and spalling of otherwise satisfactory floor coverings occur rarely in the cases of application of well designed floor types to good quality bases under defined loading conditions. However, as the application of jointless resin floors extends to environments with major temperature changes, exteriors, repairs of industrial floors, application to less suitable bases or in unfavourable conditions, or the necessity of using certain binders /polyester resins/, these problems become central and necessitate solution.

The paper presents the main general causes of the state of stress which causes, in the majority of cases, the failure of the contact zone, the state of the art in the ascertainment of this stress state and the practicable method of obtaining data reauired for the assessment of long-term durability of floors.

2. GENERAL CAUSES OF CONTACT ZONE FAILURE

To be able to make an integral assessment of jointless industrial floor coverings it is necessary to ascertain and assess, apart from the customary and usually producer-stated properties, also further substantial properties which are essential for the prediction of the safety of function and long-term performance of the resin system in the structure. Their number includes not only the deformation and rheological properties of the binder itself or of the flooring material, but also - and primarily - the properties of the whole composite system in interaction with adjacent material /base/ and ambient environment.

The producer usually monitors and gives in technical literature the properties characterizing, often in great detail, the resin flooring material as a separate material. However, he fails to give any data required for the ascertainment of the relation between the flooring material and the base.

Jointless floor coverings, applied to building bases as adhesive layers, bring about the problem ofmutual relations of both jointed materials. In these wider connections a number of initial values of the flooring material acquires a different meaning depending on the quality of the base and the floor thickness, and particularly on the magnitude of volume changes of the flooring material.

Flooring materials based on synthetic resins differ considerably in their properties from the base, which is concrete most frequently. Due to the different properties of both materials - shrinkage of the flooring material durind hardening, and particularly their different thermal expansion - a certain state of stress originates during their cooperation, which manifests itself adversely particularly in the contact joint. This stress state is further increased by the horizontal component of the stress due to the loading of the floor by concentrated loads /travel of bogies, cars, etc./.

The danger of failure of the contact zone can be reduced by the selection and design of an optimum floor covering which would show minimum stress state under given circumstances, while satisfying all other requirements /mechanical resistance, chemical resistance, appearance, workability, etc./.

Therefore, the possibility of assessing the function of the floor covering in relation to its base and the thermal load conditions, requires the ascertainment of the magnitude of the stresses due toto solidification and temperature changes as one of the decisive quantities.

3. ASCERTAINMENT OF GENERAL STRESS STATE

The contemporary methods of stress state ascertainment are based particularly on calculations based on the data of shrinkage, temperature expansion, moduli of elasticity and other quantities, which are difficult to determine. These calculations are considerably inaccurate, because the resin materials change consireably their properties in the course of their hardening and temperature changes. Their magnitude is considerably time-dependent and the factors of time deformation, stress relaxation, influence ot structurality and internal stress state cannot yet be reliably defined on the basis of data currently obtained from tests. This paper, therefore, does not give any theoretical formulations which cannot be yet practically utilized for concrete ascertainment of stress state values.

The currently used method of ascertainment of performance of flooring materials with reference to their inner stress state is their practical application. This "test" affords, after a certain period of time, information whether the floor covering performs its function or fails to do so, but without any detailed knowledge of the relation of originating stresses to their ultimate value /e.g. adhesion to base/. It can be stated that a majority of organizations concerned with the application of resin floorings has made, often unintentionally, such "tests". The costs and problems connected with the liquidation of an unsuccessful application need not be described here.

Technical conditions of producers for the application of flooring materials are based on long-term experience, empiric knowledge or estimates of the properties of flooring materials based on the assessment of some of their properties. This is confirmed also by the uniform requirement imposed on the quality of the base /tensile strength of the surface layer/, which should be more sensibly defined in accordance with the stress state of the flooring material and its mechanical loading.

The purpose of the test procedures described further on is the determination of the values required for an objective assessment of the durability of the floor coverings.

As stated in /1/ it is not important for the significance of volume changes for the stress state, whether they are due to temperature changes, shrinkage, drying, ageing etc. Important is only the magnitude of the resultant volume change. However, because of their different character we describe further the general aspects of these volume changes which are of fundamental importance for the stress state.

4. SHRINKAGE DURING HARDENING

The reduction of the volume of the flooring materials during their hardening is caused, as a rule, by the shrinkage of the resin binder during its curing reaction /the cross-linking of the monomer/. In some cases also the escape of free, unbound substances /non-reactive solvent, softening agent/ represents an additional cause of the reduction of the volume.

The shrinkage produces in the resin binder -matrix - unwelcome inner stress state from the moment of limitation of its free movement. Advantageous, therefore, are such resins in which the majority of hardening shrinkage takes place still during the time when the material eliminates these changes by plastic deformation. The influence of the possible shrinkage and strength increase histories on the inner stress state of flooring materials is described in detail in /2/.

The shrinkage volume change of the material is generally determined as a free linear change ω of test specimens. In actual applications the free shrinkage of the flooring system is hindered by the rigid base with which the system is jointed. It is obvious that the situation in this case changes substantially and the resulting properties of the applied floor covering need not correspond with the values ascertained on test specimens which can shrink freely, without any constraint.

Further it is obvious that on the basis of the magnitude of free shrinkage and the modulus of elasticity in tension in the given time t_1 it is impossible to determine even informatively the magnitude of the stress state arisen in the applied flooring material where the shrinkage has been hindered. The major part of the shrinkage takes place in the time, when the modulus of elasticity in tension increases from zero to a certain value. The authors' endeavour to determine the stress state magnitude σ_ω as a sum of the stresses due to the individual shrinkage increments ω in the selected time interval, considering the respective relaxation moduli of elasticity E_r corresponding with age and time of the given interval

$$\sigma_\omega = \int_0^{t_1} \varepsilon(t) . E_r(t)\, dt$$

led to more accurate, but still only informative results. Further increase of accuracy could be achieved by the assessment of residual shrinkage ω_R . The residual shrinkage at the time t_1 of hardening gives the value of linear shrinkage of the floor covering hindered from the beginning to the time t_1 as in actual application. In the case of tearing-off of applied floor covering at the time t_1 only residual shrinkage ω_R would manifest itself which differs from the value of free shrinkage ω , because a considerable part of the deformation is eliminated, particularly in the initial phase, by the creep and relaxation of the stress state.

Then, using $E\,/t_1/$ it would hold that

$$\sigma_\omega = \omega_R(t_1)\,E(t_1)$$

However, even this value does not characterize accurately the actual state.

5. TEMPERATURE CHANGES

Another circumstance which is of decisive importance for the durability of the system is the difference in thermal expansions of the individual components of the composite floor covering, and particularly of the floor covering as a system and its concrete base. Similarly as in the case of hardening shrinkage the estimate of the ensuing stress state is difficult, with regard to the fact that the modulus of elasticity and the rheological properties of the flooring material are functions of temperature and time.

When the temperature increases from the "birth" state first the stress state generated by hardening shrinkage is equalized, and subsequently compressive forces originate. With increasing temperature the modulus of elasticity of the flooring decreases considerably. Apart from that greater and speedier stress relaxation takes place because of the viscoelastic behaviour of the resin binder. Generally it can be stated that proportionate temperature increase is not dangerous for the failure of the contact zone and for the durability of flooring materials. However, it is necessary to consider also the possibility of adverse effect of these changes on accelerated ageing of the material or the changes of its properties due e.g. to the evaporation of volatile unbound modification components.

Thus it is obvious that the highest stress state originates when the temperature drops and the rheological properties of the flooring material deteriorate, the relaxation modulus increases, the toughness and the ultimate deformation decrease, and even a small deformation causes a high stress state to originate. Moreover, the drop of temperature produces tensile stresses which increase the stress state, due to hardening shrinkage, remaining in the flooring material. In winter and during cooling periods also the failures of jointless, particularly cast floors have been observed most frequently. Most unfavourable and, unfortunately, most frequent, is this progress of cooling: environment, flooring material, base.

Thus for internal stresses in the floor system it holds that

$$\sigma_{in} = W[t, T, \varepsilon_{\omega}, E_r(t,T), \alpha(T), T_0]$$

It follows that a mathematical assessment of the stress state, which could be practically used, is extraordinarily complex and depends on the ascertainment of suitable cummulation functions of the individual variables. For this reason the simple partial assessment, e.g. of the product $E_{/+20^{\circ}C/} \cdot \alpha$, cannot yield sufficient information. Moreover, the ascertainment of the properties of floor coverings at low temperatures /for extreme applications of at least - 20°C/, which are indispensable for any assessment, is considerably difficult. In addition to it, a number of materials of excellent "floor" properties /e.g. elasticity, ductility, relaxation/ at normal temperatures loses these properties at reduced temperatures, and even a small deformation, due e.g. to a further drop of temperature, results in the origin of critical stresses. This property, typical e.g. of asphalt, is characteristic, unfortunately, of also the majority of softened resin binders. Moreover, at a drop of temperature the haircracks originate or increase in the base /shrinkage cracks of concrete, construction joints/, and the ability of the flooring material to bridge them is considerably limited in these cases.

6. SUMMARY OF INFLUENCE OF VOLUME CHANGES

From the general description of the influence of volume changes of the flooring material on its stress state which causes stresses in the contact joint and thus influences the performance safety and the durability of the floor covering, there follows particularly the dangerous influence of temperature changes when the temperature drops. The hardening shrinkage is not dangerous for the failure of adhesion /contact zone/, as a rule, in case of suitable flooring material formulation. Considerable danger, however, can be caused by unsuitable binder composition, comprizing free volatile substances the evaporation of which increases the shrinkage of the flooring material even after several years of application. Also unsuitable are the measures intended to accelerate the exothermal hardening reaction which, apart from increasing shrinkage, increases also the "birth" temperature of the system.

The tests of size 4/4/16 cm test prisms of polymer concretes and polymer mortars jointed to concrete slabs only along 1 cm at their ends /see Fig. 1/ have confirmed the above conclusions. Only in the case of unmodified polyester concrete the adhesion to the base failed because of hardening shrinkage. In all other cases of epoxy resin flooring materials the failure took place, when the temperature dropped. In the case of several optimally formulated polymer concrete composites of the 3rd type the failure did not take place even after the temperature of -25°C had been reached and even after further temperature cycles of -25°C, +40°C /3/.

The importance of the stress state problem confirms the need of some simple methodology for the assessment of the stress state due to hardening shrinkage and temperature changes. The relative assessment of fundamental quantities can then become a basis of the selection and assessment of flooring material types, their modifications, hardening systems, formulation of mixtures or determination of base quality required by the respective type of flooring material and the thermal loads, determination of the maximum thermal loads of the given flooring material and base quantity, etc.

The method described further on represents a proposal of a practically applicable integral assessment of fundamental properties, particularly because it directly measures the magnitude of linear stress state originating in the floor covering by the constraint of deformations due to hardening shrinkage and temperature changes.

7. DESCRIPTION OF TESTING APPARATUS AND METHOD

The type RGM-03 testing apparatus /see Fig.2/ was developed by the national enterprise Armabeton, Prague, /4/, which is the biggest contractor of jointless industrial floors in Czechoslovakia /over 140 00 sq.m annually/. The apparatus measures the stress state magnitude as a magnitude of the reaction required for the equalization of the resultant of internal forces in the flooring material, at which the relative longitudinal deformation of the test specimen with regard to the apparatus equals zero. Since the thermal expansion of the apparatus metal can be considered equal the thermal expansion of concrete, the stress state ascertained under a certain temperature change corresponds with the state during the application of the tested material to a concrete base.

The design of the apparatus is schematically represented in Fig. 3, the actual apparatus is shown in Fig. 4. The apparatus consists of frame 1 comprozing also the dismantling groove 2 for the clamping of the tested specimen 5. The other end of the test specimen 5 is clamped in a similar groove forming part of a mobile jaw 3. The jaw 3 is horizontally displaceable along the apparatus axis with minimum friction on four bearings 4. The base plate 6 surface between the grooves is polished and serves as separation surface. Between the base plate 6 and the jaw 3 there is a space 7 which is filled accurately to the base plate level with silicone rubber before the specimen is cast. The travel of the jaw 3 is picked up by the sensor 8 of a centesimal indicator 9 firmly fastened to the frame 1.

The mobile jaw 3 is connected on the opposite side via another hinge 10 by means of the thread of the adjusting nut 13 with the frame. The turning of the adjusting nut 13 shifts the dynamometric ring 11 and, consequently, also the jaw 3. Laterally the apparatus is closed by two sides 14, which are removable and slide in vertical direction.

The initial distance of the jaw and the measured length of the test specimen is 240 mm. For this length the displacement indicator 9 is set to zero. The width of the test specimen and of the apparatus is 150 mm. The dynamometric ring is calibrated up to 9 kN. The ring deformation is read on the diameter perpendicular to force application by means of the centesimal indicator 12 firmly connected with the dynamometric ring.

The test specimetn is cast directly in the testing apparatus. To this purpose the sides, set at an appropriate height, are used. The depth of the test specimen corresponds with the type of the flooring material tested and is, as a rule, 5 mm in case of cast floors and 10 mm in case of polymer concrete floors.

8. STRESS STATE DUE TO HARDENING SHRINKAGE

After the casting of the test specimen with the mobile jaw fixed at zero reading of the centesimal indicator 9 the flooring material changes its state during hardening from the liquid state to the solid state. Also its modulus of elasticity changes accordingly.

If further shrinkage takes place after the flooring material has partly hardened and acquired a certain modulus of elasticity, which means that the deformation will generate the potential stress energy, tensile stresses originate in it. In actual applications these stresses are conditioned by the adhesion of the flooring material to the base, which prevents the flooring material from shrinking. In the apparatus this state is replaced by that the mobile jaw is held in the initial zero position by the reaction of the dynamometric ring. As soon as possible, i.e. as soon as the tested flooring material has hardened sufficiently so that there is no danger of damage to the test specimen, the sides and the silicone seal are removed.

The magnitude of reaction of the dynamometric equipment, required to hold the mobile jaw in the zero position, related to the cross section area,represents a relative comparable value of linear stress state

$$\sigma_{\omega}\,(t, T = 20\,°C)$$

originated in the flooring material, when is was prevented from shrinkage during hardening.

The period of observance of σ_{ω} usually is 14 days from the casting of the test specimen.

9. DETERMINING RESIDUAL SHRINKAGE

When the measurements of the stress state due to shrinkage have been terminated /or at another chosen interval/ the value of residual shrinkage ω_R of the test specimen is determined by the release of the reaction of the dynamometric equipment and by reading the displacement of the mobile jaw. This value, which is the function of time, is usually determined within 60 minutes after release.

10. MODULUS OF ELASTICITY IN TENSION

The apparatus can be further used for the determination of the stress state arising at the selected elongation of the test specimen. This elongation is selected, as a rule, as $\varepsilon = 1 \,.\, 10^{-3}$ /or in case of harder materials or lower temperatures as $\varepsilon = 0.5.10^{-3}$/. The value of selected deformation is maintained constant. In this way the relaxation modulus of elasticity /usually within 60 minutes/ is determined.

11. STRESS STATE DUE TO TEMPERATURE CHANGES

Another important value for the assessment of the performance safety of the floor covering is the stress state ascertained at a temperature drop. For relative comparison of various types of flooring materials the temperature of -20°C has been selected. In this way the value of $\sigma_{(\omega + T/-20°C/)}$ is obtained. The same temperature is used also for the determination of the values of residual deformation and the relaxation modulus of elasticity. The difference of the residual deformation value at -20°C ε_R and the same value at +20°C ω_R ,ields the comparative mean coefficient of linear thermal elongation α_R

$$\alpha_R = \frac{\varepsilon_R\,(T = -20\,°C) - \omega_R\,(T = +20\,°C)}{40} + 12 \cdot 10^{-6}$$

For the purpose of relative assessment of various resin binders and flooring materials a number of experimental measurements by the described method were made. The individual materials were tested in the type RGM testing apparatus according to the arrangement schematically shown in Fig.5, first at the temperature of +20°C and different ages /Test I/, than at the temperature of -20°C /Test II/. This determination of properties is considered basic.

After the basic tests /Test I and Test II/ a comparative measurement is made: the whole experiment is repeated after the curing of the material at an elevated temperature /48 hours at +85°C/, once again at the temperature of +20°C /Test III/ and -20°C /test IV/.

Tha data A and B afford the values of the stress state due to hardening shrinkage σ_{ω}, C the value of residual shrinkage ω_R , D the relaxation modulus of elasticity in tension E_r /60 min.,+20°C/, E and G the internal stress $\sigma_{(\omega + T)}$ due to the sum of shrinkage and a 40°C temperature drop, F - together with C - enables the determination of the mean informative coefficient of thermal expansion of the flooring material α_R , H giving the value of the relaxation modulus E_r /60 min., -20°C/.

The values measured in the tests repeated after additional curing at an elevated temperature can be considered approximately as the values corresponding with long term ageing at a normal temperature. The differences of the corresponding values ascertained before and after additional curing inform also about the degree of conversion during hardening at a normal temperature. An example of the possible presentation of basic test results can be seen in Fig. 6.

12. DETERMINATION OF FREE SHRINKAGE VALUES

To supplement the afore mentioned information the values of linear changes of freely placed specimens were measured. In these measurements the following quantities were ascertained:

- shrinkage during hardening and curing of the material in normal environment, the value of free shrinkage $\omega(t)$ was obtained;
- shrinkage after additional thermal curing for comparison with the shrinkage curve in normal environment;
- shortening at a temperature drop /T = -20°C/ to ascertain the mean coefficient of linear thermal elongation.

The test specimens for the tests of free shrinkage were made simultaneously with the test specimens cast in the RGM testing apparatus. The test specimens were made in special metal moulds /see Fig. 7/ of great mass selected to ensure good heat conductance during the hardening reaction. The test specimens are 500 mm long, of conical cross section, sized 25 - 27 mm / 10 mm for cast flooring materials. The mould is used for simultaneous casting of 5 test specimens. Their shrinkage was measured by means of a simple gadget using a centesimal indicator mounted outside the mould.

13. DETERMINATION OF TENSILE CHARACTERISTICS OF FLOORING MATERIALS

The determination of tensile characteristics of flooring materials is important for the assessment of their long-term durability with regard to the fact that the flooring material, when applied, is jointed to a concrete base and stressed mostly in tension. A more profound assessment of the characteristics of flooring materials was enabled by simple tensile tests of the specimens. Apart from tensile strength, modulus of elasticity and ultimate deformation, also the stress/strain diagram were determined. With regard to the fact that in the applied flooring material the volume changes proceed at a velocity which is by several orders lower that the deformations taking place in a standard tensile test, for objective information also the creep and relaxation moduli of elasticity in time of up to 2.5 and 3 hours were ascertained.

The test specimens for tensile tests were selected with the tested part 150 mm long and 20/10 mm in cross section. Both the specimens hardening at a normal temperature and those thermally cured at an elevated temperature were used. Part of the specimens were retained for verification after several years' storage.

The tests were carried out on a type TESTATRON 10 tester with deformation measurements by the INSTRON clip strain gauges. From a part of test specimens the test pieces for impact tests were made.

14. DISCUSSION OF RESULTS

The measurements by means of type RGM apparatuses /simultaneous shrinkage measurement of various materials were made of 3 apparatuses/ afforded so far the data on internal stresses due to shrinkage and temperature changes and further afore mentioned data for 55 differenc flooring systems. The considerable disadvantage of this method are the considerable time requiremens of the tests which take up the apparatus approximately 1 month for one test. Another disadvantage is the existing technical design of the apparatus requiring the monitoring and manual maintenance of the selected deformation of the mobile jaw in the course of measurements, which can cause inaccuracy /e.g. during temperature drop/. The location of the apparatus in a conditioning chamber makes the mechanical part of the apparatus and the indicator suffer considerably with temperature differences and makes their careful maintenance necessary. These facts are probably the cause of occasional occurence of some irrelevant values in the whole complex of ascertained data. These shortcomings will be eliminated to a considerable extent by the intended automatic control using the NC techniques.

Together with the determination of the invididual quantities by the RGM apparatus also the tests of free shrinkage, tensile tests and impact tests were carried out.

As a concrete example of test results Table 1 gives the ascertained values of four types of flooring materials:

- type ChS SADURIT epoxy flooring material /on basis of a low-molecular epoxy resin modified by a mixture of esters of dicarbon acids, cured by a polyamide hardener, with some 20 % of microfiller/, which is the principal type of cast flooring material produced in Czechoslovakia at present,
- type ChS SADURIT 1330 epoxy flooring material with special corundum filler CS1 in the screeded mortar formulation /filler content 63 % by weight/,
- binder of type ChS 104 polyester resin /on the basis of phtalic acid and ethylene glycol/ softened by 12.5 % /by weight/ of ChS 200 polyester resin /on the basis of adipic acid and diethylene glycol/,
- softened epoxy binder CONCRETIN GMH /F.R.G./.

The table gives fundamental resulting data obtained by the tests on the RGM apparatuses.

The measurements on free shrinkage test pieces are important particularly for easy determination of the change of values of shrinkage ω as a function of the flooring material age /or thermal curing/ from the moment the test piece has been taken out of the mould. The absolute value of the "free" /unconstrained/ shrinkage is informative, as it depends considerably on the separation or de-moulding time. For the sake of comparison the long-term values of "free" shrinkage of older test pieces are given in Table 1.

The tensile test affords further important information about the characteristics of behaviour of the material in the stress regions under observation and the change of their properties after thermal curing. The characteristics of stress/strain diagrams of tensile tests of flooring materials given in Table 1 are graphically presented in Fig. 9.

On the basis of an assessment of the tests of the afore mentioned set of 55 types of flooring materials by the RGM apparatus and the twenty years' experience with the practical application of jointless resin flooring materials it can be stated that the ascertained relative values of the stress state due to hardening shrinkage and temperature drop correspond most with reality. The ascertained stress state represents an integral assessment of several quantities in actual dependence on their variables and on the rheological properties of matter. The values of residual shrinkage ω_R and relaxation moduli of elasticity E_r ascertained up to 60 min. after the test piece separation /in 10 minutes' intervals/ are not stationary yet in the majority of cases, and the short time of their monitoring makes it possible to determine the viscoelastic behaviour of the test specimen only informatively /e.g. the mean relaxation time/. The different course of viscoelastic behaviour and the recording of only transitory values of residual shrinkage influences also the determination of the coefficient of linear thermal expansion α_R, which must be considered only as a supplementary information to a more accurate value of α ascertained on the free shrinkage test pieces.

The results obtained by the RGM apparatus tests have confirmed the low /in some cases even immeasurable/ values ofstress state due to shrinkage during hardening σ_ω. These values increase in all cases after thermal curing, but in high quality types the increase is not substantial. On the basis of test results it can be stated that the majority of tested flooring materials will be satisfactory in respect of performance safety at constant temperatures. The danger of failure originates primarily by a temperature drop, when the stresses increase considerably. The ascertained values of $\sigma_{(\omega+T)}$ are high. In the majority of epoxy types the stress state ascertained varied within the limits of 3.6 and 6.0 MPa /the values below 2.0 MPa being only exceptional/, and a major increase of stress state after thermal curing only worsens assessment.

From the number of 55 tested systems none is optimally satisfactory from the deformation and rheological viewpoints for cast flooring layers in the cases of major temperature drop, although some of them are - according to the producers' statements - directly intended for the application of cast floors.

In the case of the materials contained in Tab.1 the unsatisfactory stress state of the SD 1330 flooring material at a temperature drop can be reduced considerably by admixture of corundum filler. Cast flooring material in this formulation, however, can be safely applied only in interiors, where only unsubstantial temperature drops can be assumed. The ChS 104/200 polyester binder is obviously unsuitable for cast layers and its impact toughness and ultimate deformation are low, too. The best results in the four types compared were ascertained in the case of the CONCRETIN GMH binder in which, in spite of stress state increase after thermal curing, the stress state value at a temperature drop lies at the lower boundary of values ascertained in all tested epoxy binders usable for flooring purposes. However, after thermal curing a substantial reduction of ultimate deformation was ascertained. The impact toughness is only average.

It is only natural that the properties of composite flooring materials formulated with the use of tested binders, particularly in the composites of the 2nd and 3rd types /bonded fillers/ will differ considerably and some unfavourable binder properties will be eliminated. An interesting achievement of the

RGM test in this connection is the ascertainment of the influence of the use of standard quartz filler which reduces effectively the stress state only in case of its high contents in the mix /bonded filler/. The use of fine-grained quartz filler /e.g. of 0.1 - 0.2 mm grading/ in the amount still enabling the self-levelling of the flooring material, on the other hand, results in the deterioration of the properties /increase of the stress state/ at a temperature drop in the majority of binder as compared with unfilled and, consequently, more elastic mixes. Stress state reduction was ascertained in the mixed corundum filler /see SD 1330 + corundum in Table 1/ due, on the one hand, to a more homogeneous transition of properties from the base to the floor covering /marked filler sedimentation towards the contact zone/, on the other hand to a considerable reduction of thermal expansion. In spite of an increase of the modulus of elasticity the overall result in respect of the stress state at a temperature drop is more favourable than in the case of unfilled flooring materials. A further reduction of the stress state can be achieved by the immediate sprinkling of the applied layer with corundum or quartz filler /e.g. of 0.3 - 0.7 mm grading/.

In the composites of the 1st type /filled binder/ the reduction of the stress state due to a temperature drop by means of fillers is more successful in the case of harder flooring materials. Some of the tested systems which were favourable in respect of their stress state are often of insufficient hardness and slow strength increase. Also a decrease of fracture energy with increasing loading velocity manifests itself in them markedly, particularly after ageing or thermal curing.

The set of ascertained properties represent already a sufficient basis for objective information on the performance safety of flooring materials with regard to their stress state. However, the values obtained cannot be unified and it is impossible to prepare a "recipe" for a relative comparison of types. Apart from the ascertained stress state values also other ascertained values are significant. Therefore, it is necessary to define a narrower set of decisive properties in accordance with the purpose of the material. As a rule, however, a flooring material with a markedly lower stress state value and satisfactory service resistance is most suitable. The need of attaining a higher stress safety in the contact joint between the floor covering and its base is accentuated by the possibility of absence of one of the assumed prerequisites for the application of the flooring material and the possibility of origin of unforeseen changes in the floor loading.

The result of the tests of various types of flooring materials carried out so far are unsatisfactory. It is obvious that little attention has been paid so far by the research of resin and flooring materials producers to the set of properties determining the long-term performance safety of their applications with regard to their stress state. It is necessary to achieve better parameters to increase durability and scope of application of highly effective cast and screeded flooring materials.

Laboratory methods cannot evaluate exhaustively the durability of new materials in the conditions of their actual application. Comparative tests, however, can enable a comparison of the fundamental properties of new materials with the properties of materials well proven in technical practice, assess the degree of their suitability and determine with a high probability, whether they will or will not prove satisfactory in service conditions.

The results of tests made by the RGM apparatus have proved the justification of the methodology of ascertainment of relative values of linear stress state of flooring materials as well as their ability to afford further important information required for their assessment.

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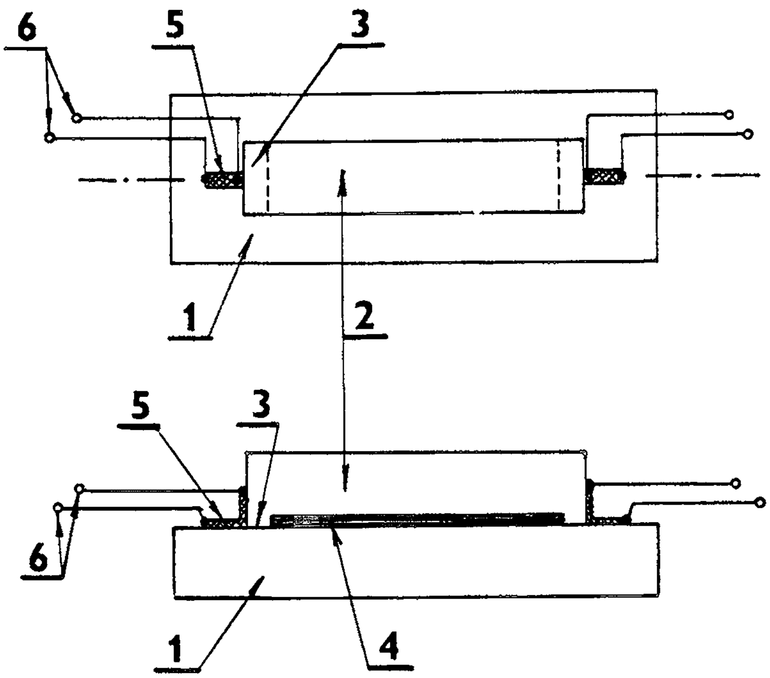


Fig. 1: Diagram of relative stress state test and method of crack origin indication

1 - concrete base plate
2 - 4/4/16 cm prism
3 - contact surface
4 - polyethylene plate 2 cm thick
5 - layer of brittle electrically conductive varnish
6 - power supply

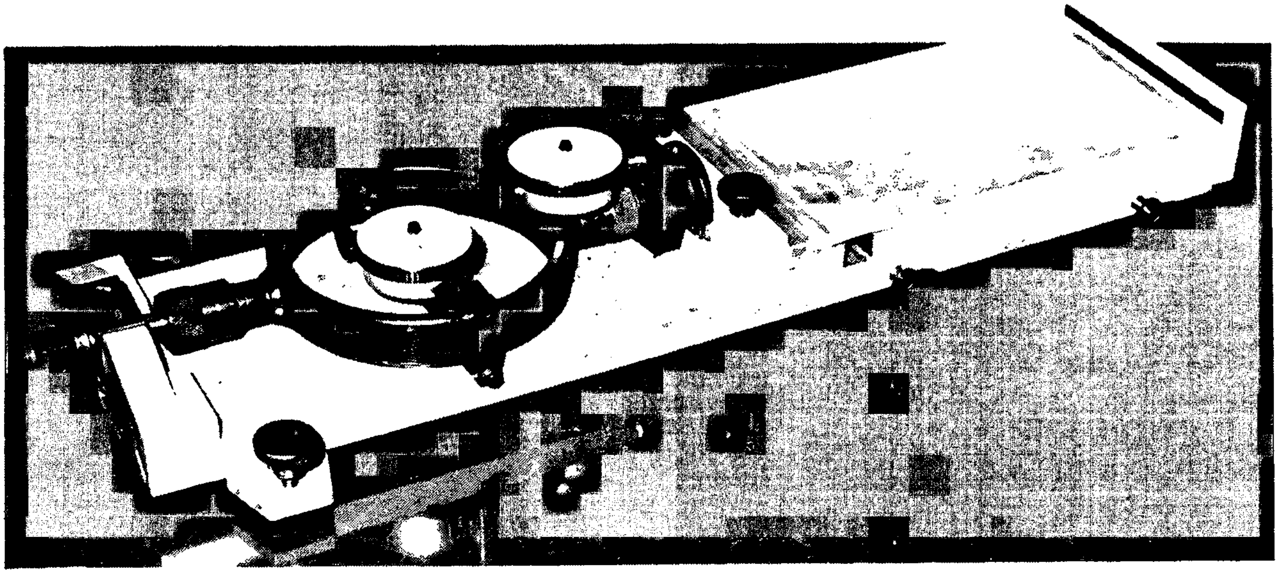


Fig. 2: Type RGM 03 testing apparatus

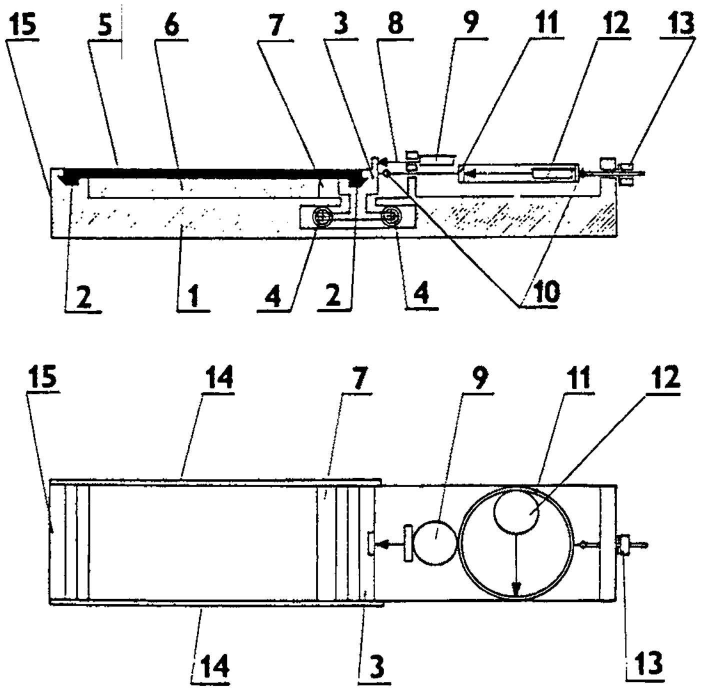


Fig. 3: Schematic representation of the RGM 03 testing apparatus

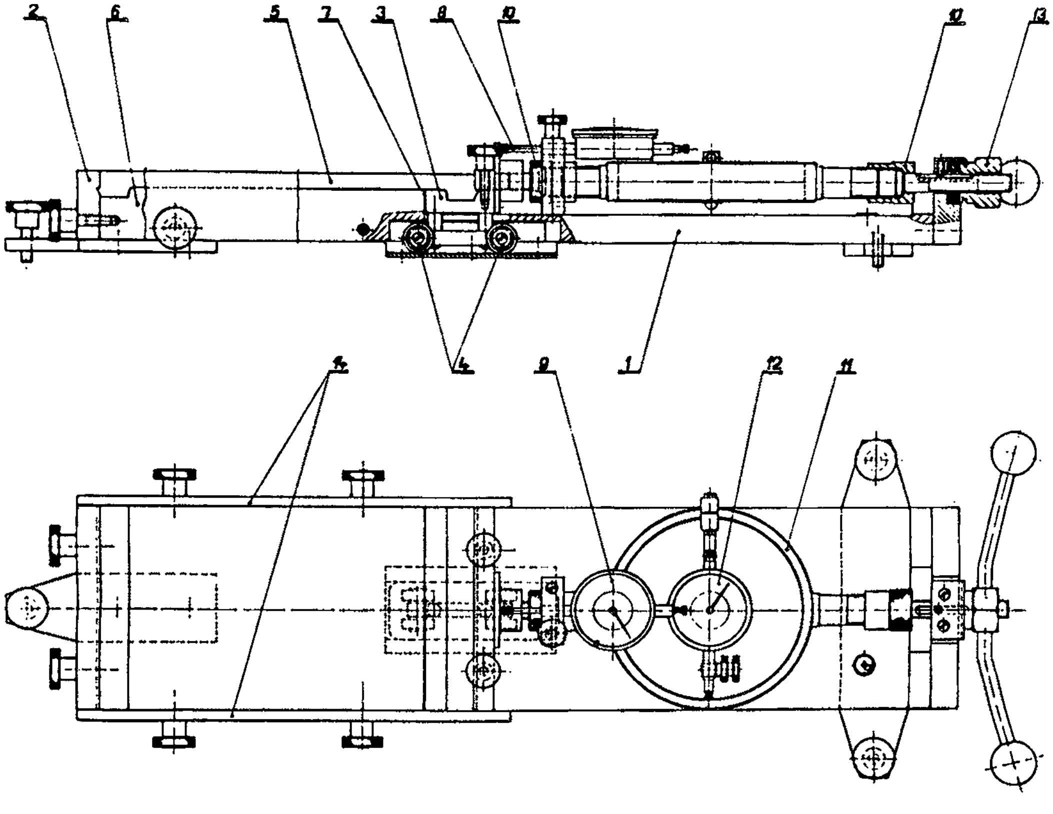


Fig. 4: Actual structure of the RGM 03 testing apparatus

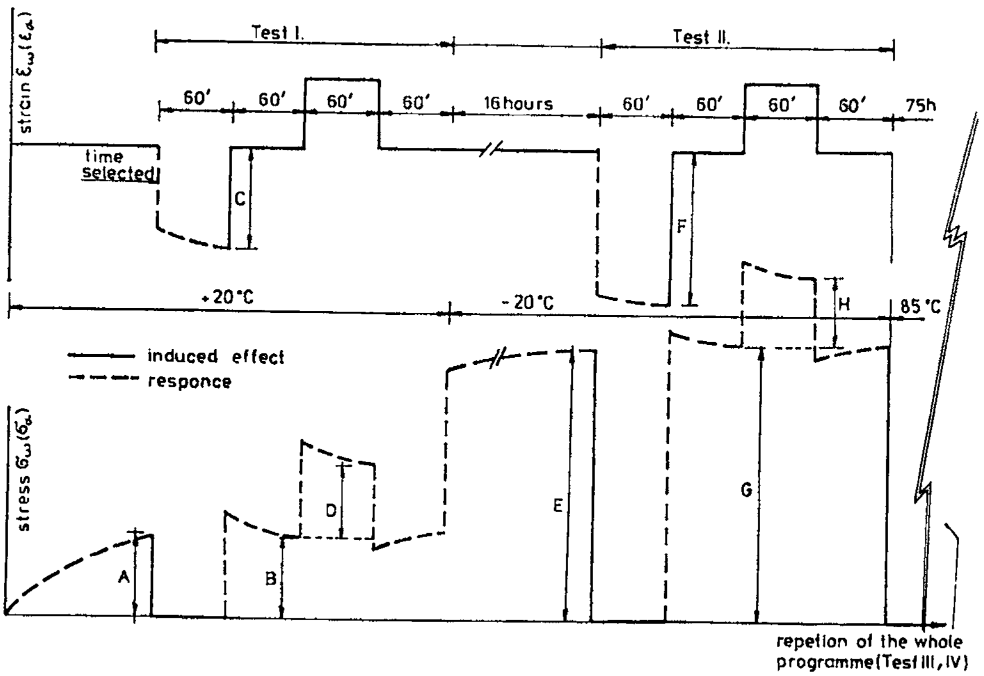


Fig. 5: Test procedure in the RGM 03 apparatus

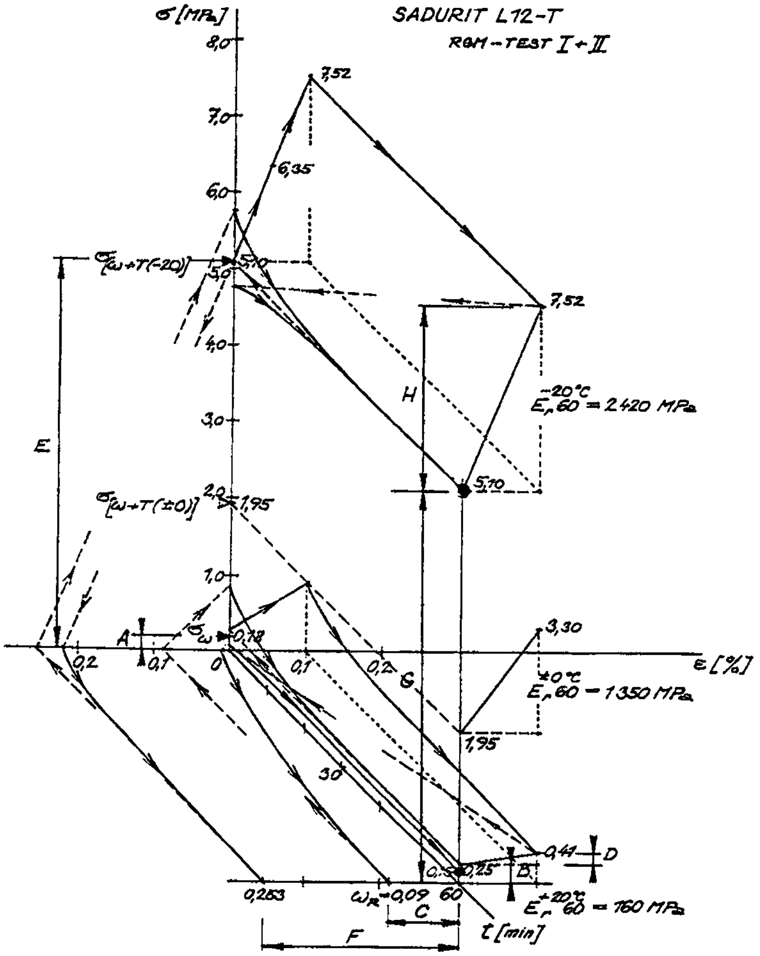


Fig. 6: Results of RGM tests (test I and II)

σ_ω ► Test I Beginning
● Test I Finish
σ [ω +T (-20)] ► Test II Beginning
⦿ Test II Finish

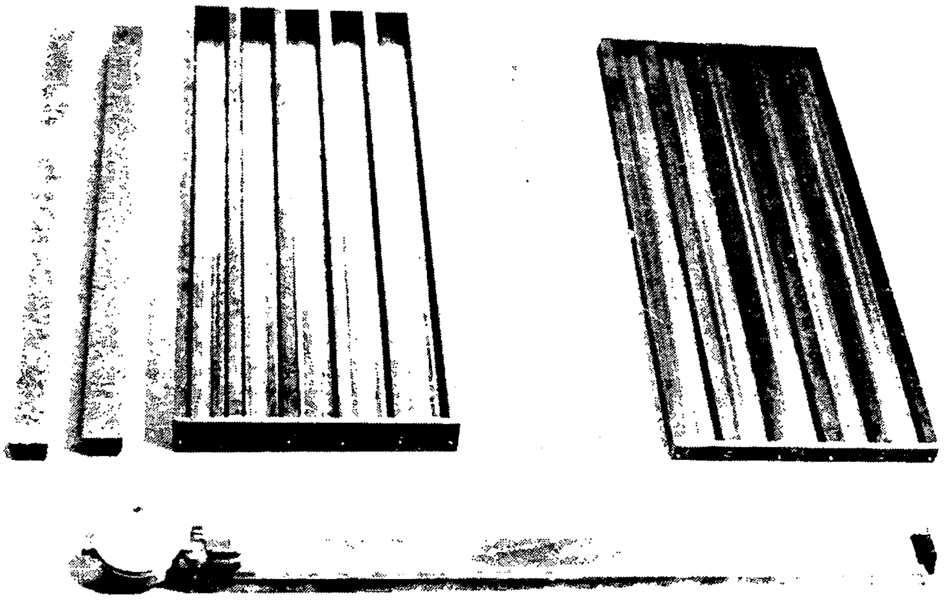
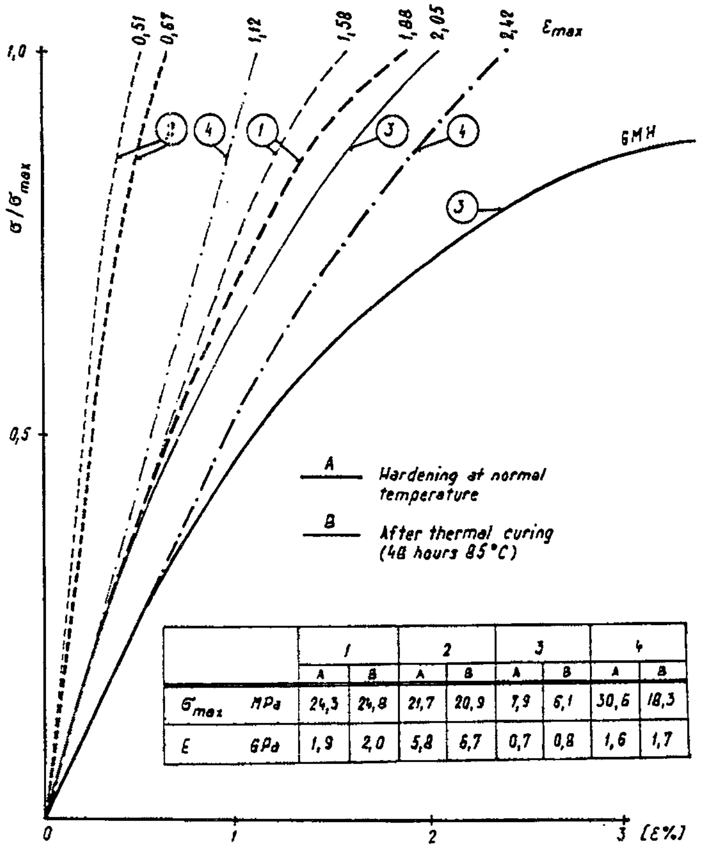


Fig. 7: Test speciemns and gadget for free shrinkage measurements



		1		2		3		4	
		A	B	A	B	A	B	A	B
σ_{max}	MPa	24,3	24,8	21,7	20,9	7,9	6,1	30,6	18,3
E	GPa	1,9	2,0	5,8	6,7	0,7	0,8	1,6	1,7

Fig. 8: Characteristics of stress/strain diagrams of the tensile test

1 ChS SADURIT 1330 epoxy
2 ChSSADURIT 1330 epoxy + corundum filler
3 CONCRETIN GMH epoxy
4 ChS Polyester 104/200

		ChS SADURIT 1330		ChS SADURIT 1330 + corundum filler		CONCRETIN GMH		ChS Polyester 104/200	
		Hardening at 20 °C							
		A	B	A	B	A	B	A	B
RGM Test	Stress due to shrinkage σ_{ω} /+20°C/ /MPa/	0,00	0,47	0,19	0,24	0,00	0,16	0.58	2.43
	Stress due to shrinkage together with the stress due to the temperature drop of 40 °C $\sigma_{\omega+T}$ /-20°C/ /MPa/	5.00	5.97	3.31	4.62	1.85	2.75	6.79	8.67
	Relaxation modulus E_r /+ 20 °C/ /MPa /	498	877	817	1773	000	57	1136	1117
	E_r /- 20°C/ /MPa /	2281	2243	3112	3147	993	1331	2344	2920
	Residual shrinkage ω_R /%/	0.000	0.091	0.008	0.014	0.000	0.097	0.058	0.224
	Coefficient of linear thermal expansion α_R / 10^{-6} /	108	126	48	61	117	112	62	55
Free deformation test	α / 10^{-6}/	104	107	55	38	117	109	81	83
	Free shrinkage ω /%/	0.054	0.105	0.016	0.098	0.330	0.464	1.200	1.340
		0.100	0.116	0.000	0.112	0.406	0.506^{+}		1.462^{+}
	ω	662 days		662 days		0.408	0.506^{++}		1.478^{+++}
Tensile test	σ_{MAX} /MPa/	24.3	24.8	21.7	20.9	7.9	6.1	30.6	18.3
	ε_{MAX} /%/	1.88	1.58	0.675	0.51	15.18	2.05	2.42	1.12
	E /MPa/	1.880	2.037	5.780	6.750	730	770	1.586	1.710
	Drop of modulus of elasticity ΔE /MPa/ at $\sigma = 1/3\sigma_{max}$ during 2.5h	916	971	3329	33982	698	648	890	997
	ΔE /MPa/ at $\varepsilon = 1$ % during 3.5 h	1012	925	2899 /0.2%/	2789 /0.2%/	403	390	599	692
	Impact toughness / $J.m^{-2}$/	8,27	10,37	4.87	5.06	5.22	4.65	3.56	2.11

A - 14 days

B - 14 days + thermal curing at 85 °C for 48 hours

+ - 3 years

++ - 6 years

+++ - 5 years

Tab. 1: Examples of test results