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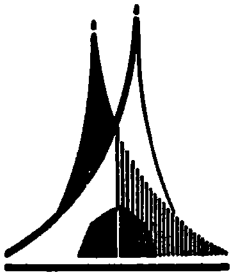

SEPARATUM

CLASSIFICATION OF COMPOSITE MATERIALS AND PLASTICS COMPOSITES

By Richard A. Bareš

Synopsis: A transition from homogeneous /or quasi-homogeneous/ materials to composite materials has become a must in human history, plastics affording one of the widest possibilities of this development. A synthetic survey of the existing widespread analytical research of composites, their deformations, strengths and other properties, as well as practical experience with their applications have shown that the behaviour of composites differs markedly in accordance with their structural composition and is governed by certain fundamental parameters. To master their purposive formulation and to foresee their properties it is necessary to classify composites into three fundamental types: Type I is characterized by a segregated dispersed phase in the matrix with the absence of liquid phase, Type II by an aggregated dispersed phase, the matrix being supplemented also by the presence of a segregated liquid phase, while Type III contains, apart from the aggregated dispersed phase and the matrix, also a continuous liquid phase system communicating with external environment. Such properties as granulometry, morphology, isotropy or anisotropy, physical and chemical properties of the solid phases present, etc., are of secondary importance. Another important factor, influencing markedly the properties of the composites by its inner energy volume, consists in whether the material comprizes only one or more phase- and dimension-continuous solid phase structure. The author gives the parametrization and classification of composites and shows the classification of various plastics composites by a uniform system. Furthermore, he discusses various other factors playing a considerable role in the external behaviour of composites and mentions some bistructural systems.

Key words: civil engineering, classification, composite materials, material engineering, plastics, plastics composites.

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INTRODUCTION

The endeavour to utilize more effectively the raw material resources available as well as to satisfy the ever growing requirements imposed on general as well as specific properties of materials, particularly in connection with new industrial branches and the general development of technology has resulted, in recent decades, in a perfectly obvious transition from homogeneous materials to combined, purpose-designed material systems, or - in one word - composites. The improvement of the properties of homogeneous materials by certain modifications ot their chemical composition or by the application of more sophisticated production technology to influence their physical structure in the endeavour to approach, as much as possible, their theoretical strength values have appeared, so far, as little effective in relation to the expended endeavour. With the exception of intirely special cases, the economic assessment has excluded such materials fully from practical application. Consequently, as a result of his own imperfection and inability to create a perfect homogeneous material, man turned the other way, to the creation of materials consciously and purposively nonhomogeneous, in which he intends to achieve the required properties of the material by a suitable combination of the properties of its components and their controlled cooperation. Nature itself has shown us, on innumerable examples in the biology of plants and animals, that the process of creating a wast number of different materials, each for a certain purpose, certain stress, is obviously more economic than creating a single, universal material with all properties perfect at the same time, the majority of which, however, remains unutilized during the service life of the material. Thus actually the failure of man to find an ideal material with theoretical properties has returned him to the correct way, viz. to the way to create special materials for various purposes, from the design of products from the given materials to the contemporary design of both product and its material.

Inertia and conservatism in the thinking of man, however, are great. Thus, although the trend of development is obvious to the majority of material and structural engineers of today, only few of them have transposed this trend into their every day work. The fundamental approach to material research has not changed much in the majority of cases; scientists and technologists apply time-proven, well-worn patterns and often investigate and describe every individual composite material in the same way they were used in the case of homogeneous materials. Generally speaking, the majority of research works is limited to a certain material "cookery-book writing" and the investigation of the results of the offered recipes. Some specialists endeavour to generalize such results and formulate, on their basis, general theories of deformation and strength of composite materials. Their experimental results are in perfect agreement with their own theories and the other way round. However, it is most unfortunate if another experimentator who has adopted the same approach uses his own data. He obtains entirely different results which are sometimes even contrary to those of the first scientist. Thus he can do nothing else but formulate another theory and further conclusions which are compatible with his own results. In this way we can quote today practically thousands of theories and conclusions on the behaviour of composites. Therefore, it is no wonder that a normal technologist who is not and cannot be profoundly and fully acquainted with all assumptions and input quantities of the individual theories is confused, that practical applications only too often are unsuccessful and sometimes even disastrous. On the other hand, however, some well thought-out designs of composites for certain structural systems are perfectly successful to such an extent that there can be no doubt about the suitability and advantages of the orientation on the composite systems in material engineering. So far, however, there are only very few /and probably only solitary/ cases in which a composite system has been designed on the basis of a profound and well founded hypothesis on its mechanical /deformation/ behaviour. The unique successes attained in some branch of industry necessarily result in unitiated following and copying in other branches. However,the results are often only the afore mentioned failures. Thus we can see, once again, as has been the case frequently in the history of mankind, "the carriage in front of the horses". On the other hand, as a result of frequent enough unsuccessful applications of composites, we often encounter a certain mistrust of the whole development, mistrust of composite materials as such. This attitude naturally only further retards the causally necessary development: should we divide the history of mankind in accordance with the prevailing materials used /which have allways determined the technical standard of other branches/ we could maintain to be at the threshold of an "age of composites". There simply is no other way to the satisfaction of the ever increasing qualitative and quantitative needs and requirements of man and the contemporary ever growing human population.

Sometimes you can hear speaking about the "age of plastics" in this respect. However, plastics alone cannot and probably will not be able to, in the nearest future, solve all material problems, even if we take into account the transition from the C-plastics to the Si-plastics or other types of plastics for which the raw material resources are available. You often hear speaking also about "cosmic age" or "the age of electronics". These branches of sciences undoubtedly characterize the contemporary state of development of mankind. However, the development of cosmic research similarly as that of the electronic industry would be unthinkable without the preceding development of material science. And these very leading branches have influenced most the development of materials in recent decades and have simultaneously shown that the majority of economic solutions and often the only possible technical solutions have been represented by the application of composites.

Undoubtedly man would overcome the contemporary period, full of summersaults and painful bruises obtained in the investigation of the laws of composites even if he would use his "cookery book" methods to the very end of research. However, it seems much simpler, easier and, last but not least, resultative to use systematically the main fundamental principles on which the advantages of composites are based. Their number includes, in the first place, the /macro/ structurality of the system, the interaction /physical, chemical, other/ of the structures or phases present, and the connection of the material system with ambient environment and its purpose. We have so many partial analytical results that we are oversaturated and are unable to digest them all. Therefore, the research should devote at present much more effort to the synthesis of results so far attained rather than increase the number of concrete analyses. Hand in hand with material research and development, there must be also the education of technologists and engineers who must realize, in the first place, the necessity of an integral approach, the necessity of considering simultaneously all properties of composite components used and their interaction with reference to the interaction with ambient environment and the actual use. The engineer simply must learn to see in a material a system and not a matter of certain properties, similarly, as he sees a system in a building, bridge, building structure, contrary to the layman who sees the building as a means of protection against elements enabling him living, working, etc., or a bridge as a means of getting from one river bank to the other without getting wet.

The first step to the knowledge and understanding of the behaviour of composites is the recognition of principal parameters on which their properties depend, and the classification of composites according to the weight of these parameters into individual types.

PARAMETRIZATION AND CLASSIFICATION OF COMPOSITES

Today, we call composite every material system which consists of more than one solid phase with a macroscopically discernible boundary. The individual phases influence the resulting properties of the material, on the one hand by their own characteristics, on the other hand by their mutual interaction. Thus it is possible to attain that the advantageous properties of the individual components are accentuated and their disadvantageous properties are suppressed in accordance with the needs of the designed element or structure. An important and often underestimated aspect of the formulation and assessment of a composite is the integral character of its analysis. For example, in the endeavour to obtain a material of maximum tensile strength one neglects such quantities as the coefficient of thermal expansion, internal generic stress and its influence on creep, relaxation and life expectancy of the material in concrete conditions of use, etc.

In all composites at least one solid phase forms a macrostructural system the principal characteristic of which is that it can exist alone, regardless of the absence of /an/other solid phase/s/. Obviously advantageous are the systems incorporating two or more such mutually independent macrostructures. In some composites it is possible to create another continuous structure of a fluid /gaseous or liquid/ phase which, however, cannot exist alone and which is in a causal interaction with environment. In other composites even a considerable quota of the overall volume may be taken up by a fluid phase which cannot communicate with environment.

Some composites can be considered quasi-isotropic, others are markedly anisotropic.

In all composites, there is a marked interaction of all present structures or phases, both solid and fluid. The interactions are mostly of physical or physico-chemical character; however, even chemical interactions cannot be eliminated. The interactions of the individual phases and structures result in new qualities of the material which cannot be attained by any of its components alone. The necessary prerequisite for a successful interaction of phases is their physico-chemical and chemical compatibility, or at least mutual tolerance. In the majority of composites also interaction with environment and the connection with the manner of use /e.g. mechanical stress/ must not be overlooked. These materials are never universal and are formulated exclusively for specific uses. This makes them economically and energetically advantageous and is the basis of their supremacy in the competition with homogeneous /conventional, traditional/ materials in which the majority of their properties is not utilized in the majority of cases.

In some composites some phase can be of markedly fibrilar character, in others of granular /particular/ character. A frequent type of composites are solid dispersions which can be, analogously with liquids, saturated or unsaturated.

It seems at first sight that it is hardly possible to devise any uniform classification of so vastly different systems. However, a more profound insight into the mechanism of deformation and failure of the individual structures has shown /1, 2, 3/ that such classification is not only possible but entirely necessary if we want to master the laws of purposive formulation and foreseeing of the properties of composite materials.

The fundamental criterion is whether the other /dispersed/ phase, inserted into the matrix, is segregated, i.e. whether it is not in mutual direct contact, does not form its own structure, is in some direction phase-discontinued, or whether it is aggregated, i.e. whether its individual particles are in direct contact, form their own structure and are phase-continuous. This definition, naturally, gives rise to the question what actually the "direct contact" is. Obviously it is a contact of two dispersed particles across a layer of the matrix of minimum thickness, i.e. the particles are at a mutual distance obtainable by a maximally effective processing. The thickness of the matrix between the two particles is 2 - 200 μ, depending on the type of matrix, its viscosity, surface tension, contact tension with the particles, density /molecular weight/ and cannot be changed any more practically by any method of processing available.

The difference between the fibrilar and granular /particular/ dispersed phase lies only in that the former may /but need not/ be at least in some direction phase-continuous, and is mostly geometrically continuous in some direction only, while the latter is always phase-discontinuous. Naturally, the phase and geometrical continuity influences markedly the properties of the composite; the phase or geometrical continuity in some direction only brings about anisotropy which becomes another important factor influencing the direct connection of the formulation of the material with the design of the structural element.

Thus there is a whole number of various systems completely filling the given space, ranging from the pure matrix /Fig.1/ /i.e. a homogeneous or quasi-homogeneous system/ over dispersed particles /Fig. 2/ to a system with a dispersed phase in the densest possible arrangement /Fig.3/, in which the component determining the properties of the composite is the matrix.

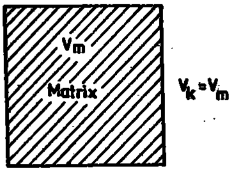

Fig. 1

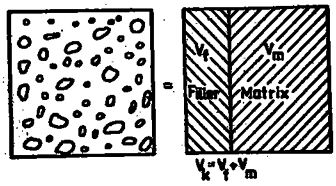

Fig. 2

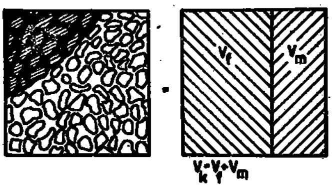

Fig. 3

The whole group of these systems can be classified as <u>Type I composites.</u> The experimental research of such systems, very wide and variagated in its extent, has yielded variagated results on which many, often contrary conclusions have been based. Most frequently the influence of an increasing quota of the dispersed phase in the matrix on the strength has been investigated. The majority of authors have deduced the layman-expected fact that the admixture of another phase /not connected by means of cohesion bonds/ reduces the strength of the matrix. Only very few have noticed that under certain circumstances the reduction of strength is not continuous, dependent on the ratio of the phase volumes only, but that it decreases or becomes even negative, i.e. that the admixture of a dispersed phase does not decrease the strength of the matrix or that it even increases it /4, 5/.

The problem can be solved successfully by energy analysis only. Some authors have approached this solution most by their inveszigations of the impact strength /toughness/ of these composite systems. The problem is how the system is capable of dissipating the supplied energy, dampen or localize microfailures, prevent them from spreading, etc. This ability depends not only on the ratio of the volumes of the individual phases /matrix and dispersed particles/ and their mechanical properties but also on a number of further factors such as:

- ratio of deformation characteristics of the phases /modulus of elasticity, Poisson´s ratio, ultimate strain, deformation modulus, creep, relaxation, etc./,
- ratio of cohesion strengths of the phases and the adhesion strength of their contact,
- ratio of the surface and the volume of the dispersed phase,
- primary inner state of stress due to the formation of the material,
- ratio of the physical properties of the individual phases /coefficient ot thermal expansion, thermal conductivity, electrical conductivity, etc./.

The overestimation of strength /tensile strength as a rule/ in the process of assessment of composites is fairly frequent but generally harmful and often misleading. The conclusions on the value of the material assessed with reference to short-term strength can be made topsy turvy, for example, after several cycles of temperature fluctuation. Apart from that it is often not decisive whether the short-term strength is for instance 30% higher or lower, but what are other, e.g. deformation or physical properties of the resulting material.

We have already said and now I should like to accentuate it that the Type I composites fill fully and without any voids the space they occupy. In the limit /boundary/ Type I composite it is impossible to change the volume of the dispersed phase in the given body /the dispersed phase remains aggregated/; further change of the ratio of the volumes of both phases is possible by a reduction of the matrix only which is replaced by the third phase entering the system, viz. the fluid phase. In the matrix there originate closed pores and the overall ratio of the volume of the solid phase to the volume of the body as a whole decreases /Fig.4/.

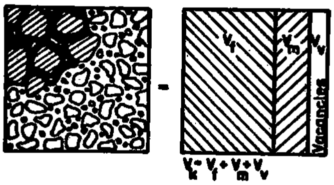

Fig. 4

There originates a three phases system at least whose all properties will begin to differ fundamentally from the preceding systems. The composites of this type form another separate group which can be designated as Type II composites. Theoretically this group terminates with a system in which the third, fluid phase is continuous and forms a certain quasi-structure, thus connecting the system continuously with its ambient environment. Practically, however, this boundary cannot be sharp, as the connection of the individual closed pores into continuous channels proceeds gradually. In contradistinction from type I composites, the solid phase in type II composites does not occupy the whole space defined by the material. If the fluid phase in the vacancies of the matrix is gaseous it is easily comprehensible; if it is liquid it is entirely non-comprehensible. The primary inner stress /due to the formation of the material/, similarly as the secondary inner state of stress /due to external effects/ of the system are different as the vacancies originate, different is also the dissipation of energy, etc. When the pores are filled with a gaseous phase /which is most frequently the case/ the material has a greater possibility of inner deformation without causing the origin of microcracks, and the microcracks which thus originate are soon localized; the dissipation of energy is more marked. An external manifestation of these effects is, for example, a change of both short-term and long-term strengths, an increase of the impact strength and the fatigue strength. an increase of the life and a reduction of the sensitivity to the changes of external conditions /e.g. temperature/. The number of parameters determining the resulting properties includes, apart from the factors characteristic of type I composites /ratio of the volumes of solid phases, specific surface of the dispersed phase and the ratio of properties of the phases/, another parameter, viz. the ratio of the solid and the liquid phases.

As soon as the porosity of the system becomes continuous /without changing the arrangement of the dispersed phase, which remains permanently in an aggregated state as at the beginning of type II composites - Fig. 5/, another /often decisive/ quantity comes to the fore, viz. the inner interaction of the composite with its environment. This changes, once again, decisively the behaviour of the system, which is characteristic of Type III composites. Another necessary parameter which is indispensable for the description of these systems, is the ambient environment. The solid phase occupies an ever decreasing part of the overall /outer/ volume of the composite; the matrix is reduced until its primary structure disintegrates and the material becomes loose, cohesionless /Fig. 6/

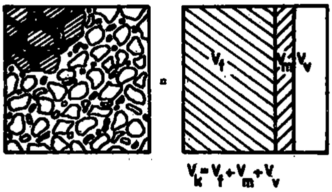

Fig. 5

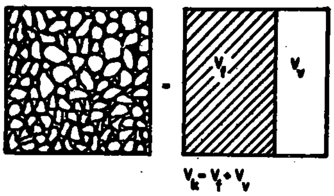

Fig. 6

The state of stress due to the pores is very complex; the stresses cannot affect a void and must, therefore, by-pass the pores. The deviation of the stress flow results not only in the changes in the stress distribution and increase /in the proximity of the pores/, but also in transverse stresses. This applies even to the smallest of pores /10 - 40 μ/, yet sufficiently large with regard to the magnitude of molecules /2 - 3 Å/. The state of stress is becoming more complex if the pores are filled with a liquid, by the affect of its reactions. Since the liquid cannot evacuate quickly under external loads /even if the pores communicate with capillaries/, and since it is incomprehensible, it produces further unfavourable radial stresses. The strength decreases more, according to some observations /6/, for the same volume of pores, if the pores are smaller. This is due to the higher number of unfavourable stresses produced, and not to the magnitude of local concentrations of stresses due to an increase of curvature which is immaterial, or to the weakening of the resisting area which does not change with the number of pores. Of importance is also the observation that the existence of relatively infrequent holes /macropores/, resulting from insufficient filling of coarse aggregate voids with mortar and sand voids with matrix, or the voids from the drops of accumulated and evaporated liquid, producing solitary transverse stresses, are not decisive for the strength. Only a greater occurrence of major voids can manifest itself directly by a reduction of the resisting surface. Similarly unfavourable for the inner state of stress as the pores are fine microscopic local cracks originated by the shrinkage of hardening matrix between solid particles preventing the matrix from shortening. Microscopic cracks originate also from unhomogeneous thermal expansion of the binder and the filler, if the material is exposed to major repeated and sudden changes of temperature /which applies, together with the effect of unequal compressibility of filler particles and the binder /matrix/ to the systems of all three types/. In this respect, the stress of the matrix is most unfavourable, when the filler particles bear on one another /types II and III composites/, so that the dimensions of the binder corpuscle between them cannot change at all. Moreover, the shrinkage of the binder between the filler particles disturbs the adhesion with the filler which in itself can result in considerable losses of strength.

The strength is influenced by imperfection of the microstructure of the materials forming the composite material, and those of the structure of the actual material. The integrity of the structure is disturbed by various defects, fissures, pores, even if of submicroscopic dimensions only. The defects and unequal properties of the components result in unfavourable stress distribution and concentration and makes possible the origin of deformations which may grow to the very failure.

Particularly unfavourable influence on the strength is exercized by surface defects from which, due to shear stresses, sliding surfaces proceed, which are the principal cause of inelastic deformations and accelerate the arrival of the critical state of particle separation. The unfavourable influence of surface defects is considerably increased in composite materials due to their large inner surface. Apart from the surface /contact/ stresses the surface defects also cause the strength of materials to depend on the environment, if it contains materials adsorbed by the surface of the present substances. The effect of the defects is increased by the effect of inner stresses due to production effects /temperature, mechanical, and other/ to which the material is subjected during its production or use or which accompany its origin /shrinkage/.

The fundamental classification of composites can be schematically presented in the form shown in Fig. 7. Only if further research, description and experimental observations are broken up in accordance with the classifiaction, there is some hope that we can attain some uniform results.

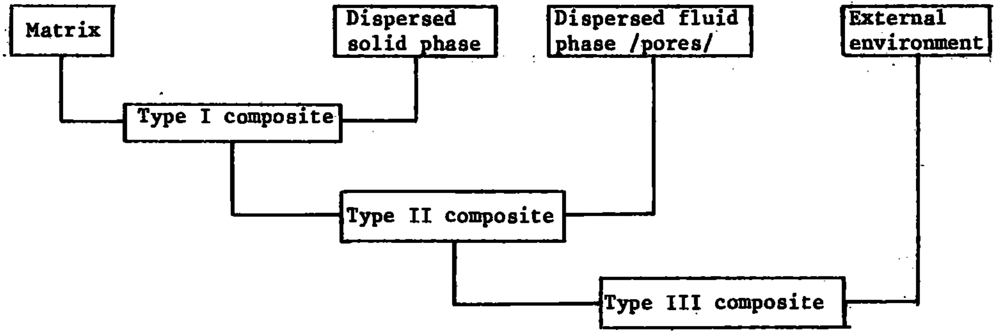

Fig. 7: Classification od composites

If we observe the properties of composites of various types /e.g. in dependence on the changes of the parameter V_m/V_f, where V_m and V_f are the volume of matrix and of the dispersed phase /filler/ respectively, in a unit volume of the composite/, we can find a marked change in the region of the second, sometimes also called "transition" type /Fig. 8/ /2, 3/.

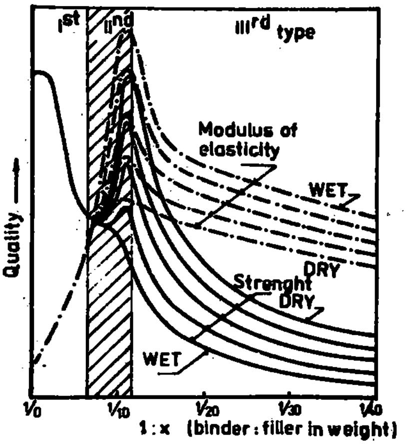

Fig. 8 a

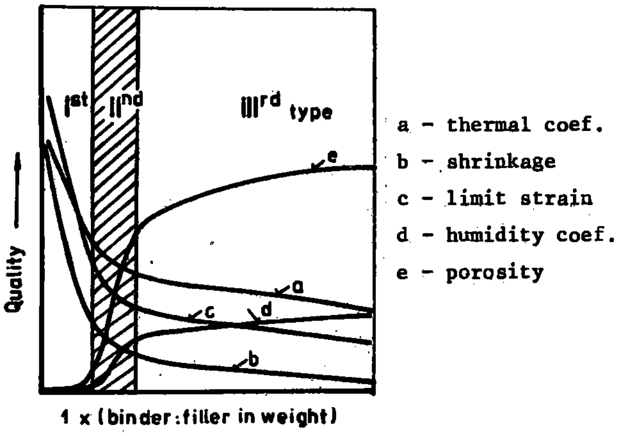

Fig. 8 b

Every one of the three above mentioned types of composites can be quasi-isotropic or anisotropic, even if the anisotropic composites have any practical sense in type I composites only.

Every one of the three composite types can consist of two or more solid phases and every one of them can be formed by one or several phases and geometrically continuous structures, i. e. structures which are capable of independent existence.

PLASTICS COMPOSITES

Using plastics the composites of all three types can be formulated.

The group of Type I composites incorporates all filled thermoplastics or thermosets similarly as a prevailing majority of fibre-reinforced plastics. The boundary between type I and type II composites varies in dependence on the ratio of V_f/V_k /where V_k is the volume of the composite/ and the specific surface of the dispersed phase F_f^k within the limits of $2 \lesssim V_m/V_f \lesssim 3$. The specific surface can be expressed, for example, by the ratio of the surface of the actual particles to the surface of spheres filling the space to the same extent as the actual particles / i.e. for the same V_f/V_k/. In the case of the boundary system with aggregated filler /i.e. for $V_m/(V_k-V_f)=1$/ moreover, there exists, for a certain filler, the relation /generally deduced statistically/ between the volume of the vacancies /voids/ of particles /and, consequently, the volume of the matrix/ and their surface in accordance with Fig 9.

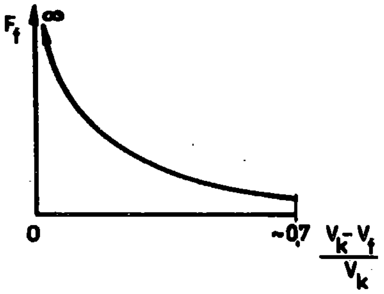

Fig. 9

When the space is entirely filled with particles, the inner surface approaches the value of the inner surface of a homogeneous material on the level of crystals, when the physical /Van der Waals/ bonds are fully effective.

On the basis of partial experimental results and general considerations, it is possible to consider the influence of a number of further factors proved. Thus, for example, with the growing difference of deformation features /e.g. characterized by the deformation modulus, ultimate deformation, etc./ of both solid phases /e.g. brittle resin and rubber filler similarly as rigid boron fibres in a soft aluminium alloy/ the impact strength increases as a result of effective energy absorption at the head of microcracks by the soft component of the material. The dampening of the failures and their propagation will be influenced also by a suitably selected interface bond or the modification of the interface by another, inserted phase.

In the type II composites, as the closed pores gradually open, forming continuous porosity, and in the type III composites, the properties of the material are gradually influenced by external conditions /environment/, particularly as a result of the filling or emptying of the pores with a liquid. Here comes another variable V_p/V_m, where $V_p = V_u - V_f$ is the volume of the voids of the dispersed phase, and the ratio V_v/V_k, where V_v is the volume of vacancies /pores/ in the material. The ratio of V_m/V_f in the transition from type II to type III depends, once again, on a number of other factors, particularly V_p, F_f, etc., and varies, approximately, between the limits of $3.5 \lesssim V_m/V_f \lesssim 6$. These groups comprize various bonded fillers, such as resin mortars, resin concretes, combinations of inorganic materials with organic materials, such as impregnated systems, etc.

The classification of the individual, e.g. granular systems with macromolecular matrices in accordance with the afore mentioned classification scheme follows also from their presentation in the triangular diagram in accordance with the volume representation of phases, shown in Fig. 10.

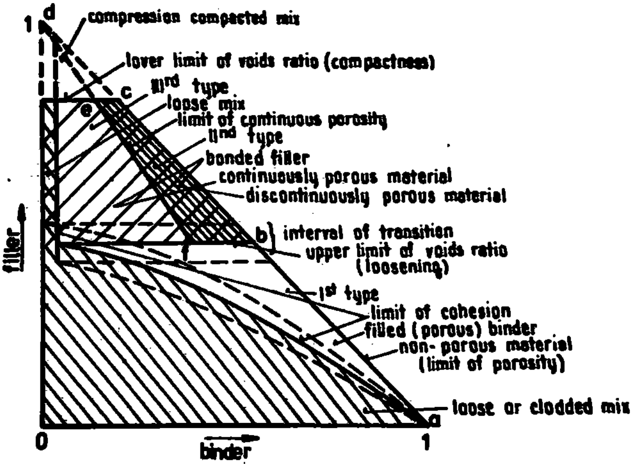

Fig. 10

The diagram shows, for example, that the systems with segregated filler /e.g. filled thermoplastics/ without pores are actually only boundary systems /located in the diagram on the a - b line only/, thus representing only a minute fragment of all possible and practically applicable granular composites. In the case of systems with aggregated filler /in the part of the diagram with the filler coordinate ≧ b/, if, for example, impermeability /i.e. discontinued porosity/ is required, only a minor part, determined by the b - c - e - f area, is of practical importance.

The afore mentioned classification is fundamental and assumes the existence of only one phase and dimensionally continuous structure /matrix/. The problem is further complicated, if - apart from the original matrix structure /which can be of organic or inorganic origin/ - there originates, simultaneously or subsequently, another /or even further/ geometrically and phase continuous structure/s/. In such a case all properties of such a composite change significantly as a result of the cooperation of solid structures during the deformation and due to a marked increase of inner energy.

The formation of solid structures by the spontaneous aggregation of dispersed phase particles, their coagulation and floculation, is the most typical process originating in disperse systems, which are studied in colloidal chemistry. Greater scientific and practical interest is attracted by that type of coagulation in which a solid spatial structure - the coagulation structure - originates due to the cohesion of the particles in the form of chains and random netwerks of such chains instead of compact aggregates. The most typical coagulation structures, comprizing a small volume of the disperse phase, originate, if the number of particles /kinetic units/ per unit volume is large enough, under conditions of sufficiently high dispersity, particularly if the particles are anisometric or their surface is uneven. In such cases the concentration of coagulation centres, i.e. the lyophobic points in the surface of the particles, is sufficiently low; otherwise, the coagulation would result in a compact aggregate rather than in closed networks. On the other hand, under the conditions favourable for the development od such three-dimensional structures in the whole volume of the body /medium/, the liquid mediumsolidifies as a result of favourable Brown collisions of particles of the finely dispersed /colloidal/ fraction even with a very low contents of the disperse phase, e.g. 0.01 - 0.1 %. Example of such behaviour is afforded by the hydrogels of vanadium pentoxide or the colloidal suspension of bentonite in water. When the coagulation structure has been formed, there remains between the particles a very thin /residual/ layer of liquid medium, whose thickness corresponds with the minimum free energy of the system /8/.

The above mentioned data are of great importance for the development of the basic principles of the production of finely dispersed structures, solid materials of high strength and industrial materials of predetermined optimum properties.

For the formation of multistructural systems, it is the very plastics that afford extraordinary possibilities, since they can be transformed, within very wide limits, from the liquid /monomer/ phase to the solid /polymer/ phase and form structures consisting of polymer chains.

For example, cement concrete into which a microgranular thermoset phase has been introduced during mixing will form the first structural skeleton by the hydration of cement. Since both in the cement itself and in the concrete, there exists, as a result of excessive water necessary for the processing, a maze of capillaries and pores after hardening, the thermoset admixture, after the concrete has been heated to a temperature above its melting point, will fill these pores similarly as other defects, fissures and cracks in the system, with relatively thin films; after cooling the thermoset will remain in different locations than before the heat treatment. From an entirely discontinued structure it will change to a more or less regular dimensional and phase continuity. Thus inside the concrete there originate another, secondary structure, cooperating under stress with the first structure. Another example is the admixture of suitable polymer dispersions or monomers to the fresh concrete mix. If we succeed in overcoming the inborn incompability of both components, it is possible to achieve the formation ot two separate and independent structures either simultaneously /concrescence of both structures/, which is best, or subsequently, when the second structure originates in the channels and voids of the first structure after the origin. The afore mentioned incompability of both components /cement paste and polymer dispersion or monomer/ causes that a marked improvement of the properties of the composite can be achieved in this way, even though from the structural point of view particularly the first method /simultaneous concrescence of structures/ should bring about important advantages. More successful is the formation of the secondary structure of the polymer in the voids of the fully hardened primary /most frequently inorganic/ structure. In such a case the inner space is filler with monomer /by impregnation/ which subsequently polymerizes. This results, in the first place, in an outstanding "densification" of the material which, together with the interaction of both continuous structures /each of which is actually a negative picture ot the other/, brings about surprizing results. Analogous results can be achieved also by the filling of the free space with an inorganic system /e.g. sulphur/. Most frequently this procedure can be encountered in the process of impregnation of cement concrete and other materials made of hydraulic cements /gypsus, asbestos cement, etc./, porous ceramica or metals.

It is not uninteresting to mention some older observations concerning, for example, the influence o moisture on such composites as cement concrete or natural stone; moist materials have a lower strength and behave, as though they have softened in water, while dried materials are of a higher strength. The differences attain as much as 20 - 45 %, almost the same as in the case of wood /9/.

There may be several reasons for this phenomenon. Water is adsorbed in wet concrete on the surface of crystals and in thicker layers enables the crystals to mutually move /shift/; it causes also greater separation of particles by the increase of the thickness of enveloping material, which manifests itself by an increase of the volume. This is proved by the observations /10/ that if dried concrete is saturated with liquids which are not adsorbed on crystals /apolar liquids, e.g. paraffin, spirit/, there is no increase of volume or reduction of strength; on the contrary, in some cases the strength increases. As a part of cement paste is in the form of gel, it softens by the receipt of water. Another factor is the size of pores in which water accumulates. Water in large pores reduces the strength of concrete less than the water in microscopic pores /11/, which simultaneously eliminates the explanation of the strength reduction by the softening of gel only. Furthermore the variability of capillar forces comes into play, which accompanies the shrinkage of concrete by its drying and swelling by soaking. The shrinkage of cement paste results in a state of compress which increases the strength, the swelling eliminates the state of compress and the strength, consequently, decreases. Also the pressure of liquid water plays some role; the water is pressed out of the channels between the cement corpuscles under load; as it cannot escape through these capillares with sufficient speed, it presses on the walls, thus causing further unfavourable stresses. During the changes of moisture content also the inner stresses play some role, resulting from the differences of volume changes in the surface layer and in the core of the material, because the moistening and swelling, as well as drying and shrinkage, proceed from the surface to the core. Against these factors, there acts the reduction of the stress concentration around the pores filled with water, as the water inside them must undoubtedly transfer a certain load and acts actually as a means increasing the density of concrete. By this it is possible to explain also an increase of the strength of concrete when it is saturated by those liquids which do not cause some of these negative effects /sorption, softening of gel/. The opinion that the principal factor causing the reduction of strength due to moisture is free and adsorbed water is confirmed by the observation that the greatest drop of strength occurs after the first 2 - 3 % of moisture have been absorbed.

The best proven and simultaneously the simplest way to the achievement of a successful solution of every problem is not a painstaking elimination of individual disadvantages and imperfections but the selection of such a new system in which the apparent disadvantages can be utilized and become actually advantages. This applies to the full extent also to our particular problem, to the formulation of new composites. The afore mentioned generalization actually shows that everything that improves the density of the material /both on the scale of the structure of the material and on that of the microstructure of the components of which the material consists/, and contributes simultaneously to the ability of the material to absorb energy, results in an improvement of the properties of the material, particularly its strength. In general, everything that has been previously ascertained for such systems as cement concrete, stone, timber, etc., is valid also for polymer composites. This was confirmed not only by a number of experiments with PCC, PC and PIC, but also by observations of the properties of PC of continuous porosity, impregnated additionally either with the same or a different monomer of which it has originated. It has been found that PC as a type III composite after impregnation has shown more favourable properties than the PC prepared from the same sum of binder quantities as a type II composite. Even more advantageous properties were obtained by the impregnation with another monomer, whose properties after polymerization differed considerably from the properties of the first polymer from which PC had been prepared. In other words, it has been proved that even with the use of identical initial materials it is possible, by creating a bistructural system, to significantly improve the properties of the material in comparison with a single-structure system. The selection of the properties of both structures can ensure the elimination of various disadvantages, resulting from the inner state of stress due to the formation and loading of the material, and thus influence decisively the resulting properties. Bistructural systems are particularly suitable also because they contribute to the deceleration and stoppage of originating microfailures and microcracks; a failure in one structure, as a rule, does not cause failure but only deformation of the other structure, which draws off a considerable volume of energy.

CONCLUSIOS

The only solution of the ever increasing requirements imposed on materials and the ever decreasing raw material resources is the replacement of homogeneous and quasi-homogeneous materials with composite materials.

Further development of composites is based on the synthesis of the knowledge achieved so far and the new spirit of education of structural and material engineers.

The behaviour of composites is governed by principal parameters; the classification of composites according to the weight of these parameters into individual types is necessary for the generalization of knowledge attained so far, the mastering of a purposive formulation and foreseeing of properties of composites.

The principal criteria of the classification are
- whether the other /dispersed/ phase inserted into the matrix is segregated /i.e. whether it does not form its own infrastructure/ or aggregated,
- whether the solid phase fills the whole space or whether also a liquid phase is present,
- whether the liquid phase is segregated /pores/ or continuous, in contact with ambient environment.

According to the manner of space filling there are types I, II and III composites characterized by a markedly different deformation and energy behaviour. The number of secondary classification characteristics includes the geometric characteristics of the structure /isotropy - anisotropy/, the geometric and physical properties of phases, etc.

Another criterion is whether there is in the material only one or more phase and dimensionally continuous rigid structures. Multistructural systems show a higher effectiveness /e.g. higher inner energy/ than singlestructure systems, which is the result of the physico-mechanical properties of phase boundaries.

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