Polymere und Beton

Vierter internationaler Kongreß Polymers in Concrete (ICPIC)
19.–21. September 1984
Technische Hochschule Darmstadt

Ziel des Kongresses

Der Teilnehmerkreis setzt sich zusammen aus internationalen Fachleuten aus den Gebieten Forschung, Entwicklung sowie Anwendung und Verarbeitung. Ziel des Kongresses ist, einen Überblick über den derzeitigen Stand der Technik sowie zukünftige Entwicklungen auf folgenden Gebieten zu geben:

- **Weltweite Anwendung von Polymeren in Beton**
- **Neuere Einsatzgebiete**
  z. B. im allgemeinen Maschinenbau, Werkzeugmaschinenbau, Bauwesen, Umweltschutz, in der Elektroindustrie, Architektur u. ä.
- **Ergebnisse der neueren Forschung und Entwicklung**
  von Polymerbeton, mit Polymeren imprägniertem bzw. versetztem Beton und Beschichtungen
- **Verarbeitungstechniken von Polymerbeton**

Einladung zu Vorträgen

Zu den oben genannten Themenkreisen werden Vorträge angenommen. Interessenten werden gebeten, das Vortragsthema zu benennen und zusammen mit einer Inhaltsübersicht von max. 1 Schreibmaschinenseite bis zum 1. September 1983 einzureichen.

Allgemeine Informationen

Die Kongreß-Sprachen sind Deutsch und Englisch mit simultaner Übersetzung. Für eine vorläufige Registrierung bitten wir Sie, umgehend die Postkarte ausgefüllt zurückzusenden oder direkt an folgende Adresse zu schreiben:

Technische Hochschule Darmstadt
Institut für Spanende Technologie
und Werkzeugmaschinen
Prof. Dr.-Ing. H. Schulz
Kennwort: ICPIC 1984
Petersenstraße 30
D-6100 Darmstadt

Weitere Informationen erhalten Sie mit einem zweiten Anschreiben im Laufe dieses Jahres.

Polymers in Concrete

Fourth international congress polymers in concrete (ICPIC)
September 19–21, 1984
Technische Hochschule Darmstadt

Purpose of the congress

The participants include international experts in research, development as well as in application and processing.
It is the aim of the congress to provide a review of the present technical status as well as future developments on the following:

- **Worldwide application of polymers in concrete**
- **New fields of application**
  e.g. in mechanical engineering, machine-tool design, civil engineering, environmental protection, electrical industry, architecture etc.
- **Results of new research and development**
  of polymer-concrete, polymer-modified or impregnated concrete and coatings
- **Working techniques with polymer-concrete**

Call for papers

Contributions to the above mentioned subjects will be accepted.
Those interested are requested to name the subject matter and hand in the summary of content on one type written sheet by September 1, 1983.

General information

The concress languages are German and English, translated simultaneously.
We request you to complete and post the attached postcard as soon as possible or write directly to the following adress:

Technische Hochschule Darmstadt
Institut für Spanende Technologie
und Werkzeugmaschinen
Prof. Dr.-Ing. H. Schulz
Kennwort: ICPIC 1984
Petersenstraße 30
D-6100 Darmstadt
W. Germany

You will receive further information in a second letter in the course of the year.

ICPIC '84

Vierter internationaler Kongreß

Polymere und Beton

Polymers in Concrete

Fourth international congress

19.–21. September 1984

Institut für Spanende Technologie
und Werkzeugmaschinen
Technische Hochschule Darmstadt

Technology and performance of epoxy PC repairs of historical sandstone building elements

Technologie und Zuverlässigkeit der Reparaturen historischer Sandsteinwerke mittels Polymerbeton auf Epoxidharzbasis

Prof. Richard A. BARES
Czechoslovak Academy of Sciences, Institute of Theoretical and Applied Mechanics, Prag, Tschechoslowakei

SUMMARY

During reconstruction of Lobkovitz's palace in Prague castle area original sandstone window frames as well as other sandstone parts (fillets e.g.) by epoxy PC were patched. The PC mixture was carefully chosen in order to obtain not only the similar structure, colour and face but also the physical properties (strength, E-modulus, vapour permeability, thermal dilatability etc.). Accelerated weathering tests were performed modeling many freezing and thawing cycles, temperature shocks, moisture changes, UV radiation etc and the changes of tensile as well as shear strengths of the PC-sandstone contact joint were continuously investigated besides externals changes.

ZUSAMMENFASSUNG

Während der Wiederherstellung des Lobkovitzpalastes im Prager Burgareal wurden die originalen Sandsteinfensteranschläge sowie andere Sandsteinteile (Einfassungen, Randsteine usw.) mittels Epoxidpolymerbetons ausgebessert. Die Polymerbetonmischung wurde sorgfältig ausgewählt um nicht nur ähnliche Oberflächenstruktur, Farbe und Aussehen, sondern auch physikalische Eigenschaften (Festigkeit, E-Modul, Dampfdurchlässigkeit, thermisches Dehnungsvermögen usw.) zu erhalten. Beschleunigtes Prüfen auf Witterungsbeständigkeit wurde durchgeführt, einschließlich Simulation mehrerer Einfrier- und Enteisungszyklen, thermischer Stöße, Feuchtigkeitsänderungen, UV-Radiation u.a.. Gleichlaufend wurden die Zug- und Schubspannungen auf der Kontaktfläche auf äußere Änderungen untersucht.

1. Introduction

In the reconstructions of historical buildings we often encounter the problem of replacing various sandstone building elements /cornices, window surrounds, sculptural details, etc./, which have been damaged or destroyed by the long time effect of aggressive atmospheric influence or by other factors. As a rule, the sites in which the original stone has been extracted, have long exhausted or are entirely non-existent. Consequently, the repairs using conventional stonemason s work and exchange of elements are considerably difficult. The preservation of the textural and colour unity of the repaired elements with the original stone can be attained, in some cases, by the application of epoxy polymer concrete /PC/. However, such repairs necessitate not only a sensitive selection of filler /often the crushed original sandstone/, binder /type, quantity/, admixtures /pigments/, working and curing determining primarily the final appearance of the repaired element, but also a careful assessment of the physical and chemical aspects of the cooperation of the original and new materials in their operating conditions, to ensure a long life of the whole building. The neglect of some aspect of this cooperation of both chemically very different materials results, as a rule, sooner or latter in defects and deterioration of the repair.

2. Theoretical Background

We shall leave aside the problems connected with the selection of the filler, ensuring enalogous texture of the PC with the original sandstone, the selection of binder and pigment, determining the suitable colour hue /including the identity of its changes due to ageing/ and with the working, which are /or should be/ a routine business of the restoration specialist, and concentrate on the problems of physical character, influencing particularly the performance of the repaired element.

Almost every sandstone, consisting most frequently of a siliceous filler and an inorganic binder, is a composite of the third type /1/, the characteristic structural features of which include, apart from aggregated filler, also continuous porosity. In accordance with the external environment conditions the pores are filled with a fluid phase in the gaseous or liquid form. The diffusion of the fluid phase through sandstone is possible and depends only on the magnitude of the diffusion resistance which varies between $0.008 \cdot 10^{-9}$ and $0.01 \cdot 10^{-9}$ s /SI/. Since the diffusion resistance is one of the principal physical characteristics of the material /markedly influencing the performance of the system/, it was quite logical that some authors have endeavoured to formulate PC of the same diffusion resistance as the sandstone for the repair of which the PC was to be used. One of the methods used was to add a certain quantity of evaporating diluent to the PC or its binder. Continuous porosity has been attained in either case; however, if the diluent has been added to the resin, it reduces simultaneously the quota of active binder in polymer concrete. The reduction of the binder content results in the reduction of not only the mechanical properties of the PC, but also -and particularly- the bond between PC and sandstone. On the other hand, it ensures that the diffusion resistance of the contact joint is analogous with that of the PC.

Internal stresses due to the polymerization of PC, temperature and humidity changes of both materials /with different coefficients of thermal and moisture expansion in the contact joint, however, necessitate a sufficient bond strength which, as a rule, cannot be ensured by a porous, resin-poor system. Sufficient bond /at least on the level of tensile strength of one of the partners/ can be ensured only by a bonding microlayer of epoxy resin, bound by chemical bond with the mechanically anchored epoxy resin particles in the sandstone after previous penetration on one side, and with the PC binder on the other side.

It is obvious that the required properties of the contact joint result in a discrepancy. If good adhesion between sandstone and PC is ensured, it will create a diffusion barrier at the contact surface which may, in some cases, cause defects /at the same time also the formulation of a continuous porosity PC loses its meaning/. If, on the other hand, the diffusion permeability of the contact surface is preserved, sufficient bond, required in certain loading stages, cannot be ensured and the defects may originate, once again. The solution is obviously possible only in individual cases, depending on ambient environmental conditions and the dimensional and spatial arrangement of the element under repair with regard to its base, by an optimization of the system based on the analysis of the individual physical quantities.

One of the ways leading to the optimization of the systemis also the observation of the strength history /of PC, of the contact joint/ and of induced stresses in the system in dependence on the PC binder/filler ratio /Fig. 1/. With the decreasing quantity of the binder in the system the value of the tensile strength of PC follows

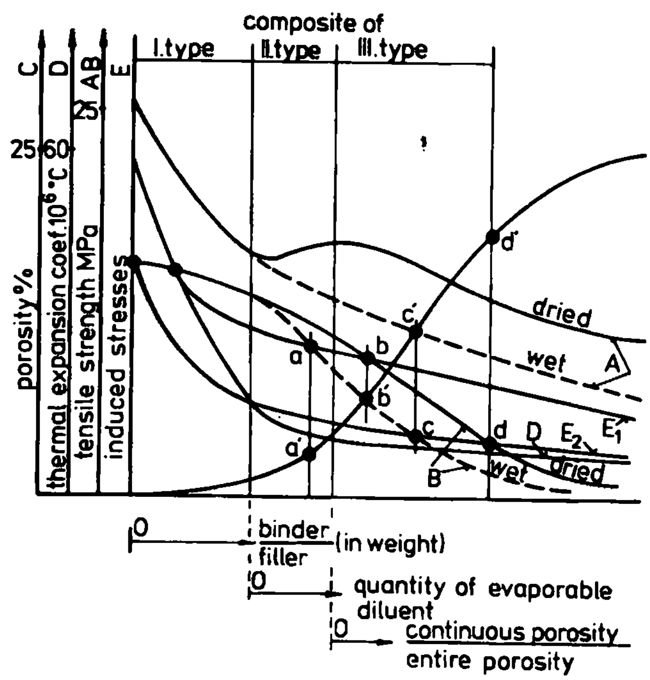


Fig. 1 : Tensile strength /A/, coefficient of thermal expansion /D/ and porosity /C/ of PC, bond strength of the contact joint with sand stone /B/ and induced stresses due to temperature changes and polymerization shrinkage in the contact joint /E/ plotted against the composition of PC. Curves E_1 and E_2 characterize the induced stresses for two different binder systems and various temperature ranges. Points a, b or c,d /for wet or dry condition respectively/ determine the minimum amount of binder, ensuring sufficient bond strength of the contact surface; points a', b' or c', d' on Curve C determine the corresponding porosity /diffusion/.

the curve A /2/, the strength of the contact joint /provided adequate penetration of the sandstone and adequate execution of subsequent operations before the hardening of the resin/ following the curve B. The change of the diffusion permeability /continuous porosity/ of PC is characterized by the curve C, and the change of the coefficient of thermal expansion of PC by the curve D. The construction of the curve E, determining the stresses induced by the changes of temperature or humidity /added to the stresses due to polymerization shrinkage/ or by mechanical loads of the same system, in the same diagram gives an /at least general/ idea of the suitable composition of PC /without the bonding layer/. If the PC system formulated in this way is unsatisfactory for reasons of appearance /e.g. because of excessive binder contents/, it is necessary to use a system with a bonding layer, if permitted by the diffusion conditions of the system. In opposite case the epoxy PC cannot be used because of excessive danger of failure. For example, the induced stresses shown in Fig. 1, vary within the limits determined by curves E /hatched area/. As soon as one of these curves intersects curves B characterizing the strength of the joint, the system is unsuitable and may fail. Only the system to the left from the point of intersection can be used, with a higher binder contents than the critical value. At the same time the point of intersection on curve C determines the diffusion resistance of the system, which must remain below the value of the diffusion resistance of the basic material /sandstone/. As the joint strength depends also on whether /and to what extent/ the material is saturated with moisture, also the critical value of the composition depends on this degree of saturation.

Since all the data /curves/ represent a statistical function of a number of variables, this analysis can afford informative guidance only. Before the concrete application of the selected system its verification should be carried out, at least by means of accelerated tests, as it is described further one.

3. Example of Practical Repair

3. 1. Description of Tests

In the overall reconstruction of the Lobkovitz Palace in Prague Castle /Fig.2/ it was decided to carry out the repairs of sandstone window surrounds, particularly the filling of the rebate on the outside of the surrounds to receive the originally outward opening casements, as well as of other sandstone elements, by means of epoxy PC /Fig. 3, 4/. The reasons for this decision included, apart from the reduction of labour requirements of the stone mason s work /exchange of elements/ also the fact that identical or even similar sandstone was not available.

The contractor formulated the composition of resin concrete and proposed the execution by the trial and error method, i.e. on the basis of practical experience only. The investor requested a proof of the long life of the proposed repairs by experimental research within the shortest period possible. Therefore, an experimental programme of modelling the effect of temperature and moisture changes /direct insolation and torrential rain/ as well as the effect of low temperatures /frost/ on samples produced by the proposed technology, was drafted.

The one year effect of the weather was modelled by 20 cycles designed as follows:

a/ air of a temperature of 55°C and relative humidity of 35% for one hour, with a gradient of 30°C per hour from the basic temperature of 5°C, together with ultraviolet radiation,

b/ water of a temperature of 5°C for one hour,

c/ air of a temperature of 5°C and a 100% relative humidity for one hour.

Altogether 60 cycles were applied.

The one year effect of frost was modelled by 15 cycles designed as follows:

a/ air of a temperature of -25°C and maximum obtainable relative humidity for 2 hours with the reduction of temperature from the initial temperature of 5°C at the rate of 10°C per hour,

b/ air of a temperature of 5°C for 2 hours with a gradual temperature increase by 6°C per hour.

Altogether 45 cycles were applied.

In the course of these cycles the changes of the contact joint were observed microscopically and the changes of colour and texture were objectively /photographically/ recorded.

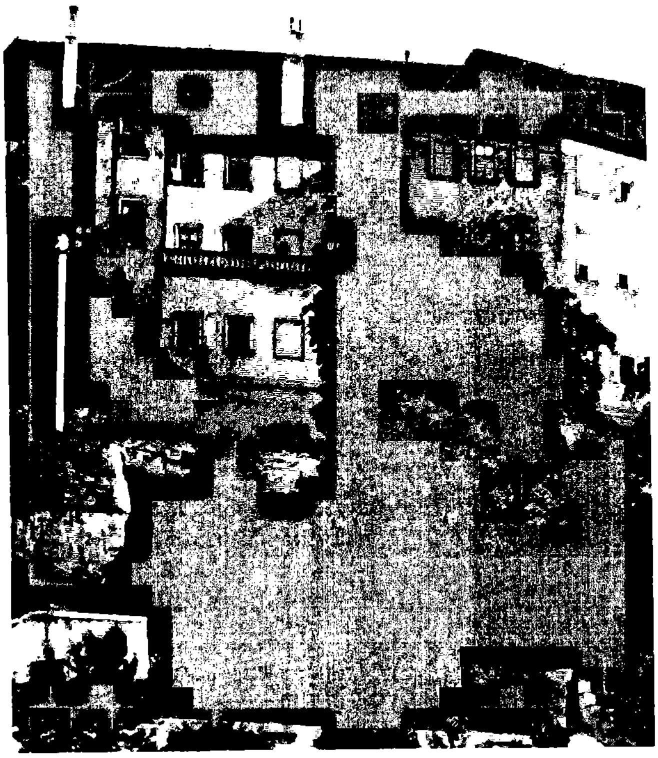


Fig. 2 : Southern wing of Prague Castle with the Lobkovitz Palace

The test samples were made of fragments of sandstone sized 8 x 8 x 25 cm with the cut-out rebate sized 4 x 4 x 25 cm filled with PC. To increase the bond between the sandstone and the PC the boreholes in sandstone, spaced at approximately 10 cm centres, were provided with copper wire anchors grouted with epoxy resin. After the atmospheric ageing tests the test samples were cut into three identical parts sized 8 x 8 x 8 cm and cubjected to tests in accordance with Fig. 5. by the loading of the contact joint by a combination of pure tension and shear. The justification of the test method used, particularly in respect of the stress distribution in the contact joint /with regard to the possibility of influence of end effects/ was investigated on a model sample by photoelasticity using reflex foils /Fig. 6/. Isoclines and isochromes were ascertained which characterize, on the one hand, the directions, on the other hand the differences of principal stresses. The magnitudes of the individual stresses were determined by integration.

It has been ascertained that the ratio of the tensile strength and the shear strength in the contact joint differs very little from the theoretical assumption.

The ratio of $\frac{dF}{dF}$ has been found as equal 1.1.

The technology of polymer concrete repairs used the following sequence of operations:

- penetration coat with a 10% solution of epoxy resin in acetone,
- application of epoxy PC with a filler/binder ratio of approximately 10 : 1 by weight and filler particles sized 0.05 - 3 mm. PC was applied by hand to the not yet hardened penetration coat,
- when the PC had hardened, it was processed by stone mason's technique /hammered/ to afford it an optically uniform surface, and provided with a siloxane coating.

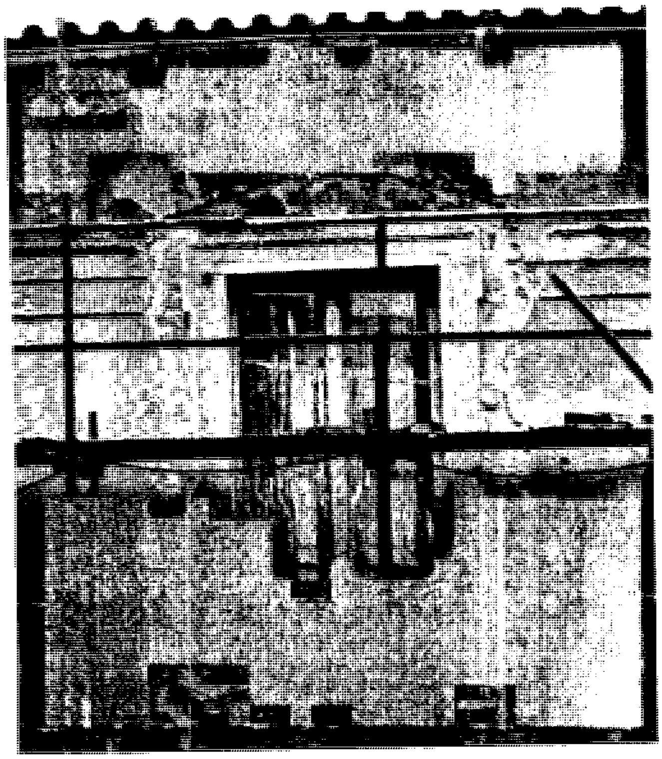


Fig. 3. Reconstructed sanstone window surrounds with the filled rebate to receive the originally outward opening casements with PC

Fig. 4. Detail of filling of the missing parts /left hand lower and upper corners/ of the sandstone window surrounds with PC

3. 2. Test results

As early as after several weathering cycles /sudden temperature changes as well as freezing and thawing/ the

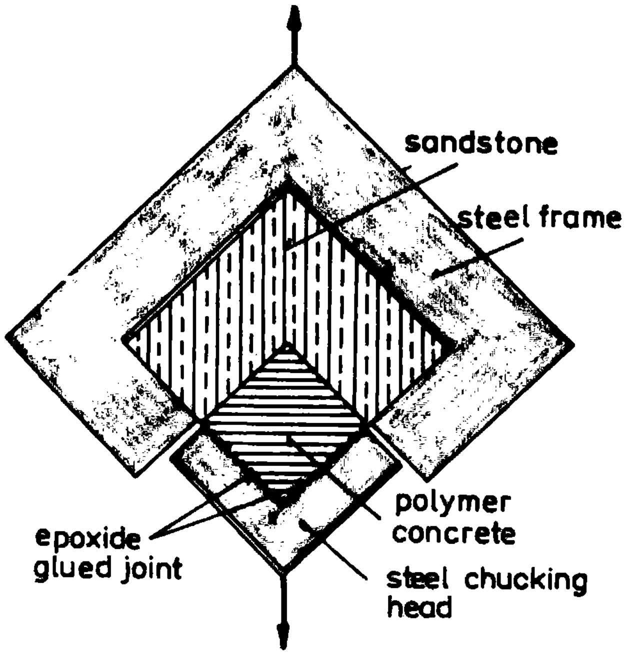


Fig. 5 : Test arrangement

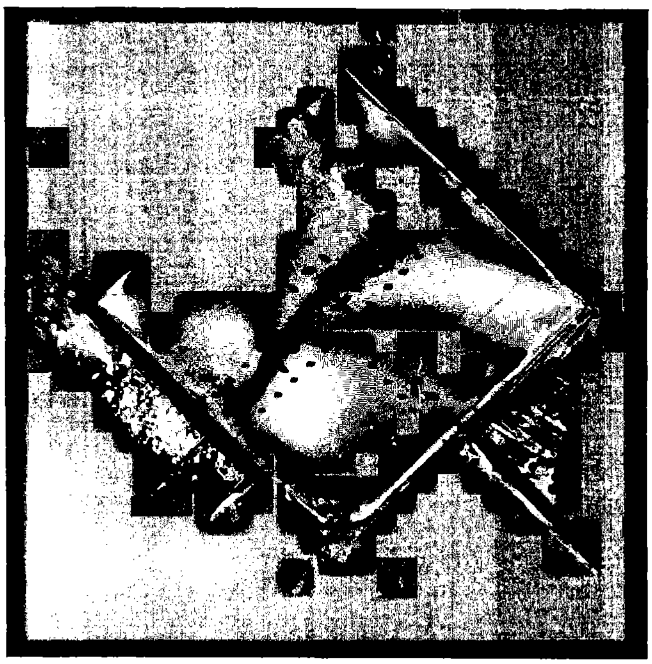
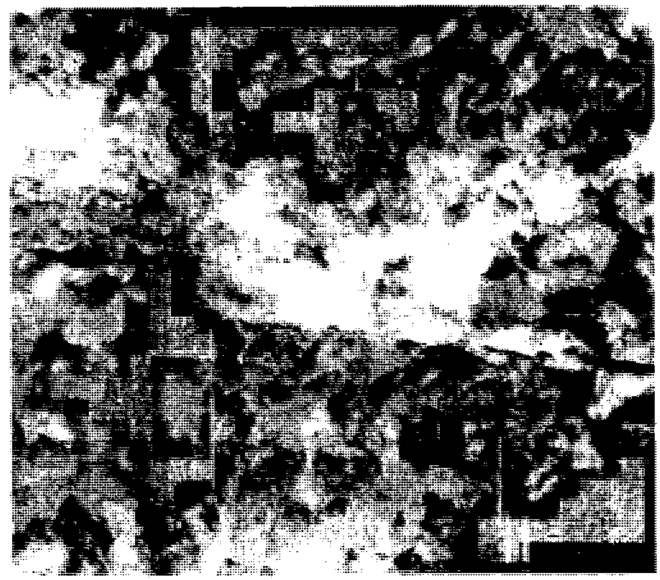


Fig. 6 : Interference elements in the optically sensitive layer

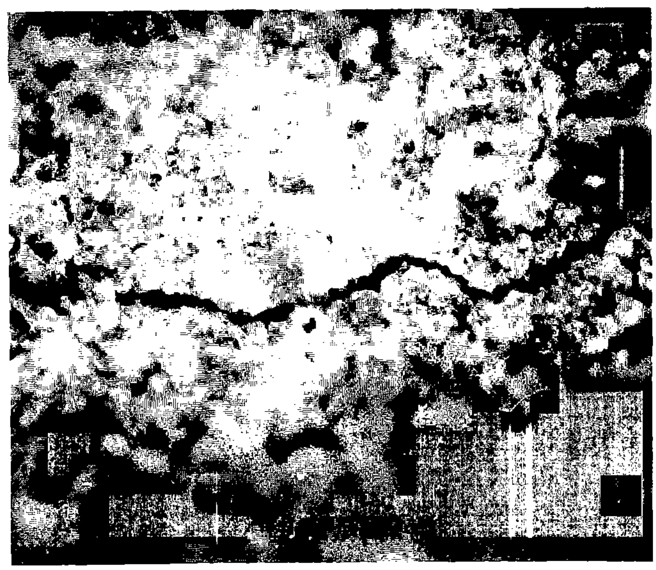
origin and development of a crack in the contact joint was observed /Fig. 7/.

The sandstone and the PC parts held together mostly thanks to the mechanical copper wire anchorage; this was confirmed also by the results of mechanical tests, in which the maximum ultimate tensile stress /before the weathering/ attained 0.39 MPa with the simultaneous shear stress of 0.36 MPa. With the application of epoxy resin bonding layer even after exposure to weathering tensile strength was ascertained at 2.6 MPa with the simultaneous shear in excess of 2.3 MPa.

Both weathering regimes exercized an unfavourable influence on the contact joint. If the joint was not visible at the very beginning of the test, it appeared after the application of only a few cycles. The width of the joint between the two materials after 45 freezing and thawing cycles or 60 weathering cycles attained the value of 0.3 mm in one series of tests and as much as 0.8 mm in the second /repeated/ series. Apart from that the freezing



before



after

Fig. 7a : Contact joint before the weathering test and after 60 cycles of exposure to temperature and humidity changes and ultraviolet radiation

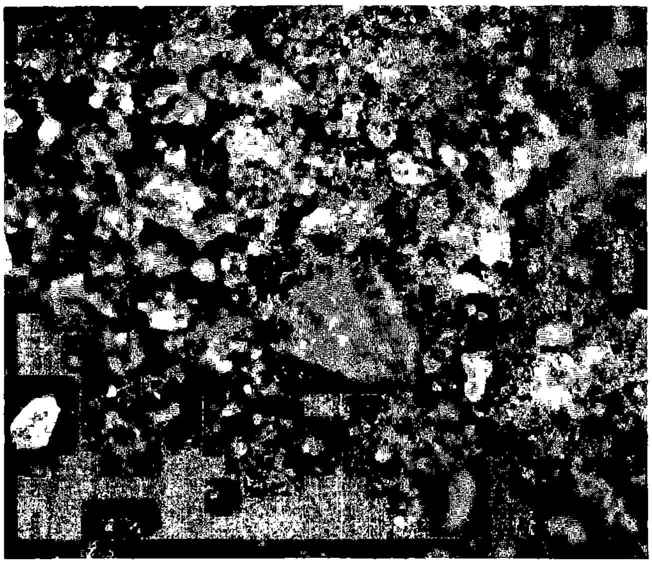
and thawing cycles resulted in some /rather solitary/ cases in the deterioration of PC by cracks parallel with the contact joint.

Ageing exercized a considerable influence also on the colours of both materials. The colour hues of both parts changed with the increasing number of cycles so that in some phase /age/ they were very similar, in others markedly different. No regularity has been ascertained in this respect. The fact remains that even if the colour unification is successful at the beginning, further exposure to the weather will necessarily result in more or less intensive diversification of colour and, consequently, with a conspicuous appearance of the repaired parts.

4. Conclusions

In the repairs of sanstone building elements with epoxy PC two basic cases must be differentiated:

- repairs in which the whole exterior surface of the part, in which a marked moisture diffusion may occur /e.g. from the soil, from the swimming pool, etc./, is



before

after

Fig. 7b : Contact joint before the weathering test and after 45 freezing and thawing cycles

sealed by the new material /PC/ and minor repairs,

- repairs in which the new material does not seal the whole exterior surface and the diffusion may proceed in a sufficient extent through untreated parts, or where there is no danger of a significant steam diffusion through the basic material and of its concentration due to unfavourable temperature gradient at the contact surface.

For the first case an open porosity system is preferable /across the contact also in the PC/,while sufficient bond must be ensured primarily by a painstaking preparation of the base, the contact joint and the sofisticated composition of the resin concrete mix.

In the second case the solution is preferable which ensures maximum strenth in the joints even at the cost of the creation of a moisture and vapour impermeable membrane at the contact. In such a case the porosity of the polymer concrete is actually of no importance, and its binder contents is determined more or less by aesthetic criteria. The efficiency of the bond is ensured by a special "bonding" layer consisting of pure or mildly filled resin.

The negative results of performance tests carried out, in our particular case of the Lobkovitz Palace, by the first method /with low diffusion resistance/ resulted in the use of the second method of reconstruction with the bonding layer. In the case of these repairs there is no danger of marked moistening of the rear face of the repaired elements. Moreover, should it occur at all, the major part of the surface on the front face of the elements remains open for the diffusion. For this reason there is small probability of condensation of a major amount of humidity /even should such unfavourable temperature and humidity conditions of ambient environment occur/ in the contact joint, which will be impermeable, and the probability that the generated stresses should exceed the bond strength of the contact joint is very low.

Of importance for the repair is to ensure perfect preparation /cleaning, preferably by sand-blasting/ of the base and the sequence of the individual operations /penetration, bonding layer, PC/ while the preceding material is in a gelated /not yet hardened/ state. For the penetration coat and the bonding layer softened epoxy resin can be used to advantage. For PC only unsoftened resin must be used. The contents of the diluent for the penetration coat /of the xylene type, e.g. the mixture of xylene and butylalcohol/ should not exceed 40 - 50% of the resin. The bonding layer, applied to the gelated penetration coat, should be about 1 mm in thickness. Care must be taken lest it should be wiped off when placing the PC. The PC is best worked by high frequency vibration /about 200 Hz/ generated by small surface vibrators.

To prevent water absorbtion by the sandstone and the PC /if formulated as a porous material/ it is advisable to provide their surface with a hydrophobic coat. Instead of the usually used siloxane coatings some silane or combined silane-siloxane coatings have proved better in respect of the long-term duration of their hydrophobization effect. The suitability of the respective type must be verified on the site.

The repairs of sandstone building elements carried out in accordance with the described principles using epoxy PC generally afford, on the basis of extrapolation of experimental results obtained so far, a reliable guarantee of long term performance.

References

/1/ Bares R., Classification of Composite Materials and Plastics Composites, Plastics in Material and Structural Engineering, Proceedings, Elsevier, Amsterodam, 1982, pp. 345-358

/2/ Bares R., Navrátil J., Berka L., Javornicky J., Practical Application of Synthetic Construction Material as a Result of Exact Definition of Material Properties, Les Congrés et Colloques de l'Universite de Liège, Vol. 32, Universite de Liège, pp.465-477.