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FORECASTING SCIENTIFIC AND TECHNICAL DEVELOPMENT OF POLYMER COMPOSITES

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Summary: On the basis of a short chronicle of science and technology periods the conclusion on the new Scientific and Technological Revolution with "System" and "Composite" as the main concepts in science and technology respectively is drawn. In this framework objectives, boundary conditions and barriers of polymer composites development are formulated. Main research categories, such as material components, structure, manufacturing, material model, composite properties: durability and reliability, are briefly discussed.

Keywords: composite materials, composite properties, durability, forecasting of development, manufacturing, material components, material model, polymer composites. reliability.

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L. Czarnecki

Motto:
Nothing exists more practical than
a good theory
L. Boltzman, 1844-1906

INTRODUCTION

Chronicle of Science and Technology Periods

There is no logical reason for the anticipation of the future from the experiences of the past (1) .Induction is an attempt to transform incomplete information into full information, which is impossible according to the theory of information. However, to have a vision of further development is the necessity of life and of science and technology as well.

The Paradigm in Science and the Material in Technology are the principles of classification in the historical sense. The paradigm is the main pattern of the way of thinking, dominating the "scientific workshops" in the given period of time. According to this Kuhn (2) concept, the development of science can be roughly categorized in the following periods:
- metaphysical - descriptive formulation /since Aristotle, 350 BC/
- reason-result relation /since Galileo, Descartes, 16th c/
- system theory /since Bertalanfly, 1937/.

With regard to the prevailing material used in the history of mankind the following phases characterized by the standard of technology can be defined:
- Stone Age /until 3500 BC/
- Bronze Age /3500 - 1000 BC/
- Iron Age /since 1000 BC/
- Composite Age ? /since the end of 20th c/.

The phases of human culture are measured in hundreds of thousands of years. It is just coincidence that we shall start the third contemporary millenium with "System" as the new paradigm in science and "Composite" as the new concept in technology. It means only that the new Scientific and Technological Revolution has already started (5) . One of its main attributes (5) is the creation of large Complex Research Programs covering the full cycle from the conception to practice, viz. the three phase programs: Idea - Invention - Innovation /I^3- program/.

This Symposium is also an attempt to sum up the Polymer Composite Program outlined by UTAM-ČSAV. The picture of ongoing valuable research and its successful results presented at the Symposium shows that at least the "threshold of Composite Age" is made of Polymer Composites. The great tasks and responsibility for further progress issue from that standpoint.

Between the terms "System" and "Composite" there exists an inherent adequateness noticeable intuitively, at least. They both derive (15) from Aristotle's dictum: "The whole is more that just the sum of components". The polymer composite could be defined (7) as: A solid material s y s t e m consisting of two or more phases, at least one of them wholy or partially built from solid polymer, with macroscopically distinguishable boundary among phases, which attains properties not attainable by any compound /phase/ singly nor by simple summation of them.

It is of interest that contrary to its significance the system as a category of contemporary science has not been well defined yet (3, 6, 8) . For the purpose of this paper, we can treat the System Theory as the way of thinking (9, 10) concerning each problem /subject/ as a set of items so related as to form a unity /internal relations/ and at the same time as a particular part of some higher system - "environment" /external relations/.

OBJECTIVES, BOUNDARY CONDITIONS, BARRIERS

No object, no structure of even the most sophisticated design can be realized without material. The aim of material production in the future will be also an implementation in practice - application. Requirements for materials are becoming more and more stringent to satisfy the demands dictated by continuous engineering development and growing industrial activates. There is no universal material with all properties perfect. A universal material is not the goal of the future either, which is obvious from the economical point of view (11) . Device "tailor-made" materials for particular applications - that is the guiding rule for the present and the future (12) , which leads to formulation of the material by way of its design from the given engineering application /an analysis of technological and service conditions/ to the polymer composite with required properties, usually a "high performance composite" /Fig. 1/.

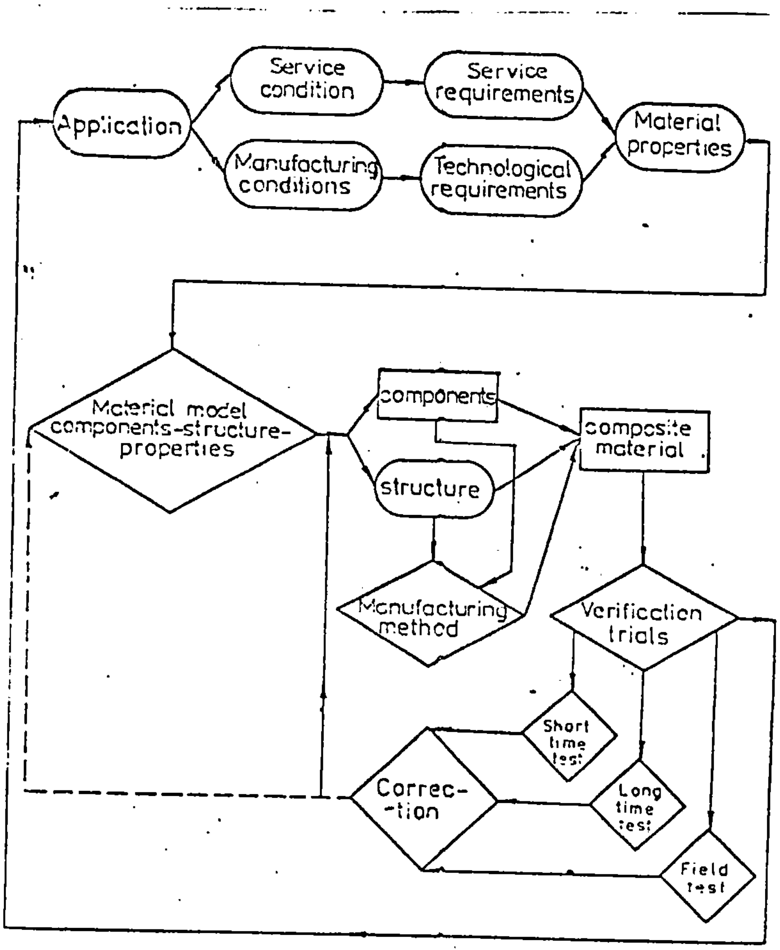


Fig. 1 General scheme of material composite designing according to material engineering method

One can foresee that the remainder of this century will be a period of great changes in structural engineering. It is rather unlikely that the development of materials, per se, will play a dominant part in the changes of design practice. However, the composites create the unique chance for contemporary design of both structures and their materials (11) with positive feedback. Unfortunately these possibilities have not been very often taken advantage of in the practice.

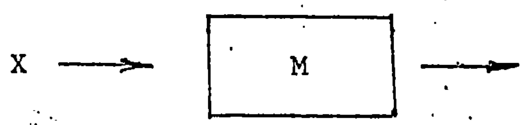
Energy - Ecology - Economy relationship could be treated as the main boundary condition /E^3-system, so called E-triangle/ imposed by Nature itself (13) .

Inertia and conservatism in the thinking of man seem to be the most important /but not sole/ barriers to the rational fabrication and use of polymer composites (11). Although the trend of development is obvious to the majority of material and structural engineers of today, far not all of them have applied this trend to their every-day work. Chaos of information confirms that attitude and apparently rationalize it. The study of literature makes it obvious that "more information" is not what we need most; it is rather "embarras de richesse". The real necessity is to find the way of comprehensive arrangement and verification of information that exists. We are looking here for a Material System Theory with an adequate classification and transformation system (14) and, in consequence, for a "ready to serve" General Bank of Polymer Composite Information. In turn, there is the need to standardize terminology, standardize performance tests and educate suitable specialists. Unitil to-day mainly /but not only/ civil, chemical and mechanical engineers have kept the balance in the field (15) and it is necessary to reflect this situation in edcucation program. First of all, it creates the necessity to accelerate an exchange of ideas among various research centres.

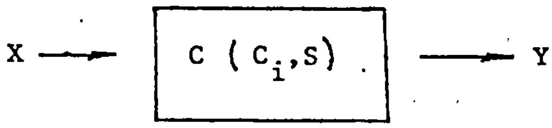
SYSTEM APPROACH TO POLYMER COMPOSITES:

Main Research Categories

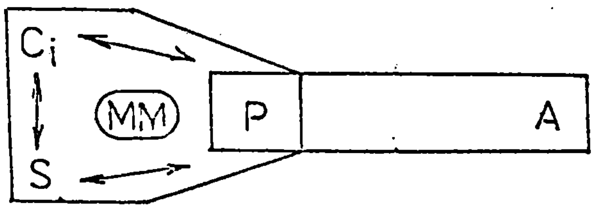
Properties of every material can be treated as the reaction /Y/ of the material to the action of some external factor /X/:



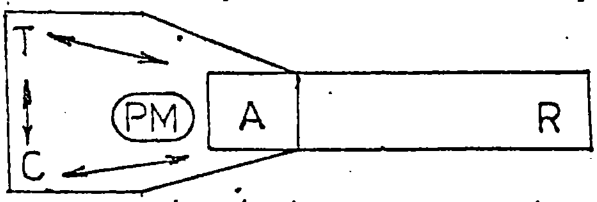
Under the given conditions the behaviour of a natural material /e.g. stone/ does not change. The response /Y/ of a composite material /C/ is determined by its components /C_i/ and structure /S/ :



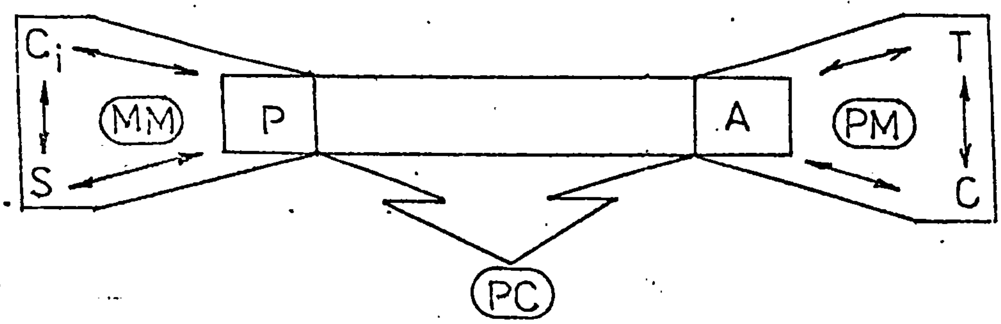
In consequence the properties of man-made polymer composites appear as "designable", at least to some extent. The main question which arises here is the so called "Material Model" /MM/ viz. Components - Structure - Properties - Application relationship /C-S-P-A model/:



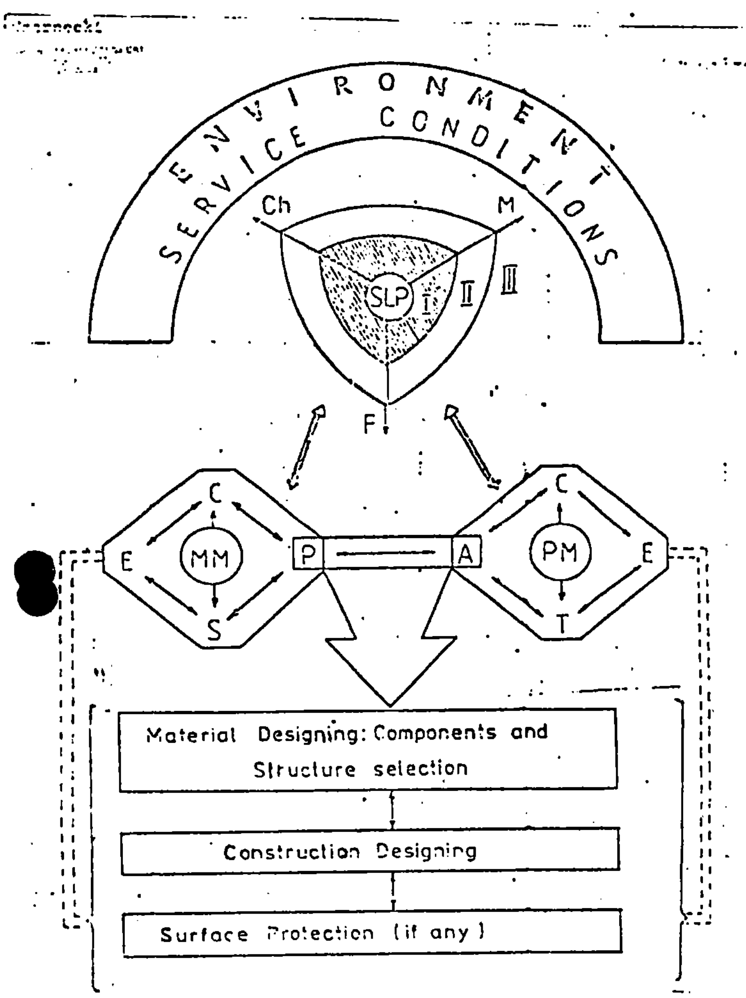
The "Performance Model" /PM/, in turn, can be defined 12 as the Technology - Construction - Application - Material Requirements relationship /T-C-A-R model/:



A properly designed polymer composite /PC/ could be considered as the result of the i n t e r s e c t i o n of the two above mentioned models:



Moreover, the given polymer composite structure is working in complicated Service - Load - Space (16) with mechanical, chemical, and physical types of loads /Fig. 2/



According to the model which has been presented /Figs. 1,2/ the main research directions (17) can be broken up into the following categories: "Material Properties", "Components", "Structure", "Manufacturing Methods" and "Material Model". Special problems are connected with the category of "Application", particularly the applicability criteria of polymer composites and the use of polymer composites in anticorrosion protection. In polymer composite development it would be useful to take into account also some general relations, like "Material-Architectural Style" (18) or "Material-Theoretical mechanics" (19) not expresses explicitly in the above mentioned model. Some of these categories will be discussed further.

Fig. 2 Material designing scheme as the result of "intersection" of Material /MM/ and Performance /PM/ Models in Service Load Space /SLP/
SLP: Ch - chemical load,
M - mechanical load
F - physical load
I - proper service conditions subspace, II - failure subspace, III - fracture subspace
MM: E-energy, C-components, S-structure, P-properties
PM: E-ecology, T-technology, C-construktion, A-application

MATERIAL COMPONENTS AND MEANS OF FABRICATION

On the macrostructural level the polymer composite system is divided into two subsystems: the matrix - as the continuous phase, and the inclusions - as the dispersed phase /Fig. 3/. Various types of binder: thermoplastics and their blends, thermosetting resins and their blends and suitable polymer-mineral hybrids as well as various types of filler, including mineral and synthetic lightweight aggregates and/or different fibres, have given the framework of material variability of polymer composites (20,21) . When considering only the existing polymers (22) their blends (23) and modifications (24), as well as over 30 groups of different fillers (25), innumerable combinations of composites in the forms of filled plastics, concretes or laminates will be obtained. This figure would be even multiplied by various composite macrostructures depending on fractional volume and geometrical arrangement od components. It means that it is not an a priori obstacle to finding a suitable polymer composite for the given application; more serious problem is to do so in the most effective way. The primal problem is the proper selection of components and structure of polymer composite as well as the method of its manufacture /Fig.4/. In the manufacturing process the significance of suitable machines, particularly mixing and casting machine (29,30) cannot be overestimated. It is important not only to look for new components, but also to implement in practice the new achieve-

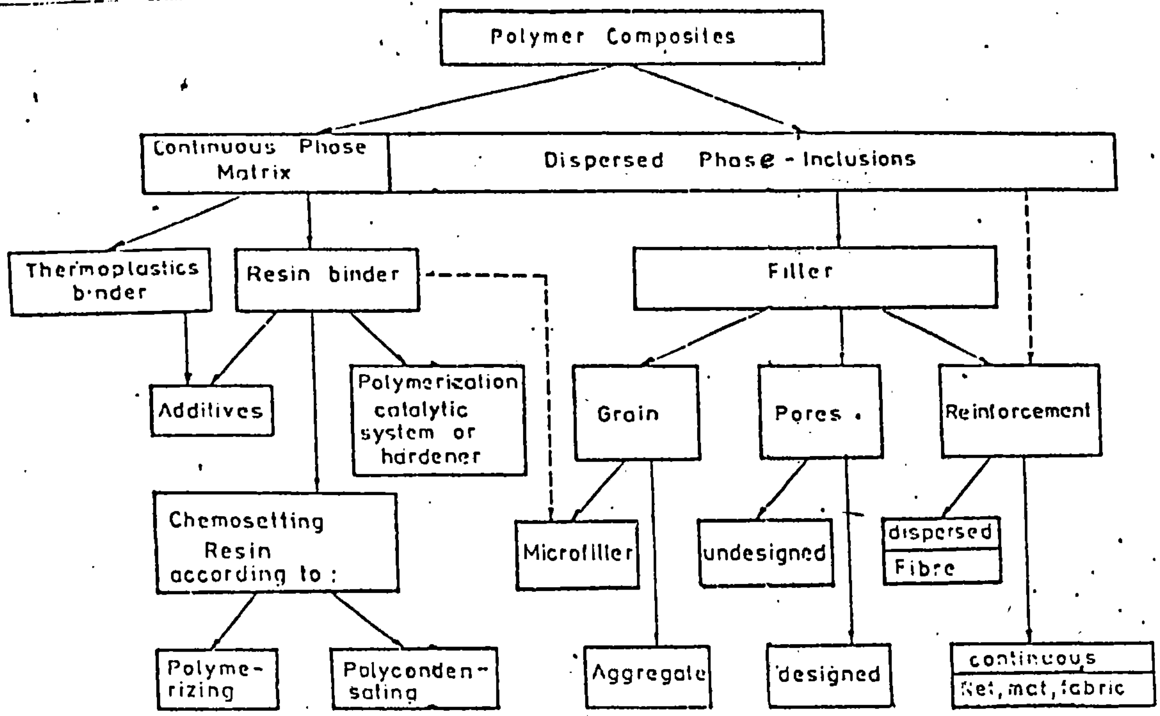


Fig.3 Structural diagram of polymer composites

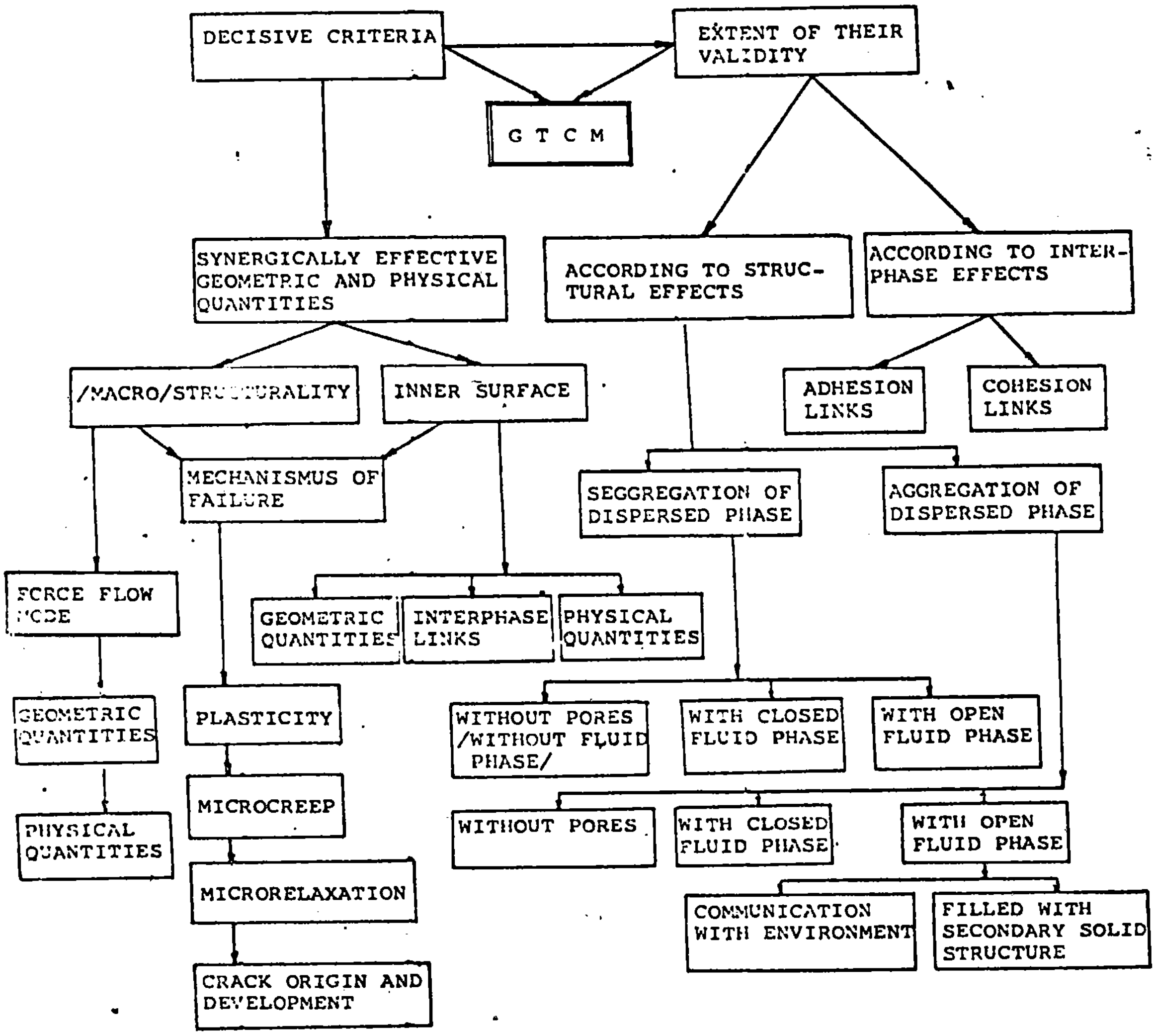


Fig. 4 Structural factors and their influence on polymer composite behaviour according to General Theory of Composite Material - GTCM (14)

ments of polymer chemistry and technology e.g. antiplastification phenomena (26,27) or interpenetrating polymer networks (28).

MATERIAL MODEL. AS THE KEY RESEARCH PROBLEM

The quantitative description of the Material Model is the most important and the most difficult problem. This is the topic of several ongoing research programs (11,31,32,33), but some useful engineering approaches have been already found. Generally speaking, the composite properties can be treated as the superposition of additive and synergic interaction between components /Fig. 5/. In such a case the polymer composite properties depend on fractional volume and bulk properties of components /on macrostructure level/ as well as on surface properties of components /on microstructure level/. Extensive study in this fiels (31) permits to treat the thickness / δ / of the resin binder envelop around the filler grain as a complex factor connecting the structure and the properties of a polymer composite. In design practice various ways can be taken into consideration. The material model permits to evaluate /to some extent, at least/ a balance between practical simplicity and theoretical accuracy of every material designing method. The main direcrion of research and technological development is the utilization of synergic phenomena to solve the needs of the application. Better understanding of composite materials is the way to higher efficiency of their use.

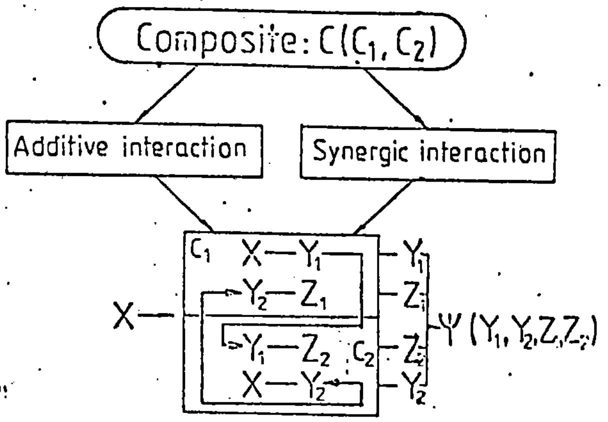


Fig.5 Schematic presentation of the composite /C/ properties as the superposition of additive and synergic both way /$C_1 \rightleftarrows C_2$/ interaction between the components /C_1, C_2/.
X - external factor, Y_1,Y_2,Z_1,Z_2- intrinsic material response, -exterior material response - material properties

DURABILITY AND RELIABILITY PROBLEM

Relative youth of the polymer composites in comparison with the expected service life of structures requires the further study of durability. These tests will determine the material behaviour under long-term action of the given factor with constant $/X = const/_{t \to \infty}$ and variable $/X/t/_{t \to \infty}$ value as well as under various factors $/X/X_i/_{t \to \infty}$ acting simultaneously, Moreover, further study of particular material features e.g. radiation resistance, fire and thermal shock resistnace, weather resistance etc. will be expected, too. It is necessary to add here that new materials require very often new testing methods, which represents another important research problem.

The open question is still the actual failure mechanism of polymer composites (34). If neglected, this problem, like the implicit character of material model relations, would be the source of real troubles in practice.

If reliability of each element is 99 %, it means that the reliability of a system consisting of 500 elements is only 1 % (1). This simple calculation has given rise to a new very important topic: "Reliability of Composites". The case of polymer composites is further complicated by the stochastic character of polymers themselves.

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Forecasting of Scientific and Technical Development of Polymer Composites

L. Czarnecki, R. A. Bareš

Mr. Chairman,
Ladies and Gentlemen,

It is my priviledge to present you the enclosing lecture of our Symposium. The lecture has been prepared together with my friend, Distinguished Professor Bareš from Czechoslovak Academy of Sciences. Our contribution has been entitled "Forecasting of Scientific and Technical Development of Polymer Composites", more precisely "Engineering Polymer Composites".

We are fully aware of difficulties and various barriers involved with so named problem. According to Polish futurologist Stanislav Lem: "There is no logical reason for the anticipation of the future from experiences of the past". The same conclusion can be withdrawn from the Theory of Information. However, to have a vision of further development is the necessity of life, and of science and technology as well. Certainly, it is necessary to stress from the beginning uncertainity of any forecastings. Usually in a scientific /technical/ forecasting we are too pessimistic, contrary to optimistic view just on life. It is the reason, that out of science, we are speaking about "Fortune-teller", not just "Future-teller".

We've encouraged also by motto from Boltzman - the end of nineteenth century - : Nothing exists more practical than a good theory".

I would like to present the lecture according to the program, as follows:

1. Introductory words, which I've already done,
2. Determination of the start-point:
   - Paradigm in Science and Material in Technology,
   - Chronicle of Science and Technology Periods,
   - Scientific and Technological Revolution /STR/; Complex Research Programs as its attribute,
3. Composite /or even Polymer Composite/ Age. Composite and system interrelations,

4. Objectives, boundary conditions and barriers
5. System approach to polymer composites
6. Polymer composite material designing problems:
   - Theory of Composite Material
   - Material model: additive and synergic - interaction, interface phenomena
7. Durability and reliability of Polymer Composites
8. Closing remarks

Let me start, according to this schedule.

The principles of classification - in the historical sense - are:
- the Material in Technology, and
- the Paradigm in Science.

The Paradigm in this meaning is the main pattern of the way of thinking, dominating the "scientific workshops" in the given period of time. According to that, we can find following period in science history:
- metaphysical description, since Aristotle
- reason - result relation, since Galileo and Descartes
- system theory, since Bertalanffy.

Regarding to the prevailing material there are wll known in the history categories: Stone, Bronze, Iron and recently Composite Age. When the new paradigm in science and new leading material in Technology appear, Technological Revolution has already started. One of its attributes is the creation of Large Complex Research Programs, covering the full cycle from the Conception to Practice: Idea - Invention - Innovation, that means I^3 - program. This Symposium is also attempt to sum up the Polymer Composite Program outlined by Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences. From the results which have been presented here, it is obvious that at least the "threshold of Composite Age" is made of Polymer Composites. That statement confirms the previous one, about simple "Age of Polymer Composite" which has been expressed by Academician Lipatov.

as it has been called also by Academician Mrulo

Btween the terms "system" and "composite" exists inherent adequateness. Both of them derive from Aristotle's dictum: "The whole is more than just the sum o components". This adequateness has never happened before. It is shown how close is in nowdays and should be in future the relation between Science and Technology, as it has been stressed by Academician Němec in the Opening Remarks.

The aim of material production presently and in the future is just application. Requirements for materials are becoming more and more stringent. Materials should satisfy chellenges decitated by advances in engineering, as:

- increase of height and spacing of constructions,
- reduce of weight and cross-section,
- increase of service load: mechanical and chemical ones, and dictated also by economical conditions - in the broad sense, as
  - shortcoming of raw material and energy,
  - relative reducing of financial means for researches, in the meaning, that we should obtain much more effects from the same fund.

There is no universal material with all properties perfect at the same time. There is obvious from the economical point of view also that a universal material is not the goal of future. We need "tailor - made" materials for particular application. It leads to formulation of the composite materials by way of its material design from the given engineering application - an analysis of technological and service conditions - to the polymer composite with required properties, usually "high performace" composite. That has been called by Academician Němec as "to be master of materials".

The composites create the unique chance for contemporary design of both structures and their materials with positive feed back. Unfortunately these possibilities have not been very often taken advantages of in the practice.

What kind of barriers are here?

- the first, boundary conditions imposed by Nature itself, that is : Energy - Ecology - Economy: E^3 - system /E-triangle/,
- inertia and conservatism in the thinking, apparently rationalized by chaos of information,
- material nature understanding level; the balance between practical symplicity and accuracy.

The properties of composite materials as the response /Y/ to the action of some external factor /X/ are determined by its components /Ci/ and structure /S/. In consequence composite appears as "designable".

A properly designed polymer composite could be considered as the result of intersection of the two subsystems: "material model" and "performance model". In such case, main research categories will be involved with: Components, Structure, Properties - Application on the side of Material Model /MM/, C - S - P - A model and with Technology - Construction - Application - Material Requirements on the side of Performance Model /PM/: T - C - P - R - model.
Moreover, the polymer composite structure is working in complicated service-load space, I mean, chemical - mechanical and physical loads. That Service Load Space, in other words Environment influence has been reflected in material designing, construction designing and element surface protection /if necessary/.

The structural diagram presents material variability of components of Polymer Composites, Various types of binder: thermoplastic, thermosetting and their blends, as well as polymer - mineral hybrids. Various types of fillers including pores, light- and heavy-weight grains as well as different fibres have given almost innumerable combinations of composites.
The figure would be even multiplied by various composite macrostructure degrading on fractional volume and geometrical arrangement of components.
The problem is how to find suitable composite in the most effective way?
Assuming that the composite properties are resulted from superposition of additive and synergic interaction between components as the first step into material designing would be found:
- decisive criteria - structural control factors, and
- extent of their validity.

The synergically effective geometric and physico-chemical quantities involved with macrostructure, inner surface and mechanism of failure could be considered as the decisive criteria.
Their validity depends on:
- adhesion - cohesion balance
- aggregation and segregation phenomena of dispersed phase,
- balance between grain and pores,
- kind of porosity: close or open and their interference with environment.

Relative youth of polymer composites in comparison with the expected service time and their inner complicated structure requires further study of durability and reliability of the system, the failure mechanism including. It is of significance that three opening lectures, given by Academicians Němec, Enicolopian and Guz, have been involved with those problems.

In the lecture some overview of scientific problems has been presented. Now, what that means in the technical sense?

Need of various new materials for various applications has been already stressed.

On the other side, untill today we've used ~~about ten~~ only few percent of potential, I mean theoretical strength of composite materials. No any other mechanism exists so unefficient. The future should bring the improvement:

- using only still existing components but with proper material designing, we believe the efficiency ratio should be increased, may be, above 10% ~~untill 25~~ %. Particularattention should be drawn to:
  - synergic effects and their role in the "interface zone", e.g. by using active microfillers, coupling agents, plasticizers and antiplasticizers atc.

    Examples:

    "Aureola effect" of polyester oriented zone around mineral microfiller. The picture has been done by Paturoev.

    "Mineral flowers" - tobermorite crystals in the presence of methacrylate in polymer cement concrete. The picture has been done by Sugama.
  - forming the proper structure of polymer composite during processing; including "postmix polymerization" - polymerization during processing,
  - porousless polymer composites and polymer composites with special designed porosity, including integral reinforced foams,
  - polymer matrix with interpenetrating polymer networks,
  - multihybrid polymer composites: organic - mineral matrix, and fibres - particles filler.
- using the new "better" components, still in development (modified polymers, new kind of fibres and form of fillers) together ~~as well~~ with method mentioned above ~~and subsequently multi-composite systems~~; the absolute value of properties surely will increase

however not necessary it is valid also for the efficiency ratio. The next step would be multicomposite system. In such case, we believe that the further increase of the efficiency ratio is also possible. It is just a chance. It is our wishes to all of us: Let's take it chance!