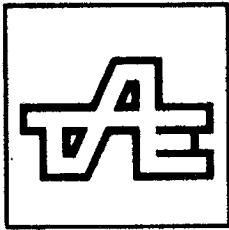


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Some Notions on Jointless Synthetic Floor Coverings

Meinungen zu fugenlosen Beschichtungen aus Reaktionskunststoffen

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1. INTRODUCTION

In literature as well as in practice we can encounter the most varied classifications of jointless synthetic floor coverings: according to their thickness or according to the method of their application /coating, cast floorings, screeds, polymer mortars, polymer concretes/, according to their purpose or type of plant /those which can be walked-on, driven-on by light-duty or heavy-duty vehicles/, according to the place of their application /interior, exterior, wet environment, dry environment, etc./, according to the base they are applied to /concrete, cement screed, anhydride, etc./ or according to some specific characteristic /flexibility, hardness, electric conductivity, skid-resistance, abrasion resistance, etc./.

All these classifications certainly serve their purpose when selecting and assessing the floor coverings according to the selected criterion. However, since they mostly have not physical basis, they cannot afford an objective picture of the sum of short-term as well as long-term properties, performance and service life of the floor covering and the whole floor system or to explain them, and the optimization of the system for the given purpose lies more or less in the empiric plane, depending on experience and technical erudition of the designer /if we neglect purely commercial criteria which, unfortunately, often dominate/. Every individual system must be then verified by empiric methods, modified, if necessary, and again verified.

We should like to look at the matter from another, more principal, physico-mechanical viewpoint, and consider the floor as a complex structural system, in which the floor covering and its base courses consist of composite materials, the behaviour of which is governed by certain laws, and the whole floor forms a composite system the individual layers of which are in mutual interaction and influence one another.

The objectivization of the performance incorporating - apart from properties - also complex stress and strain states of the floor covering and of the whole floor system, can be based only on structural characteristics comprizing both geometrical and physical parameters. If we look at the jointless synthetic floor coverings from this viewpoint, we can classify them in accordance with the schematic diagram shown in Fig. 1 into three or four separate groups markedly differing in their physical behaviour and their response to outside actions. Apart from the pure /unfilled/ polymer, applied only in the form of coatings either by brush or a spray-gun /generally unsatisfactory for industrial floors/ the remaining floor coverings break up from the structural-geometrical point of view into two types:

filled binders /cast floor coverings, screeds/ and bonded fillers /polymer mortars, polymer concretes/. The former system, characterized by that its particular particles are segregated in the polymer, i.e. are not in the so-called force contact and, consequently, the stress transfer is carried out exclusively through shear flows in the matrix, is the composite of the 1st type. /1,2,3/. The latter system, characterized by that the stress transfer is effected mostly by normal forces among the particles of aggregated structure, can form - in accordance with the type of the ever present fluid phase - the composites of the 2nd or 3rd types. As long as the fluid phase is enclosed in disjunct pores, it is the composite of the 2nd type /polymer mortar or polymer concrete with closed porosity/; if the fluid phase can communicate with external environment, it is the composite of the 3rd type /polymer mortar or polymer concrete with open porosity/.

There arises a justified question as to why the composites are structurally divided in this very manner, what are the reasons for this classification and what does it contribute? Let us look first at how the various properties of the composite vary with the change of structural arrangement, expressed - for the sake of simplicity - by the ratio of the solid phases, the binder to the filler. Fig. 2 shows quite indubitably that all properties vary continuously and monotonously in the first and the third parts of the diagram, corresponding with the composites of the 1st and the 3rd types. A sudden change occurs always in the central part of the diagram, in the area corresponding with the composite of the 2nd type. The classification into these structurally different types makes it possible to predict for every type the changes of characteristics with a far greater assurance; it will enable even to control the properties of the composite to a considerable extent without any exacting, costly and long-term experiments and without empiricism. In some works the methods of calculation of elastic and physical properties of structural materials incl. their physical interaction with ambient environment have already been described /4/, for other properties analogous methods can be expected. There will remain only a single problem which requires a concentration of attention: what properties are we to require from the floor covering material in accordance with the composition of the whole floor system and the way of its use.

If we outline simply the various possible systems of synthetic jointless floor coverings in a triangular binder-filler diagram /Fig. 3/, we can see that the porefree mixtures /cast floor coverings, screed/ form a marked minority of possibil-

ities /on the diagonal only/; the polymer mortars with closed porosity /densely hatched area/ cover only about 1/20 of the triangle surface. Other systems /with the exception of a part of the unhatched area/, representing cast floor coverings or screeds with closed porosity/, i.e. the prevailing majority of combinations of binder, filler and the fluid phase /pores/ have not practical meaning for floorings.

The individual types, naturally, can be combined in a single flooring material /stratified floorings/; apart from that it must be borne in mind that the floor covering is only one part of the whole floor system which - as a whole - is decisive for its performance.

The performance of the floor system is influenced decisively by a major set of physical, chemical and physico-chemical properties of its components, the system and its environment /incl. its base/. In every group, however, other properties are of decisive weight, which is shown, in a much simplified way, in Fig. 4. The highest requirements in respect of the number of properties to be observed separately, are imposed by cast floor coverings and screeds, i.e. the very types which are most widely used in construction practice.

The selection of components influences, apart from the required initial properties of the composite, also the primary state of stress /due to the factors connected with the birth of the material, its polymerization shrinkage, influence of exothermy and of the solidification cooling/ as well as the secondary state of stress due to the action of external factors after solidification. Primary stress state should be as low as possible at the "birth" temperature mostly near the temperature of application, and the secondary stress state should be as homogeneous as possible. Apart from that the system must contain a sufficient number of energy barriers preventing or retarding defect propagation. The relations among the phases of the system, the system, external environment and properties, primary and secondary stress state and the performance of the composite are shown, on the example of a polymer mortar /polymer concrete/ in Fig. 5.

Let us have a closer look now at some aspects of the stress state of the system basing our considerations on the assessment of the floor as a structural system /composite system consisting of the floor covering and its partly impregnated base course, an insulating layer and the load-bearing structure/ and on the assessment of every layer as a further substructural system.

2. BINDER SHRINKAGE

The polymerization of a resin, which takes place after it has been mixed with other components, is a heavily exothermal process, accompanied always by volume changes due, on the one hand, to polymerization shrinkage, on the other hand to cooling after solidification. By means of various modifications /chemical or genetic/ the polymerization shrinkage can be limited; in the case of exothermy only its history can be modified.

The filler segregated in the binder reduces the shrinkage of the system until a filler aggregate is formed. The further reduction of the binder reduces the overall shrinkage only very little; on the other hand, the inner primary stress state continues to diminish. In aggregated systems the shrinkage drops with increasing compaction.

Shrinkage produces stresses, on the one hand, in the substructure of the hardening layer /tensile stresses in the resin, compressive stresses in the filler, and shear stresses at their contact/, on the other hand in the composite system as a whole /tensile stresses in the floor covering, compressive stresses in the base course, and shear stresses at the contact of the individual layers/.

The stresses in the structure of a bonded filler /polymer concrete/ due to shrinkage of the matrix are estimated, on the basis of experimental investigations /5, 6/ at at least 2.5 - 3.0 MPa for the binder with high polymerization dynamics, tensile strength in excess of 30 MPa and ultimate strain of about 1 %; in unsuitable resin systems these stresses can attain even the strength value. The shear stresses attain, after hardening, according to investigations /7, 8/ 27 - 15 % of normal tensile stresses, if ratio of the binder and filler moduli of elasticity is about 1/10. At the same time the growth of the shrinkage of the binder /or of a part of the composite system/ in time may be only so quick as to enable the relaxation of the part of the originating stresses thanks to the creep of the individual phases or a part of the system or phase contact and, naturally, not to exceed the momentary strength values. In other words: the slower the progress of polymerization, the more advantageous /lower, more homogeneous/ the stress state due to stresses generated by the polymerization volume changes.

The binder modification, therefore, should aim at influencing the dynamics of growth of the macromolecular infrastructure so as to make the growth of viscosity slower than the growth of the system shrinkage. This can be achieved, for example, by the growth of long linear chains at the beginning of polymerization and their cross-linking only at the end of the polymerization process.

The stress state due to shrinkage in a structural system consisting of a polymerizing binder and a filler is, as we have already mentioned it, the lower, the lower the volume of binder in between the filler particles, which is the consequence of adaptability of the weaker partner under the action of interphase stresses. For this reason also a certain volume of voids /closed/ in the system is advantageous /9, 10/, which can be achieved, on the one hand, by the reduction of the absolute quantity of the binder in the system, on the other hand by the reduction of the mean thickness of its layers. Moreover, the voids will enable, without the origin of major stress peaks, considerable deformation of the individual connecting links formed by the binder. According to experimental investigations /6/ the characteristic stresses /due to shrinkage/ in models with a pore were lower by as much as 12 %, and the overall stress reduction /in terms of energy/ amounted to more than 15 %. A lower mean thickness of binder layer can be achieved also by a denser arrangement of filler particles /optimum granulometry-grading, intensive working/. A significant reduction of primary stresses in a structural system can be achieved also by the use of a "binder" prepared previously by mixing the resin with a certain amount /50 - 100 % by weight/ of microfiller with particles several times as small as the average thickness of the envelope of major particles /i.e. min. below 50 μm /. Without imparting mechanical properties this method results also in a considerable reduction of costs of the product.

Practically for the same reasons as in the structural system itself also the shrinkage stresses in the contact joint with the base course are the higher, the higher the thickness of the hardening layer. This is of importance particularly in the unfilled or little-filled systems with high overall shrinkage. The overstepping of ultimate deformation at the contact of adjacent layers results in immediate or subsequent sudden destruction of the whole floor covering. On the other hand, overstepping of momentary strength values by the shrinkage stresses in the structure of the hardening layer results usually only in the origin of microdefects which can, only in a subsequent phase and for different causes /e.g. under aggressive attack/, become the origin of overall failure or reduction of service life.

The above mentioned findings about the influence of polymerization volume changes lead to the requirement that

- the average thickness of segregated /cast layers and screeds/ floor coverings should not exceed 3 mm,
- the binder:filler ratio in aggregated floor coverings /polymer mortar, polymer concrete/ should be within the limits of 1:1 - 1:12 /depending on the specific surface of the filler, viscosity, and intensity of mixing and working/,
- the full hardening of all floor coverings should proceed gradually, within at least 24 hours.

3. THERMAL EXPANSION

The coefficient of thermal expansion of a pure resin varies within the limits of 6 and 11×10^{-5} ; it is many times as high as that of other materials used in the floor covering and in the floor system. Any change of temperature from the "birth" temperature, at which the polymerization of the resin proceeds, brings about the origin of further internal stresses in the floor covering and in the whole flooring system.

In the flooring structure with quartz $\alpha = 0.8 \times 10^{-5}$ / a difference in linear deformation of 0.072 % against the resin is produced by a temperature change of 10 °C. According to experiments mentioned in the preceding part this difference generates stresses of the order of 5.0 MPa /of opposite signs in the binder and in the filler/. The different deformations of both partners generate a shear stress of 0.7 - 1.3 MPa /depending on the velocity of temperature change in the contact joint. A role of great importance is played by the thermal capacity of the flooring: the higher the thermal capacity /e.g. of polymer concrete/, the less vulnerable the flooring is by temperature changes. However, it has been ascertained that significant internal stress state or even the origin of microdefects in the structure of the flooring due to thermal loads can occur only rarely.

Far more serious is the influence of temperature changes in the composite system as a whole. The coefficient of thermal expansion of a segregated structure of the flooring similarly as the shrinkage, drops speedily with the increasing quantity of filler, while after filler aggregation the further changes due to the reduction of binder content are very small. The great difference of coefficients of thermal expansion can exist also between the individual layers of the floor covering /wearing course - cast, load-bearing course - polymer concrete/. The thinner the floor covering layer and the lower its thermal capacity, the higher the speed with which it will react to temperature changes, and the less advantageous it becomes - due to the lower possibility of utilization of relaxation mechanisms /in contrast to the effects of shrinkage/.

The drop of temperature below the "birth" temperature is always more unfavourable than its increase, as the effects due to a temperature change are speedily added to the effects of shrinkage; simultaneously also the creep and the toughness of the material worsen.

At the contact of different layers temperature changes produce considerable shear and sometimes also normal tensile stresses, the magnitude of which depends also on the moduli of elasticity and deformability. When the temperature drops, the floor covering is axially tensioned, while the base course is compressed. When the temperature rises, the process is inverted. The nearer the moduli of the floor covering and the base, the lower the shear stresses in their contact /and the lower the stress state of the system as a whole/. The speedier the temperature changes, the higher the stress state of the floor covering and of the contact zone.

The course of the shear stress along the thickness of the floor covering /and of the base/ is non-linear, attaining the maximum in the environs of the contact zone. Normal stresses in the floor covering vary along its thickness /also in case of its separation from the base/ only very little. At the edges of a tensile area crack in the contact zone, similarly as at every end of the floor covering /e.g. near the expansion joint/ high concentrations of horizontal shear stresses originate, the peak of which is even three times as high as the mean shear value. The moment of failure depends on a number of circumstances, particularly on permanent strength, stress-strain diagrams, ultimate deformations, creep, etc.

The afore mentioned data on the influence of temperature changes on the stress state of the floor system lead to the requirement of minimization of the modulus of elasticity of the base /while preserving its strength/, the minimization of the binder content of the floor covering, and the minimization of any gaps or ends of the floor covering layer.

4. COMPOSITE ACTION

Every synthetic jointless floor covering either consists of several layers or its density and, consequently, its structural arrangement, is not homogeneous along its thickness. Any afore mentioned changes /polymerization shrinkage, temperature changes/ produce, because of the different physical characteristics of the individual layers, the so-called composite action, i.e. the mutual mechanical loading of the layers by single-sided shear flow, followed by the bending of the system similarly as in the case, for instance, of the bimetallic element. Increase of temperature produces a camber giving origin of considerable tensile stresses in the contact joints of the individual layers, a drop of temperature, on the other hand, lifts the edges originated either in the course of production /expansion joints, ends, openings, working joints/ or spontaneously as a result of internal stresses /tensile area cracks/. In case of major temperature changes the only way to prevent the origin of the defects produced by these stresses is the maximum reduction of the differences of physical properties of the individual layers, particularly the floor covering and the base on the one hand, and a high tensile stress of the bonding layer and the base on the other hand. The best way is the use of aggregated systems /polymer concretes/ with the minimum achievable binder content. The less filled the layer, the thinner it should be to limit its influence on the overall loading of the composite system. Moreover, it is always advisable to arrange the floor covering so that it be symmetrical to its middle plane. That means, for example, that if a surfacing /little filled/ layer is applied to polymer concrete, it is necessary to apply a similar layer /in respect of composition/ also to the opposite face of floor covering as a bonding layer to the base.

5. MECHANICAL LOADS

The loading of the floor covering by a static concentrated load produces transverse horizontal stresses /tensile stresses in the floor covering, compressive stresses in the base/, which can decisively influence the serviceability of the floor covering. Of decisive importance are the moduli of elasticity /or deformability, in case of long-term application/ and the Poisson's coefficients or the differences of the magnitude of these quantities in adjacent layers. Dynamic loads produce, due to the different damping, the higher stress state of the contact zone, the greater the difference of the moduli of elasticity.

The static concentrated loads produce the higher stress state of the contact zone, the greater the differences of Poisson's coefficients. The smaller the thickness of the floor covering /except for the very thin layers of coating character of less than 1 mm thickness/, the greater manifestation of the differences in the afore mentioned quantities and the greater importance of the strength of the base and the mutual cohesion of the layers. The permissible static concentrated loads for the shear strength of the floor covering - base /concrete/ contact joint of 1 MPa and the load distribution under angle of 45°, for various values of the Poisson's coefficient of the floor covering μ are given in Fig. 6.

It is obvious that the thinner the floor covering, the higher base strength is desirable: in the case of millimetre layers 20 - 25 MPa in compression and at least 1.5 - 2 MPa in tension /pull-out test/, in the case of centimetre layers 15 - 20 MPa in compression and 1.0 - 1,3 MPa in tension. This is directly connected with the base preparation before the placing of the floor covering.

6. BASE PREPARATION

The importance of base preparation for the placing of synthetic jointless floor coverings cannot be overaccentuated. From the surface of the concrete base the surface layer consisting of light cement and aggregate particles must be always removed. It is necessary to enable the priming coat /which is also essential/ to penetrate to sufficient depth and thus enable the distribution of shear stresses from a single plane to a whole zone.

To make priming effective the priming solution must penetrate to a certain depth below the surface. At least to this depth the base must be dry, i.e. its pores must be empty. The priming solvent must be so selected as to enable the penetration of the solution to this depth before it evaporates /in dependence on viscosity and surface tension/. If these principles are not observed /e.g. if a speedily evaporating solvent, such as acetone, is used/, the priming does not penetrate and get anchored in the pore structure of the base and the peak of shear stresses at the contact joint has no possibility to become blunt.

The full utilization of the mechanical properties of the base is ensured only, if the shear /tensile/ strength of the contact joint is higher than /or at least equal/ its own strength. This is the golden rule governing the harmony of requirements imposed on the mechanical properties of the base and the mechanical properties of the joint of the base with the floor covering.

7. MOISTURE CONTENT OF THE BASE

The problem which is often discussed is the permissible moisture content of the base. The regulations usually require the moisture content /as a static property/ near the equilibrium value /e.g. 3 % by weight/, but rarely afford attention to the kinetics of the moisture in the system.

It has been found that if the hardened resin is not susceptible to hydrolysis /as some types of unsaturated polyesters are/ and if the surface layer of the base is dried to at least the depth of the presumed priming penetration, a higher moisture content of the base need not necessarily be harmful. Actually in 90 % of all cases the moisture content of the base exceeds the required limit, which everybody knows, but keeps tactfully quiet.

The actual required moisture content depends primarily on temperature conditions of the environment and on the prevailing temperature gradient in the whole floor structure. If it is ensured, for instance, that the temperature gradient will be permanently or mostly negative, i.e. the floor temperature drops from the floor covering downwards, the moisture present in the structure will be transported away from the floor covering. Only if the moisture in the floor structure is permanently transported towards the floor covering, i.e. in case of a positive temperature gradient produced, e.g. by a radiant heating system /critical/ built in the ceiling so high vapour overpressure below the floor covering /with the resistance to water vapours diffusion of at least 2 orders higher than that of concrete/ or even moisture condensation can arise which will exceed the bond strength in the contact joint or the tensile strength of one of the partners, and a local or overall failure of the floor covering will occur.

For this reason, when assessing the moisture contents of the base /as one of its principal characteristics/, it is advisable to take into account also its temperature gradient. It would be desirable - and also more respectable - to amend the respective regulations in this sense.

8. CHEMICAL AND ATMOSPHERIC RESISTANCE

In industrial plants with heavy chemical loads the polymer concrete floors with the binder on the furane resin basis, concretely the furyl-alcohol-furylaldehyde polycondensate, have proved best. An example of its application is the cladding of all surfaces in an acrylic resin plant /Fig. 7, Fig. 8/, where no other polymer concrete had by far satisfied the preliminary tests.

The problem of synthetic floor coverings is the low resistance of all polymers used for flooring materials to atmospheric factors, particularly the UV radiation. However, there are two realistic ways to a successful solution of this problem. On the one hand, the resistance of the composite materials /flooring materials/ against UV radiation increases by jump at the transition from the first to the second type, i.e. after the aggregation of the filler and the minimization of the binder in the system. The tests carried out in the course of 10 years have shown that the degradation of resins in such systems is so retarded that it becomes insignificant.

Another way, particularly in cast floorings and screeds /which, however, are less suitable for exterior applications particularly because of their higher sensitivity to temperature changes/ is the sprinkling of the hardened surface with fine-grained gravel.

It can be concluded that for the hardest chemical loads the flooring systems with furane binder have fully proved in performance conditions. For exterior applications the most suitable synthetic flooring material is polymer concrete, or - exceptionally - cast floorings or screeds densely sprinkled with fine-grained gravel.

9. SUMMARY

Classification of jointless synthetic floor coverings according to structural characteristics of their material system. Primary and secondary internal stress states of the individual systems. Requirements for the selection of a suitable material structure of the composite. Some aspects of the stress state of the floor covering considered as a structural system: influence of binder solidification, thermal expansion, composite action, mechanical loads. Mechanical properties of the base and moisture conditions of the floor system. Chemical and atmospheric resist-

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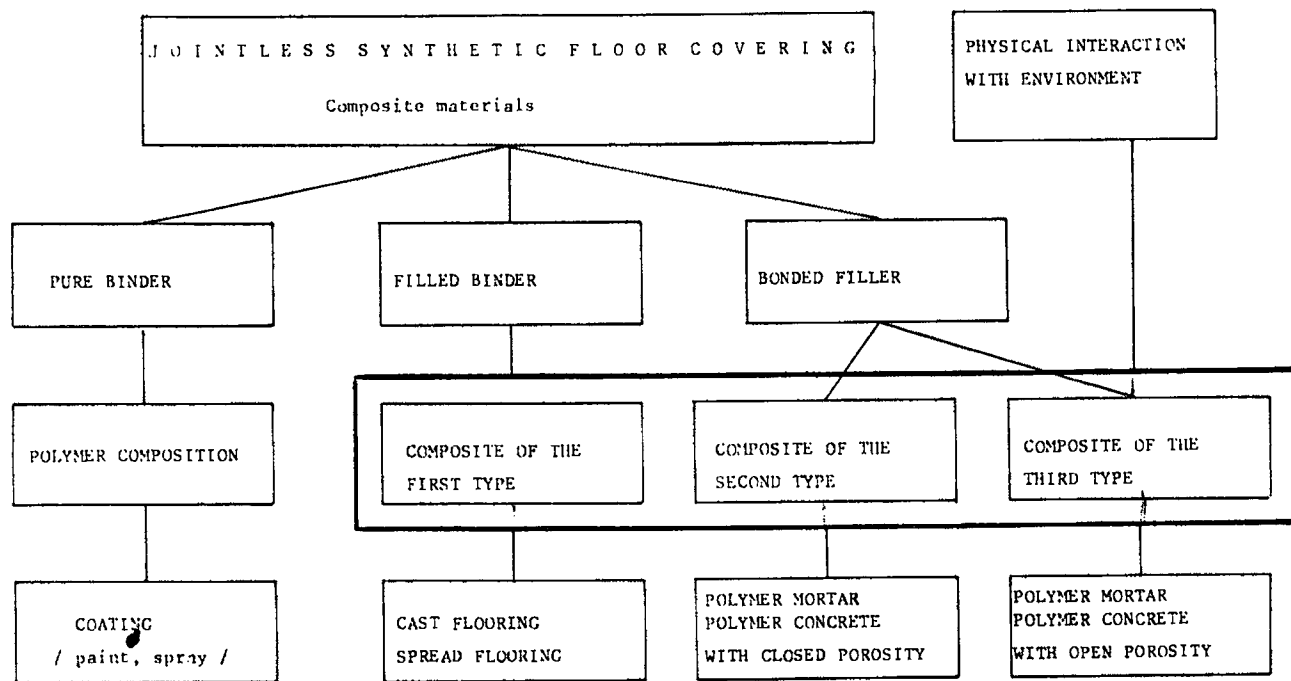


Fig. 1: Structural classification of jointless synthetic floor coverings

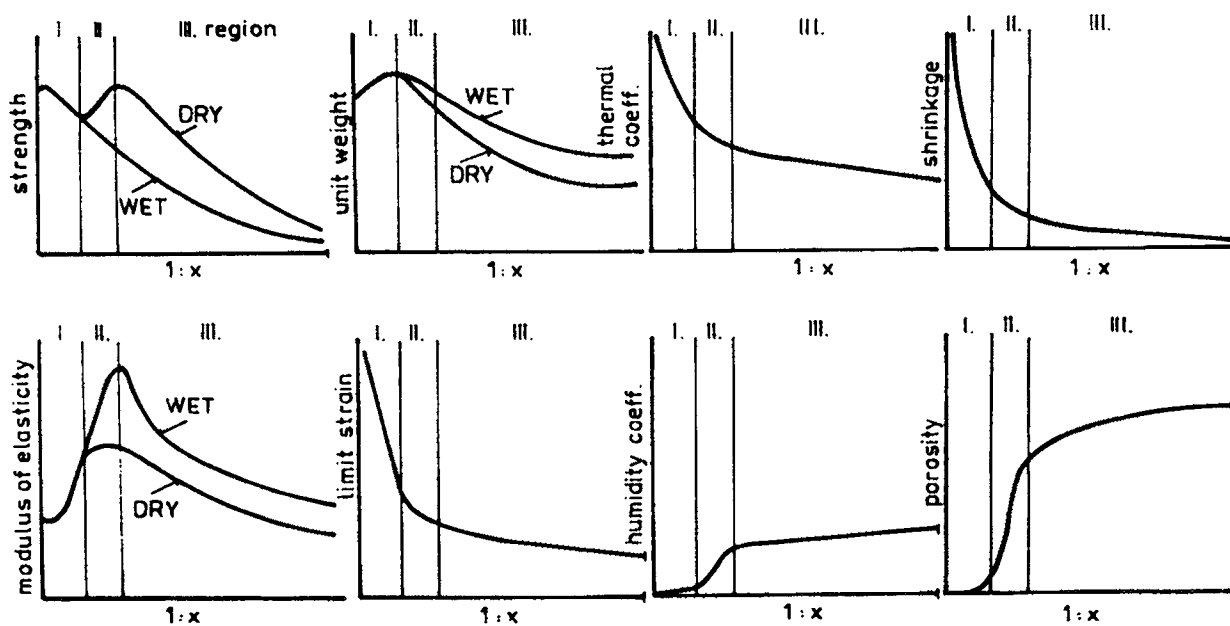


Fig. 2: Changes of various properties of a particular composite material according to the change of structural arrangement, expressed by the weight ratio of the phases (binder to filler ratio)

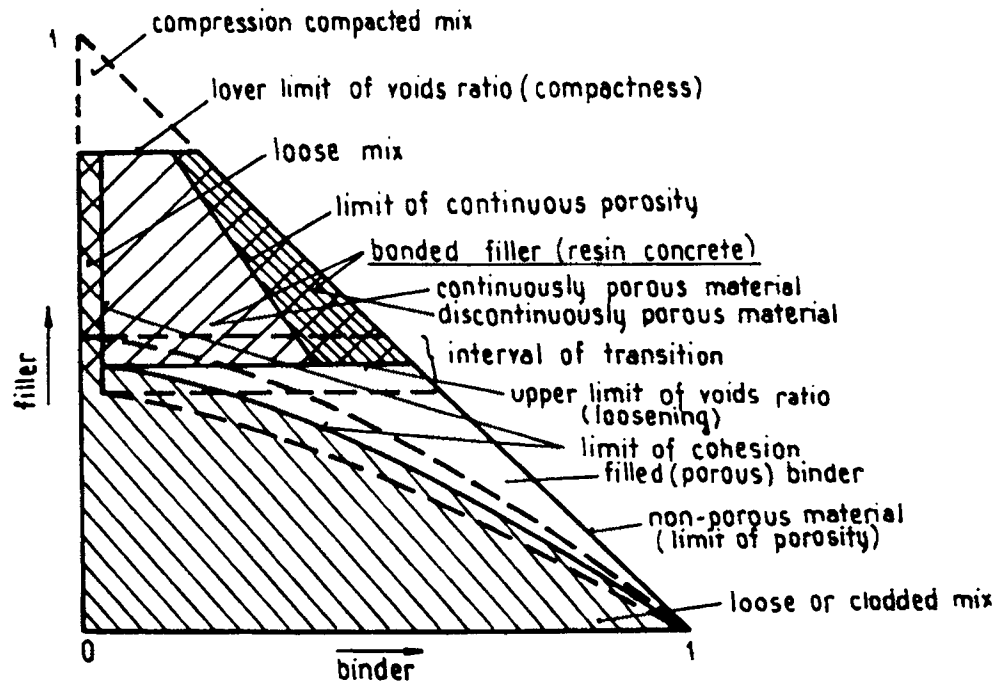


Fig. 3: Location of various floor coverings in the triangular binder-filler diagram comprizing all structural combinations

<p>COATING / paint, spray /</p>	<p>CAST FLOORING SPREAD FLOORING</p>	<p>POLYMER MORTAR POLYMER CONCRETE with CLOSED POROSITY</p>	<p>POLYMER MORTAR POLYMER CONCRETE with OPEN POROSITY</p>
<p>wettability viscosity content of nonreactive diluent /range of porosity/ adhesion to floor boarding abrasion resistance hardness ageing resistance chemical resistance</p>	<p>surface tension /wettability, flushing/ viscosity adhesion to floor boarding dispersion homogeneity limit strain shrinkage thermal coefficient of expansion abrasion resistance hardness creep and relaxation modulus of elasticity toughness /impact strength/ thermal and humidity conditions in the floor ageing resistance chemical resistance</p>	<p>shrinkage strength thermal coefficient of expansion stress-strain diagram limit strain creep and relaxation impact strength thermal and humidity conditions in the floor chemical resistance gas diffusivity</p>	<p>shrinkage strength thermal coefficient of expansion stress-strain diagram limit strain creep and relaxation impact strength chemical resistance humidity coefficient of expansion absorbability</p>

Fig. 4: Set of decisive properties of components, system and environment for various structural systems

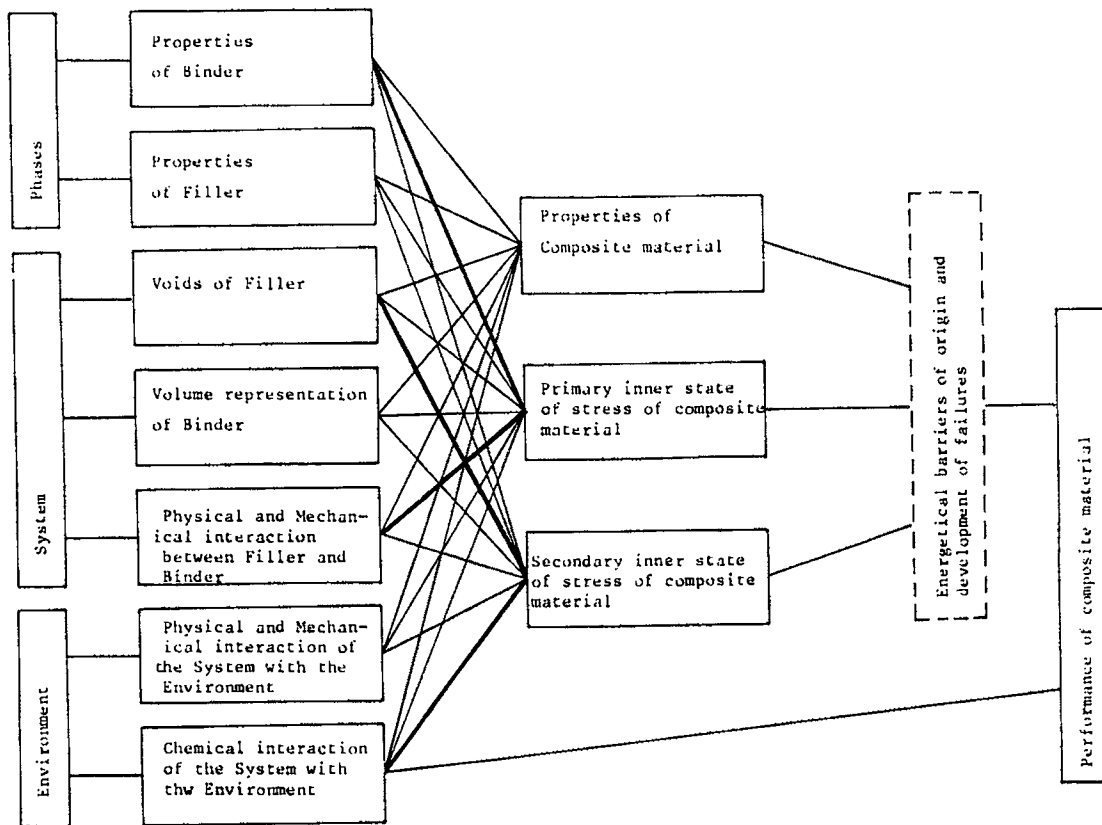


Fig. 5: Schematic representation of links among the phases, the system, environment and performance of the composite.
Example: polymer concrete

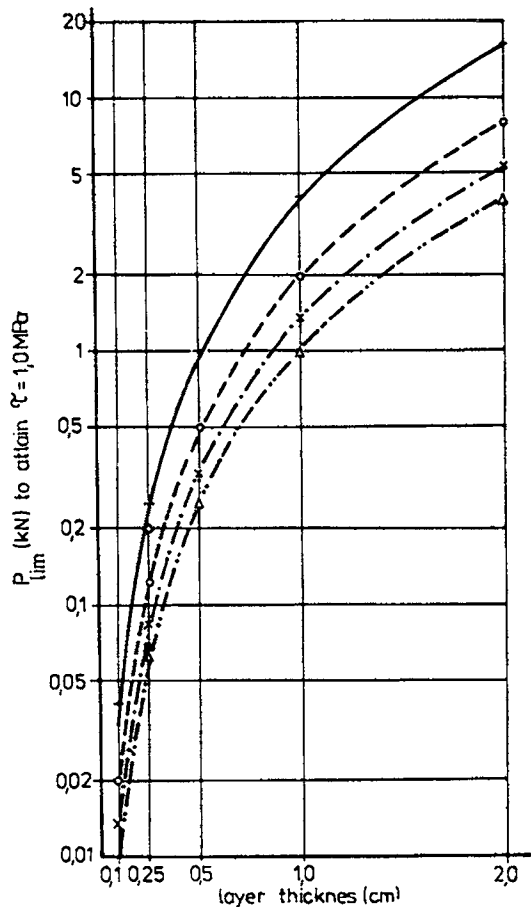


Fig. 6: Permissible concentrated load applied to the floor covering

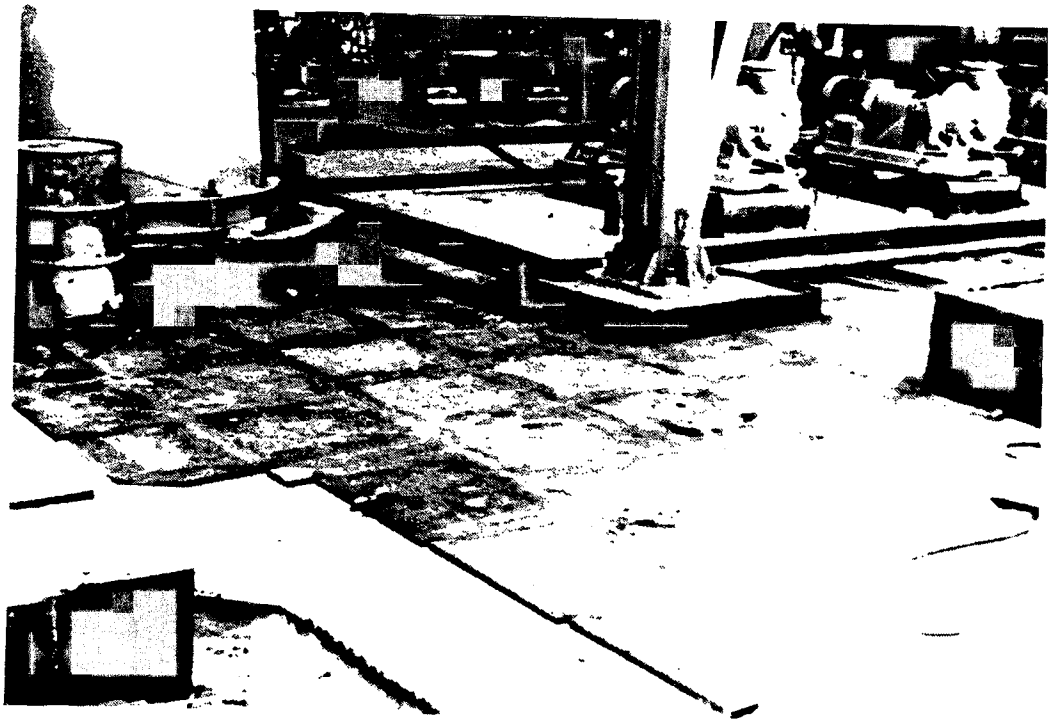


Fig. 7: Precast FPC (furane polymer concrete) plates were placed in a furol-epoxy copolymer mortar bed and jointed with furol polymer mortar

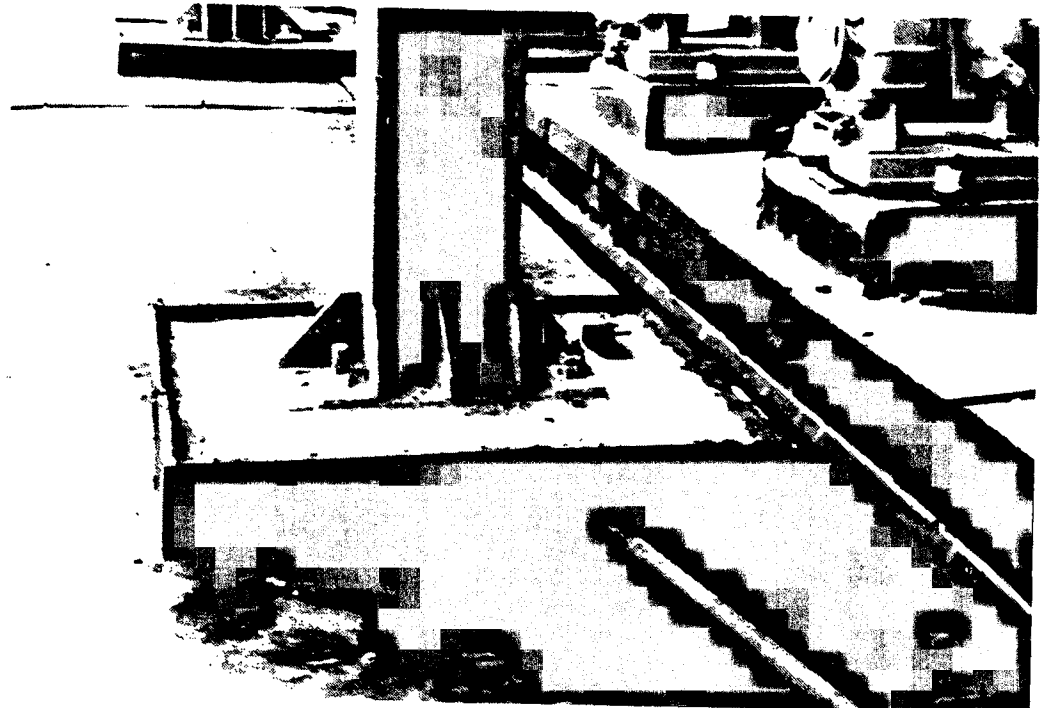


Fig. 8: Special FPC tiles or in-situ cast plates were used for the protection of channels, machine and plant foundations