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FUTUR DES MATIERES PLASTIQUES DANS LES CONSTRUCTIONS NEUVES ET DANS LA MAINTENANCE, LA REHABILITATION, LA REPARATION ET LE RENFORCEMENT DES STRUCTURES EXISTANTES

FUTURE FOR PLASTICS IN NEW CONSTRUCTIONS AND IN MAINTENANCE, REHABILITATI REPAIR AND REINFORCEMENT OF EXISTING STRUCTURES

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BELGIAN RESEARCH CENTRE FOR PLASTIC AND RUBBER MATERIALS

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THE OPTIMIZATION OF PC MACHINE FRAMES PROCESSING TECHNOLOGY

L'OPTIMISATION DU PROCESSUS TECHNOLOGIQUE DE FABRICATION DES CHASSIS DE MACHINES EN PC

Polymer concrete has become an important and irreplaceable energy-saving material not only in the building, but also in the mechanical engineering and electrical engineering industries. Various requirements imposed on its properties can be met by a sophisticated design of the respective composite based on the optimization of its components, composition and the production process. As a synthetic activity the optimization requires profound knowledge the individual factors and their mutual relations which cannot be achieved by any other means but an extensive experimental analysis. For the design of polymer concrete machine tool frames an experimental analysis of the components /resin, hardening system, binder, microfiller and filler/, the mix /PC system/, the processes of mixing, processing and curing was carried out with the purpose of optimizing the production process and the physical properties of the composite to satisfy the requirements of the product. The optimized system was used for the design and manufacture of the frames of precision horizontal grinders in the national corporation of TOS Hostivař, Prague, Czechoslovakia.

Le béton Polymère est devenu un important et irremplaçable matériau, économisant l'énergie, non seulement dans la construction mais aussi dans les industries mécaniques et électriques. Les nombreuses exigences imposées quant à ses propriétés peuvent être remplies grâce à une étude sophistiquée du composite en question, basée sur l'optimisation de ses composants, de sa composition et du processus de production. Etant une activité de synthèse, cette optimisation requiert une profonde connaissance des facteurs individuels et de leurs relations mutuelles, qui ne peut être atteinte que par une large analyse expérimentale. Pour l'étude du béton-polymère, destiné aux châssis de machines, une analyse expérimentale des composants (résine, durcisseur, liant, microfiller et filler), du processus de mélange, de moulage et de durcissement, a été menée à bien, dans le but d'optimiser la technique de production et les propriétés physiques du composite, afin de satisfaire aux exigences du produit. Le système optimisé fut utilisé pour la conception et la fabrication de châssis de broyeuses de précision, produites par la fabrique nationale de TOS HOSTIVAR, Prague, Tchécoslovaquie.

INTRODUCTION

The development of knowledge of the properties and the processing technology of polymer concretes have enabled recently a far higher effectiveness /in respect of both material and energy requirements/ of their application in a number of mechanical and power engineering parts, in the manufacture of which the dominant position was occupied by grey cast iron or, in rare cases, by cement reinforced concrete /machine foundations, machine frames, gearbox housing, compressor housings, measuring plates for machine tools, machine tools, HV and VHV insulators, transformers, etc./. The number of advantages of polymer concrete as the representative of granular composites includes the possibility of selection of its properties within a wide range in accordance with the requirements imposed on the product. On the other hand, this possibility results in the necessity of designing not only the part produced, but also the composite system used in every particular case. Every generalization in this respect may be harmful. In one particular case the stability of form in a wide temperature range may be decisive, in another case the mechanical or dielectric strength, in yet another the damping efficiency, etc.

To achieve the required properties of the frames of precision machine tools it is necessary to provide

- high strength, hardness and toughness,
- high rigidity,
- stability of dimensions, i.e. minimum temperature-produced changes, minimum creep
- high vibration damping capacity,
- good appearance, requiring no or minimum additional finishing,
- good chemical resistance to oils, cooling liquids, etc.

Economy of production requires easy workability of fresh mix /mixing, moulding/, while achieving maximum density /minimalization of pore volume/, low energy requirements of the polymerization process and low contents of special and costly components. These requirements are often contradictory, such as high hardness and toughness, high rigidity and damping capacity, minimum temperature-produced changes and creep /at least in respect of binder requirements/. Consequently, it is necessary to make acceptable compromises or to compensate one unfavourable property of, for example, the binder by the construction of the material system or by another component /e.g. filler/. The paper describes some aspects of optimization of the composition and the production process intended to ensure suitable rheological characteristics of the fresh mix and the required properties of the product after its hardening.

OPTIMIZATION POSSIBILITIES

The optimization of a composite system /which is particularly dependent on a number of input parameters and their interaction or synergy/ with regard to a number of properties of the system in unhardened and hardened states, is, of course, very difficult. The fundamental process of optimization is shown in Fig. 1. The optimization is based on one principal property /or properties/, in which only small deviations from the ideal state are possible, and the admissibility criteria are gradually softened for secondary properties. The number of input parameters includes the binder /comprizing the resin, polymerization system, cross-linking agents, viscosity reducing agents, agents reducing surface tension, shrinkage, etc./, the filler /type, size, granulometry, shape, specific surface, etc./ with the exception of microfiller which is considered as a part of the binder, the system composition and the processing method /mixing, forming, curing, etc./. The fundamental prerequisite of any optimization, which is a synthetic process, obviously is the deep knowledge of the individual factors and their links, which is enabled only by a previous extensive experimental analysis. In further part the considerations will confine to an epoxy resin granular composite of Type II /non-continuously porous polymer concrete/ for machine frames.

while the strength, E-modulus and toughness of the hardened polymer are simultaneously increased.

The Hardening System

Low shrinkage, small temperature-produced changes and a high form stability at elevated temperatures, similarly as the low exotherm and a high pot-life require that at normal temperatures a latent hardening system be used. On

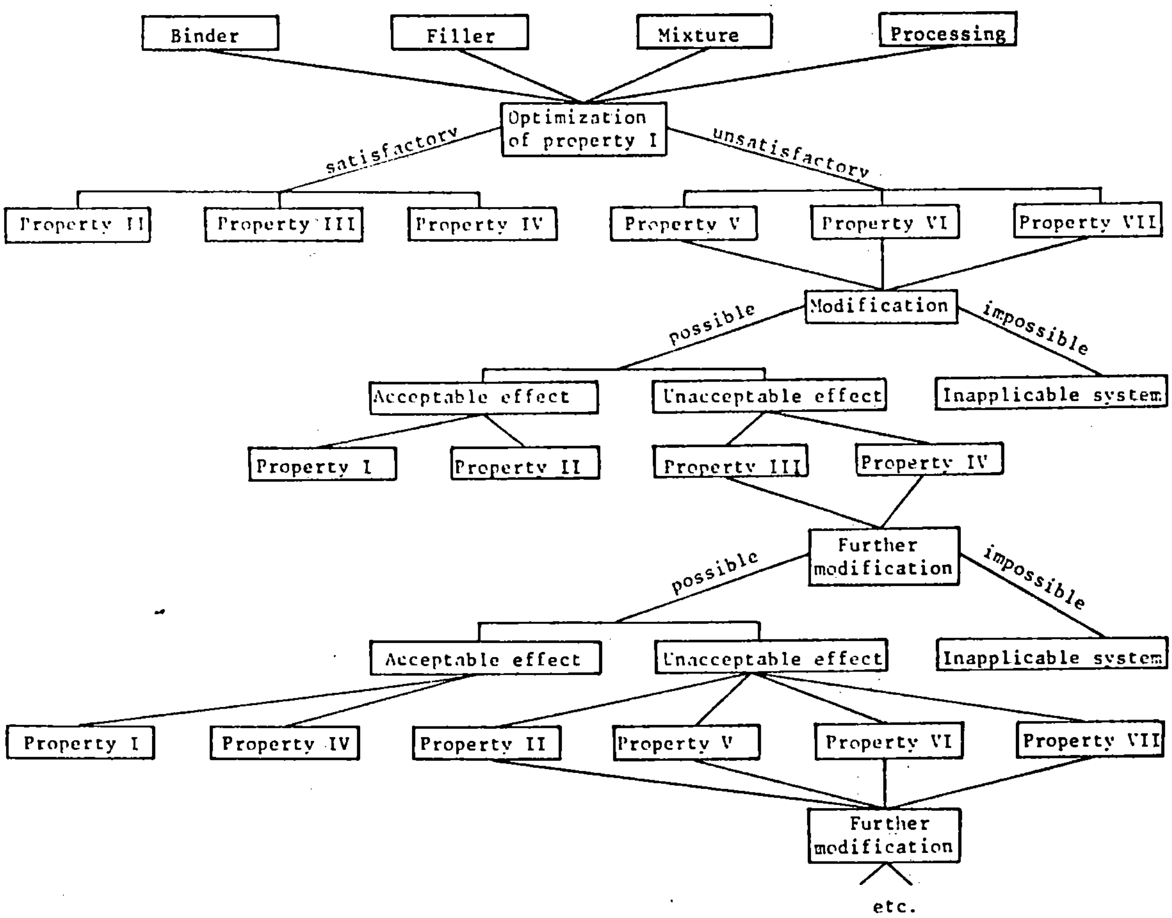

Fig. 1 Schematic representation of the optimization process for the formulation of a composite for the given purpose

EXPERIMENTAL ANALYSIS

The Resin

The given application requires that the resin has a high strength, high toughness, high moduli of elasticity and viscoelasticity, low shrikage and low temperature-produced changes on the one hand, and low viscosity and good wetting ability towards the filler on the other hand. The requirement of high moduli /of elasticity and viscoelasticity/ prevents a priori the use of any softening /reactive and non-reactive/ agents. The requirement of high toughness, however, brings about the necessity of existence of certain phenomena in the system capable of sufficient absorption of energy during the strain without unfavourable permanent changes. A number of experimental results has shown that such system is best suitable in which pure /unmodified/ low-molecular dian resin is used with an epoxy equivalent of 0.50 - 0.55 and a viscosity of 23 Pa s/20°C /13 pa s/25°C/, modified by a suitable co-polymerizing furan derivative of low viscosity /~5 mPa s/20°C/ as reactive diluent. In this way the viscosity is reduced to 2 Pa s/20°C, which is below the applicability limit of 3 Pa s/20°C,

the other hand, the requirement of economy of energy /for hardening purposes/ and the circulation of moulds necessitate a system in which maximum polymerization conversion is attained in a relatively short period and with a relatively small increase of temperature. A number of tests has proved that most suitable is the hardener based on the BF_3 diamine complex combined with an anhydride of a suitable dicarboxylic acid to ensure high conversion and slower gelation. The hardening temperature is only 60°C and the form stability /Martens/ is higher than 100°C.

Binder

Apart from the hardening system, the reduction of the polymerization shrinkage of the composite is influenced most by the microfiller, the maximum particle size of ehich must be safetely below the minimum thickness of the layer enveloping major filler particles, the granulometry within the curves a and b in Fig. 2, and the specific surface about 0.5 sq.m/g. Under these conditions an admixture of a perfectly dispersed microfiller /up to 55 - 60% of the weight of the mix/ to the resin will increase its viscosity only minimally, as it is shown in Fig. 3. This

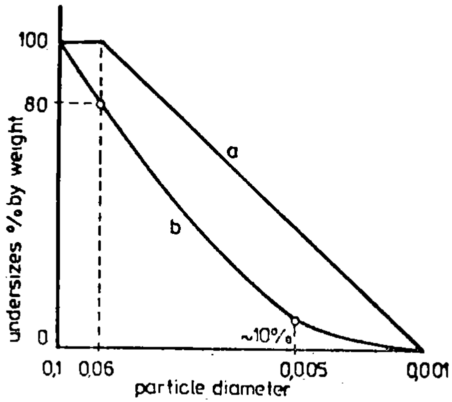

Fig. 2 Granulometry of microfiller

mixture of the resin and the microfiller can be further considered as the "binder" of the filler, i.e. sand and gravel. The properties of the composite depend, naturally, also on the chemical composition of the microfiller. Greatest bond was achieved with diabase microfiller /bond strength over 10 MPa/.

Apart from low viscosity a perfect mixing of the filler particles with the binder is facilitated also by the low surface tension of the resin /good wettability/.

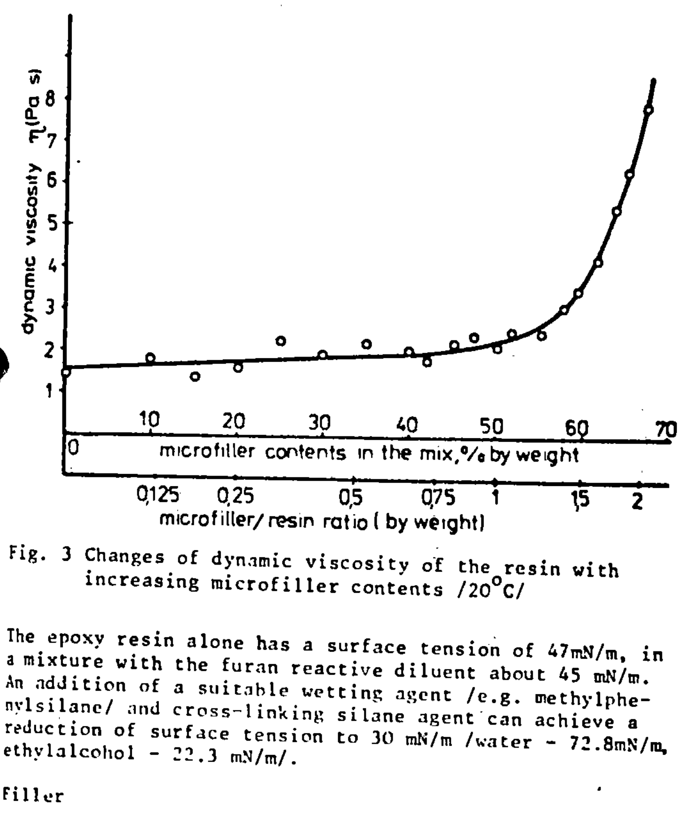

Fig. 3 Changes of dynamic viscosity of the resin with increasing microfiller contents /20°C/

The epoxy resin alone has a surface tension of 47mN/m, in a mixture with the furan reactive diluent about 45 mN/m. An addition of a suitable wetting agent /e.g. methylphenylsilane/ and cross-linking silane agent can achieve a reduction of surface tension to 30 mN/m /water - 72.8mN/m, ethylalcohol - 22.3 mN/m/.

Filler

The strength of the composite and its further properties depend on the mechanical properties of the filler /strength, modulus of elasticity, toughness/ and on the binding energy of the resin and the filler which is, among other factors, the function of the chemical composition and the morphology of the surface of the filler. The highest linkage energy /bond/ of the resin used was ascertained in the case of amphibole and diabase /over 10 MPa/, as well as andesite or gabro and quartz /9.7 and 9.2 MPa respectively/.

PC System

From the viewpoint of a number of physical properties /coefficient of thermal expansion, creep, modulus of elasticity/ as well as from the viewpoint of economy it is advantageous, if the binder contents in the mix is as low as it is permitted by the strength and porosity of the composite. A certain porosity of the system can be permitted. With regard to inner stresses /and, consequently,strength/ it is even advantageous, as it has been proved by a number of tests /1,2,3/; however, it must remain discontinued. The optimum ratio of binder and filler, therefore, is that ratio which corresponds with the position closely below the boundary between Type II and Type III composites /4,5/. This boundary depends on the initial void volume of the filler, which should be bver than 15%. The achievement of such low volume of voids is possible only through a very careful granulometry of the individual filler grades in which /particularly with regard to practical possibilities/ optimum results can be attained only by the use of 3-4 gap-graded narrow gradings with large gaps between the individual fraction /$d_{2min} = 4\text{-}6d_{1max}$, where d_1 is the particle diameter of the lower fraction and d_2 the particle diameter of the higher fraction/. In optimum conditions it is possible to consider the ratio of the "binder" /i.e. the mixture of the resin with the microfiller/ and the filler of 1 : 4.5 - 1 : 5.5 by weight, which represents the ratio of weights of the resin and all filler /incl. the microfiller/ of 1 : 9 - 1 : 14. The maximum compaction of the system is the function of not only the efficiency of processing, but also of the magnitude of contact stresses between the individual phases.

Mixing

The problem of mixing the binder and the filler must be divided into two phases. In the case of the microfi: it is a dispersed system whose primary structure must first desaggregated to achieve the homogeneity of dispersal of the individual particles. The reduction of effective viscosity by several /7 - 8/ orders and the achievement of structural uniformity /in time/ will be enabled by high-intensity vibrations /with a frequency of 150 - - 200 Hz/, with the possible addition of surface-active admixtures /reducing the surface tension of the resin/, as it is shown in Fig. 4, in a few seconds /6/.

The mixing of the "binder", i.e. dispersion system /the microfiller dispersed in the resin/, with the filler calls also for an intensive process. Optimum results can be achieved by intensive simultaneous kneading of all components; the great difference between the smallest and the largest particled /e.g. from 0.1 mm to 20 mm and over/ excludes the use of continuous screw mechanisms which cannot ensure sufficient homogeneity of the resulting mixture. For this reason the discontinued way of mixing by means of counter-rotating screws, or the combination of continuous mixing /of fine particles/ in extrusion screw mixers with the discontinued kneading /with coarse particles/ affords the best results in respect of the regularity and homogeneity of the layer of the binder enveloping the filler particles, the workability /viscosity/ and the homogeneity of filler distribution in the mix. All of these parameters are subsequently of decisive importance for the physical properties of the hardened material.

Processing

The processing of the fresh mix and its working into the required form is proportionate particularly with the viscosity of the mix, its surface tension and the contact stresses between the binder and the filler, and depends on the optimization of the vibration characteristics

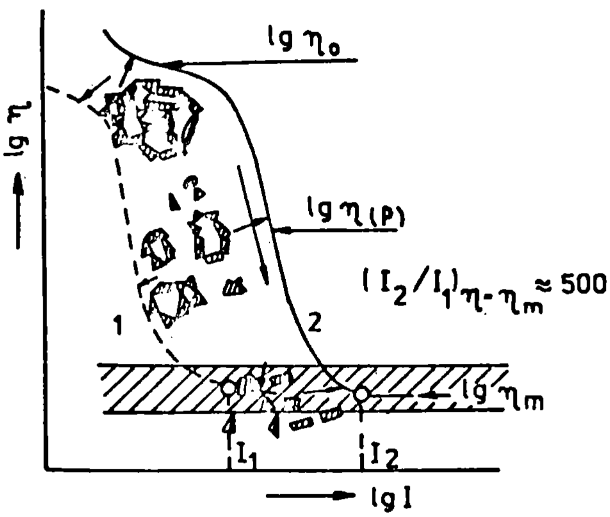

Fig. 4 Character of relation of the degree of structure disaggregation in dispersed systems /and viscosity η / on the intensity of mechanical processes I or the strain velocity $\dot{\varepsilon}$ or magnitude of shear stresses τ/

η_o – maximum viscosity of practically undisturbed structure

$\eta_{(P)} = f/\dot{\varepsilon}, \tau$ / – effective viscosity, characterizing the degree of structure disaggregation

η_m – minimum attainable viscosity of disaggregated structure

$\dot{\varepsilon} = d\varepsilon/dt$ – strain velocity /in shear/

τ – shear stress

$I/cm^2/sec^3/ \doteq a^2 . \omega^3$ – vibration intensity, where a – amplitude, ω – circular frequency

1 – with the addition of surface-active agents

2 – without the addition of surface-active agents

/amplitude, frequency, time/ with reference to those as well as further quantities /e.g. the weight of the product and of the mould, the particle size/. It has been ascertained that optimum results with PC are obtained, when using small amplitudes /~ 0.2 – 0.5 mm/ and relatively high frequencies /~ 100 – 150 Hz/ of vibration. The limit in this respect are the amplitudes of 2.5 – 5 mm for the frequences of 50 – 100 Hz. The vibration intensity varies about 10^4 cm^2/sec^3. Better results are afforded in some cases by the combination of low frequency vibration /with the frequency of about 60 Hz and acceleration of 100 m/sec^2/ with high frequency ultrasonic oscillation /e.g. with the frequency of 22 kHz and the energy of 100 W/cm^2/ /7/. At the same time the ultrasonic treatment accelerates the kinetics of polymerization /and not only by temperature increase due to the effect of ultrasound/ by about two thirds, which may be advantageous in some cases and disadvantageous in others.

Curing

The smooth course of the polymerization reaction, acceptable exothermal effect, minimum inner tension, sufficiently long latent period after mixing, high temperature stability combined with temperature expansion, high degree of cross-linkung and maximum polymerization conversion within a few days are practically attainable only by curing /or additional curing/ at a high temperature with carefully selected hardening system. On the other hand, the energy saving criterion requires minimum temperature in the course of temperature treatment. It has been proved that optimum results can be obtained with the above mentioned hardening system at a temperature of 60 – 80°C maintained for 4 hours and a continuous rise and fall of temperature, which will ensure 95% conversion after the elapse of 8 hours from the beginning of the heat treatment and 98% conversion after the elapse of 10 days from the manufacture of the products.

Physical Properties

Optimization of composition and of the production process enables the attainment of excelent values of physical mechanical properties of the composite. The compressive strength /ascertained on 10 x 10 c 10 cm cubes/ exceeds 150 MPa, the flexural strength /ascertained on 10 x 10 x 40 cm prisms with three point application/ exceeds 35 MPa, the modulus of elasticity exceeds 30 GPa, the creep under the loads below 35% of strength is immeasurable, the permanent strength exceeds 80% of short-term strength, the coefficient of thermal expansion is 13 – 14 x 10^{-6}, residual stresses /due polymerization shrinkage and temperature drop from the hardening temperature of 60°C to 20°C/ is 0.25 MPa.

EXPERIMENTAL RESULTS

The optimization process resulted in the determination of the following criteria of the preparation and production of polymer concrete ensuring the attainment of the required final properties:

– maximum admissible viscosity of the binder /the mixture of all of its constituents/ 3 Pa s/20°C

–maximum permissible surface tension of the binder /the mixture of all of its constituents/ 30mN/m

– modification of the resin /e.g. by means of a suitable furan derivative/ to attain the impact strength in excess of 25 kJ/m^2, modulus of elasticity in excess of 3.3 GPa, flexural strength in excess of 20 Mpa

– the necessity of microfiller with particle size of 1 – 50 µm and a specific surface of about 0.5 sq.m/g, with a bond strength with the resin in excess of 10 MPa, in the quantity amounting to 55 – 60% of the weight of the microfiller plus resin mixture

– the minimum bond strength between the binder and the filler in excess of 9 MPa

– gap-grading of the filler consisting of narrow fractions with great gaps between them and containing at least three fractions, with a void contents inferior to 15%

– mixing of the resin with the microfiller b[illegible] of high-intensity vibration /~200 Hz/

– mixing of the binder with the filler by a [illegible] nued process in a kneading machine or by a combina[illegible] the continuous mixing of fine particles with the di[illegible] nued mixing with coarse particles

– processing by high-frequency vibration /100– 150Hz/ with the amplitudes of 0.2 – 0.5 mm or in combination with ultrasonic oscillation

– curing /or at least additional curing/ at a high temperature to achieve polymerization conversion in excess of 98% after 10 days from the manufacture of the product.

PRODUCTION OF MACHINE FRAMES

On the basis of the described research results the frames of precision grinders of a new serie were designed. Their manufacture began in the national corporation of TOS Machine Tool Factory/ of Hostivař /Fig. 5/. In comparison with the cast iron frames formerly used for analogous products the economy of energy /referred to the material and manufacture/ attains some 80%. Considerable is also the economy of labour /about 33%/, not to mention the economy of metal. Moreover, the use properties /e.g. vibration damping/ are significantly more advantageous.

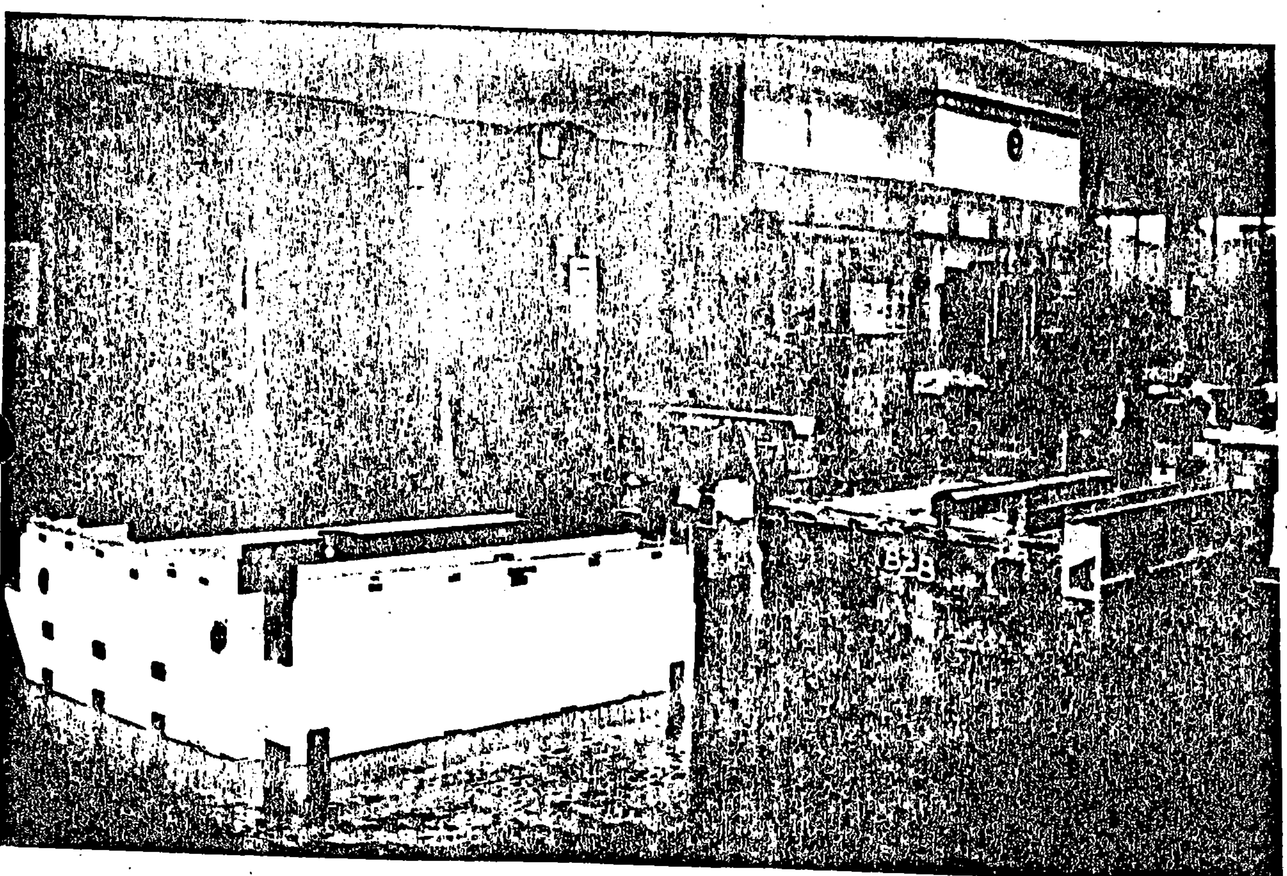

Fig. 5 Polymer concrete frames for precision grinders /weight - about 3000 kg/ produced in TOS Hostivař, Prague /works-photo by TOS/

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