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[illegible], 20 - 24 October 1969

COMPLETION AND SUBSTITUTION OF ASBESTOS CEMENT BY PLASTIC MATERIALS[1]

by

H. Schultheis,
Department of Application, Farbenfabriken Bayer AG,
Leverkusen, Federal Republic of Germany

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SUMMARY

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H. Schultheis
Department of Application, Farbenfabriken Bayer AG,
Leverkusen, Federal Republic of Germany

Asbestos cement is known as a suitable and cheap construction material with a good mechanical and high weathering performance. It is therefore of particular interest for developing countries.

Problems may arise in two ways:

1. Some properties, e.g. the heat insulation power, surface appearance, sound absorption and so on, may be insufficient for a given construction problem;

2. one or more of the raw materials for the production of asbestos cement may not be available in the developing country.

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The present paper deals with the possibilities to overcome these problems by the use of plastic materials in the production of asbestos cement, either in combination with or by substitution of this material.

The term "plastic material" is defined as a generic notion for a variety of high molecular products with different properties. The classification of the main types of plastics is discussed, and thermosetting resins and foams are found to be particularly interesting materials for asbestos cement. A short synopsis is given about the development, production cost, properties and methods of application of these materials.

They may be used for completion of asbestos cement mainly in two ways:

1. as a surface coating material (particularly unsaturated polyester and polyurethane resins);

2. as a heat insulating material to achieve a better heat and sound insulation (foams based on polystyrene, phenolic resins and especially polyurethane).

Examples are given for these applications. They are particularly interesting for light-wall-systems, curtain walls, heat insulated bungalows and so on. The technical effect obtained by the combination of asbestos cement with plastics is in any case greater than with other materials. However, the cost of these composites is elevated in comparison to the price of pure asbestos cement.

It is demonstrated that production costs can be reduced by means of rationalization and that asbestos cement / foam composites are of high interest for developing countries. Information is given about the development of so-called "foam-light-concrete" and its composites with asbestos cement for pre-fabricated walls and installation centres.

In case the production of asbestos cement is not possible in a developing country for lack of raw materials, e.g. asbestos fibres or cement binder, plastic materials are not suited to substitute one of these products in a simple, cheap manner. In principle it is possible to use unsaturated polyester resins, epoxy or other resins instead of cement as a binder for the asbestos fibres. The mechanical and chemical behaviour of these composites is even better than in the case of normal asbestos cement, but the price of these materials will restrict their use to special purposes. Examples are given.

Finally the total substitution of asbestos cement by plastic materials is discussed. Particularly glassfibre-reinforced polyester resins may be used to a certain extend instead of asbestos cement, the advantage being, that they are lightweight, translucent materials. In this case too, however, prices will limit the substitution to special applications, particularly in combination with asbestos cement to assure light transmission.

As an outlook for the future one can say that plastic materials are very interesting in combination with asbestos cement, particularly in the field of pre-fabricated housing.

Substitution of cement as a binder for asbestos fibres does not seem to be useful for developing countries, but the use of pure plastics instead of asbestos cement may be of interest.

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Substitution of cement as a binder for asbestos fibres does not seem to be useful for developing countries but the use of pure plastics instead of asbestos cement may be of interest.

1. Introduction

Asbestos cement is known as a very suitable and cheap construction material for different purposes with high mechanical performance. Therefore it is of particular interest also for developing countries and may there be used not only for housing, but also for the construction of factory halls, hangars and so on.

There is no construction material which is perfect in all ways and also asbestos cement has in spite of the excellent properties a very low heat insulation power, the surface appearance in pure state is not very attractive and the brick behaviour under load is not optimal. In these and other points it would be desirable to combine asbestos cement with other materials to conserve its good properties and to complete the material in its weak points.

On the other hand it could arrive that particularly developing countries do not dispose of one of the raw materials to produce asbestos cement. That would mean that asbestos fibres or cement are not available in this region. In this case there would be the problem to substitute the lacking raw material by another product available in this country.

This paper deals with the possibilities of resolving these problems by the use of plastic materials.

As has been pointed out already in the summary, plastic materials can never be a real competition product for asbestos cement. There is practically no plastic material which can hold the price of Portland cement, and in spite of the fact that there are a lot of synthetic fibres they cannot be used in a simple manner as a substitution product for lacking asbestos fibres. The use of plastic materials in combination with asbestos cement or in substitution of one of its raw materials is justified in most cases by the increase of the technical properties of the end material in comparison with pure asbestos cement. But in this manner the technical possibilities for the application of such a modified asbestos cement are much more various and therefore very interesting also for developing countries.

2. Major properties and general application methods of plastic materials

2.1 Definition of the term "plastic material" - classification

In a similar manner as the terms "wood" or "metal", the term "plastic materials" is a generic notion for a variety of products with different mechanical and chemical properties. The common characteristic of all these materials is that they are industrial products of a high molecular structure, which are never encountered in nature. This definition would practically comprise also synthetic fibres, varnishes and rubber. Indeed, the boundaries between these great sections of synthetic high molecular materials cannot be defined in an absolute manner. According to the habit of science and technique this paper means with the term "plastic materials" the compact, solid products, synthetic resins and so on as well as plastic foams and the liquid, pre-polymerized resins which are in most cases viscous oils and can be hardened to the final high molecular product.

It is a common property of nearly all plastic materials that their heat resistance is limited to a range of about 100 to 200° C. If the plastic material is more and more heated it will either become weak and then viscous and liquid or it will decompose in a chemical degradation. In the first case the loss of the solid state is reversible and the viscous or liquid state may be used for the transformation of the plastic to a new shape. Plastic materials of this kind are called "thermoplastic materials", while the other class which decomposes in an irreversible manner in the heat belongs to the "thermosetting" materials.

This division into thermoplastic and thermosetting materials is very important, and also the plastic foams do not form a special group, but in spite of their different outer aspect they are only plastic materials in the state of a foam which belong either to the first or to the second fundamental group.

Thermoplastic materials are wide-spread as typical plastics in household, machinery, sports and so on. They have also a certain significance for housing, but they are not very important in connection with asbestos cement. Only one special case is interesting in this direction: rigid foams based on polystyrene.

The second main group of plastics, the thermosetting materials cannot be transformed by heating because they undergo a chemical decomposition normally in the range between 150 to 200 °C. Therefore thermoplastics are normally furnished from the producers as a powder or granulate which may be shaped to final products by the transformers, but thermosetting plastics are furnished as liquid resins which are not real plastic materials, but intermediate products which are reacted or hardened by a second component in the moment of application and shaping.

These thermosetting resins or two-component-systems are of very high interest in connection with asbestos cement for they may be used as well for surface coating materials as also for the production of foams with high heat insulating properties. On the other hand resins of this kind are suitable too as binder for asbestos fibres to form new materials and also for the production of glassfibre reinforced plastics which may be a substitute for asbestos cement for some special cases.

2.2 General properties of plastic materials

In spite of the very different mechanical and chemical properties of the various plastic materials it is nevertheless possible to define some general characteristics which are typical for this kind of products and which are important also for the purpose of use with asbestos cement:

a) Very high variety in shaping, therefore also the construction of complicated forms can be realized.

b) Relatively low weight which is mostly between 1 and 2 g. per cm^3 in the case of compact materials, while plastic foams go down to 10, 20, 30 kg per m^3. Therefore plastics are typical light-weight construction materials.

c) In most cases high resistance in use and against chemical and weathering attacks which reduces repairs.

Special groups of plastics, for instance glassfibre reinforced plastics, foam materials and so on, possess special properties:

high tensile strength, respectively high dielectric insulation. This fact renders these [illegible] particularly interesting.

On the other hand, the application of plastic materials is limited mainly by the typical [illegible]:

a) relatively low heat resistance in comparison with other working materials. The [illegible] plastic materials cannot be used above 80 to 100° C, and also the thermosetting [illegible] begin normally to decompose between 150 and 200° C.

b) inflammability. The behaviour in burning is very different for the various types of plastics and may be improved considerably by chemical modification. The fact that plastic materials as organic materials on the base of carbon are considered to be combustible materials, has given rise to [illegible] whether they could be used in housing construction and so on. Therefore [illegible] that also wood and other well known materials for construction and housing are combustible. [illegible] rules in every country which [illegible] the use of the different construction materials for the various cases of application. Experience has shown that plastic materials can be used in a high effective manner as construction material within the building orders of the different states. This paper deals only with such applications which are approved and admitted by one or more of the Central Europe authorities.

Particularly in the case of combination products with asbestos cement the burning behaviour of a sandwich construction between for example asbestos cement and polyurethane foam is not given as the behaviour of the pure polyurethane foam, which may be rendered "difficultly inflammable" but has its own characteristic [illegible] governed by the protection of heat of the asbestos cement.

It will be further shown in this paper that there are some sandwich constructions between asbestos cement and foam material with an excellent fire resistance.

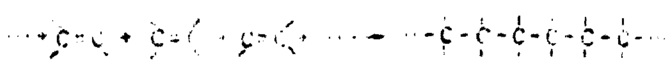
A further common characteristic for all plastic materials is the modulus of elasticity. While that modulus lies mostly above 100.000 to 1.000.000 kg/cm² for most of the conventional materials like concrete, steel and so on, the modulus of plastic materials is normally much lower. Even in the case of glassfibre reinforced plastics it reaches only 100.000 kg/cm². This fact does not have any importance when the plastic material is joined to another material of high modulus, for example asbestos cement, but when plastic materials are solely used in construction, it must be considered that great plain-shaped sheets [illegible], and therefore it would be better to profile the surface of the plastics to give them more stiffness. This is the reason for the use of corrugated sheets or other three-dimensionally shaped plastic bodies like domes, shells, tubes and so on in construction. Examples for this manner of construction are given in the last part of this paper in the case of complete substitution of asbestos cement by plastic materials.

2.3 Single classes of plastics in so far they are important for the use with asbestos cement.

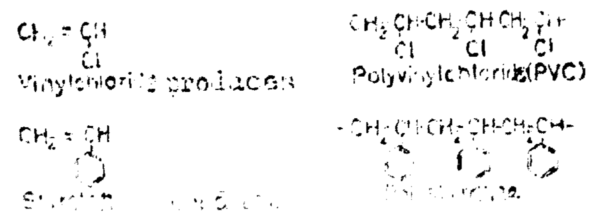
Remark: Even when plastic foams are not a special group of plastics from the chemical standpoint, but belong to the thermoplastic or thermosetting products, they are nevertheless treated in the following in a special manner by reason of their particular method of preparation and technical properties.

2.3.1 Thermoplastic materials

As pointed out before thermoplastic materials are scarcely used in connection with asbestos cement. A short characteristic may nevertheless be given because some of them may be transformed into plastic foams, which are important for the forming of composite materials with asbestos cement. Technically this kind of plastic materials are normally produced by polymerization of very simple low molecular substances, which reaction double bond between two carbon atoms. The term polymerization means that by the effect of a catalyst the double bound splits off and liberates new binding forces.
so that now some 1.000 or 100.000 of this low molecular weight compounds may join to a very high molecular plastic material:



Some concrete examples guide to known products. The polymerization of $CH_2=CH_2$ (Ethylene) produces $-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-$ (Polyethylene)



For the here mentioned thermoplastic materials polyvinylchloride is practically the eldest and also one of the most important plastics of this class. The unshaped product is normally a white powder, which undergoes gelification by heating above 100° C. The gelified product may be shaped into sheets, tubes and so on, while it is even possible to mix PVC powder with plastifying agents to obtain flexible sheets or plastisols, which may be used for the coating of metallic sheets and also in some cases asbestos cement. For these coating operations it is necessary to cure the coated material at temperatures above 100° C. Another advantage of these plastic materials is the fact that the production of PVC is wide-spread in the world, and also developing countries dispose normally of sources for this material.

While pure, hard PVC becomes brittle at low temperatures, improvement of its impact strength may be obtained by chemical modification, which leads to a tough working material. This can be transformed into corrugated sheets or similarly shaped articles, which may be used as translucent, pre-fabricated contruction materials. To a certain extend, these light-wall elements may be used as a substitute for asbestos cement.

Polyvinylchloride too may be transformed into a foam material, which can be combined with asbestos cement to sandwich structures, but normally foams of another chemical base are used in this case.

Another thermoplastic material mentioned in the equations above is polystyrene. The compact product has no importance, but as it will be shown later, it is possible in an easy way to blow up polystyrene to a very light-weight foam with high heat insulating properties, whose combination with asbestos cement to sandwich structures is very interesting.

Details for the rigid foams are given under point 2.3.3

2.3.2 Thermosetting plastics

While the molecular structure of thermoplastic materials consists of very low linear chains of carbon atoms, which have still the possibility of a certain movement, the structure of thermosetting materials forms a three-dimensional network, whose mobility is very restricted. Therefore the single chains cannot slide to form a liquid like in the case of thermoplastics, but the effect caused by heating of thermosetting resins may be the rupture of the network and thus the decomposition of the material. As mentioned above, the thermosetting resins are furnished as two-component-systems, which react during transformation into formed articles to the final end product, or as pre-polymerized systems, which harden under the effect of heat and pressure during the shaping. This process of hardening of the resins is caused by the formation of the three-dimensional network.

Chemically this system of formation of a thermosetting resin may be accomplished in different ways. The oldest class of thermosetting resins are the formaldehyde phenolic resins, which are known, for example, under the trademark Bakelit since nearly 50 years. In spite of their importance for other industrial purposes, they have no great interest in connection with asbestos cement. It is true that it is possible to form also a rigid foam with these phenolic resins with high heat resistance and good mechanical properties, but in spite of the fact of the very cheap and good availability of the raw materials phenol and formaldehyde the formation and application of this foam is rather difficult and not very cheap, and therefore there is still no real break through for composites of phenolic formaldehyde foams and covering materials.

Three other classes of thermosetting resins became very important in the building industry on account of their high variability in application. These are:

a) unsaturated polyester resins
b) polyurethane resins
c) epoxide resins.

2.3.2.1 Unsaturated polyester resins

These resins are produced by polyesterification of dihydric alcohols (glycols) and dicarboxylic acids, to linear chained polyesters, which may be branched to a certain extend by the incorporation of tri- or polyhydric alcohols. The raw materials for the polyesterification comprise always a certain amount of an unsaturated compound, particularly maleic acid,

HOOC-CH=CH-COOH

or other suitable compounds. In this way the resulting polyesters contain also C=C double bonds as reactive groups, which however are able to be reacted only poorly by certain catalysts. Furthermore, normally those polyesters are highly viscous liquids or even solids. Therefore it would be difficult to use them as such.

For these reasons they are mostly diluted by addition of styrene, which is a low molecular weight and low viscous liquid with a characteristic smell and which possesses a reactive double bond between two carbon atoms according to the formula:

$C_6H_5-CH=CH_2$

This diluting agent takes part in the hardening reaction so that the final product hardly contains any low molecular unreacted compound.

The technical production of unsaturated polyester resin is a relatively simple process, which does not require complicated equipment. Nevertheless it is obvious that the scale of production lowers also its costs, and for this reason the most effective polyester assortments are manufactured by great chemical factories also existing in some developing countries which possess experience to produce optimal products for different purposes. This leads to the fact that there is also a variety of different types of polyester resins on the market, which are particularly suited for the use in surface coating, polyester putties, reinforced plastics and so on.

The hardening reaction of these middle viscous, unsaturated polyester masses of commercial types may be obtained by addition of catalytic substances in the heat or at room temperature. The catalytic systems consist mostly of two components, the first of which acts as an activator and the second as an accelerator. These products are selected from the group of organic peroxides, metal salts of organic acids, aliphatic amines and so on. It could not be the purpose of this paper to give details of the numerous possibilities to harden an unsaturated polyester. The producers give exact formulations for the optimal way to a given type of assortment.

In any case the effect of the catalytic substances is that double bonds in the unsaturated polyesters and in the added styrene are activated to react with one another and to form the three-dimensional network under final curing and hardening.

The resulting end product is a solid compact mass of a translucent resin, which may be used in this unfilled form only for certain purposes in the electric industry and so on. It is a characteristic of the unsaturated polyester resins that during the hardening process a certain volume shrinkage will take place, which may be about 5 to 8 vol.%. This shrinkage must be kept in mind during the production of large size articles from unsaturated polyester resins and also in surface coating, because it causes shearing forces which can diminish the adhesion to the background. There are some possibilities to overcome the difficulties caused by volume shrinkage of polyester resins, particularly by adding fillers such as quartz powder, sand, fibres and so on to the resin before curing. Therefore unsaturated polyester resins are vastly used, mostly in connection with reinforcing glass fibres, as a surface coating also for asbestos cement.

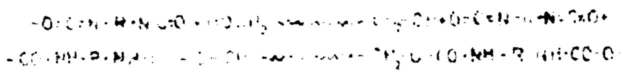
The main application in housing is the transformation into glassfibre reinforced plastics (corrugated sheets, light domes, translucent separating walls and so on), as shown at the end of this paper.

In the latest time unsaturated polyester resins could also be transformed into a foam, which became very important particularly in housing and offers a very high interest in combination with asbestos cement (see under point 2.3.4 and chapter 3.2).

2.3.2.2 Polyurethane resins

Since the hardening of unsaturated polyester resins is effected by addition of a catalyst, which enables the double bonds in the resin to open and to join one another, the hardening system of polyurethane resins is principally different:

There are on the one hand saturated polyesters or polyethers of middle or high viscosity, which possess hydroxyl groups and which may react with isocyanate groups as a second component according to the following equation:



The reaction scheme shows that there must always be a certain amount of isocyanate compounds, which may be combined with a well-dosed quantity of polyhydroxide component. According to the equation it would seem that only linear high molecular chains could be formed by this system, but practically there may be used polyesters or polyethers with a certain amount of branched compounds to ensure a real three-dimensional network on the curing and also a slight excess of polyurethane causes the formation of additional links between the chains.

This kind of reticulation was first found by Otto Bayer in 1937 in Leverkusen and was called "polyaddition". Polyaddition of isocyanates and polyhydroxide compounds became very important for a variety of industrial sections. The final products obtained by reacting the numerous commercial types of compounds range in their properties from soft, rubber-like materials to hard, high reticulated resins. According to the selection of raw materials and the conditions of reaction this system may be used for surface coating agents and for soft and hard foams which [illegible] rigid closed-cell products with extremely high heat insulating properties which are a real construction material. As will be shown below, also polyurethane foams must be considered as one of the most important combining materials with asbestos cement.

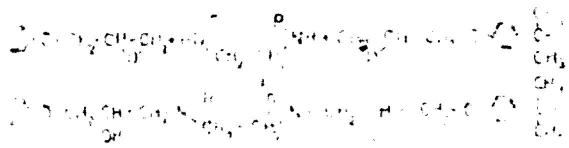
In comparison with unsaturated polyesters, the hardening reaction of polyurethanes entails no volume shrinkage. The reaction takes place after mixing of components at room temperature. It must be kept in mind that all chemical reactions go faster at elevated temperatures and become slower in the cold. In the case of reactions between polyhydroxide compounds and isocyanates the hardening of the commercial systems takes place also at temperatures in the range of 5 - 8° C.

The industrial production of the components for polyurethane compounds requires different equipment:

The production of polyhydroxide compounds, particularly polyesters is likewise simple, and besides the industrial products also natural compounds like castor oil and so on may be used particularly in the case of surface coating. Concerning the isocyanates it is much more difficult to produce suitable material on a small scale. On the other hand the industrial countries have installed very effective installations with high capacities and are able to furnish well standardized isocyanates at optimal conditions.

2.3.2.3 Epoxide resins

Like the polyurethane resins also the epoxide resins are two-component systems which react according to the polyaddition reaction to form reticulated final products. The resins are normally middle to high viscous oils, which can also be diluted by solvents or so-called reactive thinners, which are bound into the system during the hardening reaction. The reactive group of epoxide resins is a very tense, even triangular ring of two carbon atoms and one oxygen atom. This ring splits easily off if it is touched by a reactive hydrogen atom of the second component. These second components, the so-called hardeners, are normally aliphatic polyamines, whose hydrogen attached on nitrogen atoms are the functional groups for hardening. The scheme for this reaction is given in the following equation:



Epoxide resins may be used in the same manner as unsaturated polyester resins and also polyurethane resins, but because of their elevated price, they are only interesting for special purposes. In connection with asbestos cement there is only the field of surface coating which may be interesting. The main advantage of epoxide resins is the very low shrinkage during the hardening reaction, which ensures dimensional stability and avoids shearing forces.

2.3.3 Comparison between the three systems unsaturated polyester resins, polyurethanes and epoxide resins

The mechanical properties of hardened resins of all three types go up in the above mentioned sequence. But it is also the price which increases in the same sense. The relationship between unsaturated polyester resins, polyurethanes and epoxide resins concerning the price per kilo is in Central Europe about 1 : 2 : 3 1/2. This important relationship shows that normally unsaturated polyester resins are favoured by their relatively low price which lies in the range between 1.30 to 1.50 DM/kg. In practice there are also different realisations as shown in the application part of this paper, and in spite of the shrinkage problems polyester resins can be made to adhere sufficiently on the asbestos cement surface, particularly in connection with glassfibres. The weathering resistance of such coatings is also sufficient for the central European climate, but better values are obtained by polyurethane resins, which are also more various in designing. As shown in chapter 3. of this paper a lot of work has already been done to obtain surface designs for bath-rooms, corridors, outdoor applications and so on.

Epoxide resins are very [illegible] for all coating systems which must be resistant to heavy mechanical and chemical attacks. Their use in connection with asbestos cement for housing is relatively few developed. There are some applications of coating asbestos cement for roofing, cladding and so on, but if only weather resistance is required, in most cases polyurethane resins would be absolutely sufficient.

2.3.4 Plastic foam systems

Nearly all plastic materials of the thermoplastic and thermo-setting type can be obtained under certain conditions in a cellular or foam state. In practice there are some special types of plastics which became extremely important for several industrial sections because of their outstanding mechanical properties. Particularly in housing some foam systems have great success as heat insulation materials. Independently from the chemical origin all plastic foams are typical light construction materials. Regarding their application, there are principally two different ways:

a) The foam material may be used as a semi-finished product particularly in the form of sheets and may then be glued to other materials for example asbestos cement sheets.

b) On the other hand the foam can be obtained from the raw materials directly in contact with the covering materials so that the rising foam may adhere to the surface of the asbestos cement or other products and solidify in this state to form a composite structure.

In practice both systems of fabrication are used.

The most important foam systems in connection with asbestos cement are:

2.3.4.1 Polystyrene foam

In most cases this very light foam is produced in the two-step process: polystyrene is mixed in the first step with a blowing agent and blown up to little granules up to about 3 to 4 mm of diametre and these very light white balls are put into a form which is closed and heated. In this second step further expansion takes place and the single balls flow into another to form a white light rigid foam. In the last years it has also become possible to produce a polystyrene foam by an extrusion process, in which the polystyrene mixed with blowing agents is extruded from a large slot to form plates or sheets with a foam structure. The two kinds of polystyrene foams are easily to be distinguished, because the first one shows already the inner structure deriving from the welding of single little balls, while a section across extruded foam will show a very uniform cellular structure.

The densities of these polystyrene foam materials range normally from 18 to about 30 kg/m^3. For the construction of sandwich composites also with asbestos cement it is the simplest way to glue the covering sheet with the foam core. There are a lot of suitable glues, which are recommended by the foam manufacturers. It should be mentioned that solvent containing glues are not suitable because the chemical solvent will penetrate into the polystyrene and dissolve it. The most interesting value for polystyrene foams, as well as for all other foams, is the heat conductivity. It lies in the range of about 0.024 kcal/m/$^\circ$C/h, which proves this material to be a very good insulation material.

2.3.4.2 Polyurethane foams

Polyurethane foams are known as the best heat insulation material. The λ - value ranges between 0.014 to 0.020 kcal/m/$^\circ$C/h. This is due to a special blowing agent, which is used for the foam formation from polyhydroxide compounds and polyisocyanates according to the system mentioned under 2.3.2.2. The chemical raw materials are rather the same as for the surface coating systems, but there is an additional fluorocarbon solvent which boils up during the polyaddition between the two components. This reaction is practically executed in a special way with addition of certain additives, which ensure the stability of the rising foam. Such a machinery is certainly an investment of some 100.000 DM. It is relatively seldom that polyurethane foaming machines are used for one purpose only, in this case for the production of asbestos cement / foam sandwiches. Normally, and also in numerous developing countries, there are already foaming installations with considerable capacity, which may be used also in this case. The great block machines for the production of weak foams for upholstery and so on are not suitable for an economic production of asbestos cement composites, but there are the so-called HK machines, which are particularly developed for rigid polyurethane foams and they may be used also for mould foaming or spray foaming in a so-called double conveyor belt machine. The last one is very important for the production of sandwich composites and will be further described in the practical part of this paper. (see chapter 3).

The application of foams may include not only the pure foams, but also composites of foams with inorganic materials, for example blown clay, blown glass and so on. Particularly the last case has become very important in connection with polyurethan foam for the production of very good flame-resistant composites, which may be suitable not only for wall elements, but also for the construction of insulation cores.

2.3.4.3 Other foam systems

While polystyrene and polyurethane foam systems are the most important ones in connection with asbestos cement, there are, as partially already mentioned above, also other foam materials. Some of them possess a certain interest for the problems of this paper:

Besides the above treated phenol-formaldehyde foams also urea-formaldehyde foams are known as a very effective heat insulation material. However, their mechanical stiffness is very low, so that they cannot be used to form sandwich structures in a similar way.

In the last years, a new blowing agent has been found in the Uerdingen plant of Bayer, which is very suitable to form foam systems of unsaturated polyester resins. These polyester foams may be applicated in a very simple manner, preferably in connection with inorganic fillers such as blown clay, blown glass and so on. Composites of these "foam-light concretes" with asbestos cement are possible, but the system is still in technical development.

3. Application of plastics in connection with asbestos cement

3.1 Surface coating

As the normal greyish surface of asbestos cement is not very attractive, it is usual to paint it. Normal paints are dispersion paints on an aqueous base and do not concern the content of this paper. But there is also a special surface coating with synthetic binders and different aesthetic effects which may be applied in all cases where good long-time behaviour also under hard weathering conditions is required. The binders used belong normally to the three thermosetting groups described in chapter 2. They may be used as well with organic solvents as also in a solvent-less state, which is particularly suitable if surface coatings of a certain thickness are required.

Reasons for the application of surface coatings with organic resins instead of the simple painting with dispersion colours are different:

In all outdoor applications the coating with synthetic resins may increase the durability and the outer aspect of the surface, and may serve also for a certain geometrical profilation of the surface.

In case of application in the inner rooms of the house surface coating with resins may simulate other materials, for example ceramics, or may produce a certain aesthetic effect, for example for bath-rooms, corridors and so on.

3.1.1 Surface coating with polyester resins

Unsaturated polyester resins are relatively seldom used as solvent-free surface coatings for asbestos cement, because of the shrinkage during the hardening reaction. But there are exeptions, particularly if the resins are reinforced by glassfibres. There are some very interesting realisations in France where outdoor wall elements or balustrades are constructed with sandwich composites of asbestos cement with polyurethane foams. The outer surface of the asbestos cement is covered with a layer of unsaturated polyester resin filled with pigments, fillers and so on and reinforced by glassfibres. The application of such a layer is executed by spraying first a thin layer of an unfilled and specially modified polyester resin to ensure a good adhesion to the asbestos cement. Then resin is spread on the primer from a two-component spraying gun, one component comprising resin + activator, the other resin + accelerator. The two components join one another directly on the asbestos surface, mix together and harden. At the same time glass fibre rovings are cut into short pieces of about one to two inches and jetted against the surface by air pressure. On the surface the hardening resin and the glass fibre pieces mix and form a very resistant layer the shrinkage of which will be neutralized by the reinforcing effect of the glass fibres. Finally an outer surface layer is applied with filled and pigmented resin. Considering the thickness of this coating it is possible to emboss profilation into the outer surface, for example very thin perpendicular channels, which may lead the flow of the rain.

The above mentioned method of application is not obligatory. It is also possible to unify the different stages of the process or to work with a glass fiber containing paste, which may be applied by spatula. In picture N° [illegible] an example is given of one of the realisations in France, which belong to one of some new suburban colonies.

These and other similar applications of polyester resins on the surface of asbestos cement are pre-fabricated constructing elements, whose surface coating has been effected under the well-controlled conditions of a factory. According to the very various outer aspects of the surface, which may be required for a certain case, also the working conditions for the polyesters may change to a certain degree, but generally the quality and reproducibility of a large scale production is always due to the maintenance of always the same working conditions. In order to avoid dust and other impurities, which may influence the adhesion as well as the appearance of the surface, it is always desirable to execute the coating in special rooms, which are not used for other purposes. The surface of the asbestos cement may be well-cleaned and must be free from oil and other impurities, which might react as a separating agent. The storage place for the polyester resins, fillers and so on should be apart from the production under cool and dry conditions.
In some countries pre-mixed polyester systems are available, which contain already fillers, pigments and so on. It depends on the local conditions whether an applicator will use such pre-mixed compounds, which require only the addition of accelerators and activators or whether they prefer to

mix the formulations themselves. In all the cases of handling the polyesters care must be taken that the prescriptions of professional associations and suppliers concerning the processing of polyester resins be observed. Considering the smell of monomeric styrene present in the resins as a diluting agent, the working rooms must be well ventilated in a controlled manner.

The optimal temperature for the work with polyester resins is in the range of 20 to 25^{0} C, while more detailed working conditions are given by the suppliers.

For the cleaning of machinery and tools it is necessary to have always organic solvents like methylenechloride, because it is very difficult to dissolve the completely hardened product.

All this shows that surface coating with polyester resins is a typical process for a well equipped service, which does not cause high costs, but must be well supervised.

The machinery, which is necessary for an economic work, is rather the same as for other services, which execute paint and surface coating works, that means mixers, rolls, spray guns and so on. As special equiment there is only the two-component gun with additional air-spraying of glass fibre pieces.

Surface coating with polyurethane resins

The coating with polyurethane resins may be executed with solvent-less compositions as well as with solvent containing formulations. In some cases it is necessary to use both possibilities. For example when the surface is first coated with a very high diluted primer to ensure the adhesion of the second more viscous coating composition. In other cases the use of different surface coating composites allows the application of aesthetically designed coatings with different colours and [illegible]

3.1.2.1 Solvent-less coatings with polyurethanes

The coating with solvent-less polyurethane resins is principally executed in the same manner as it is described under 3.1.1 for the unsaturated polyester resins. Also in this case the surface of the asbestos cement must be clean and dry. Since the polyurethane resins are very advantageous by reason of their very low shrinkage and good adhesion, they must be handled carefully because [illegible] they are very sensitive against the humidity present in the air, in the filling substances or on the support. Therefore dry conditions of working are required, and also the resins themselves must be treated with a special water catching agent. The reason for this treatment is that the isocyanate group of the resin system will react with water traces according to the equation

$$2\ R-NCO + H_2O \rightarrow R-NH-CO-NH-R + CO_2$$

under formation of a substituted urea and splitting off of one molecule of carbon dioxide. This reaction is used for the production of soft polyurethane foams for upholstery systems and therefore very important in the industry. In this case, however, it causes trouble by the formation of the gas CO_2, which causes bubbles in the layer of the coating and a bad adhesion to the surface. There are some classes of chemical compounds, which may be used as a water catching agent. In practice particularly sodium aluminium silicates of the crystal type of zeolith are widely preferred. This inorganic product of natural or synthetic origin is able to bind considerable amounts of water in micro channels of the crystalline structure. These channels caused by a certain arrangement of the different atoms of such products, are wide enough to allow the small water molecules to enter and to combine with active groups of the silicate structure. For other chemical compounds with greater molecules, for example for the long chain molecules of hydroxide compounds or isocyanates the channels are too small, so that they are effective as a molecular sieve for the water.

These sodium aluminium silicates with zeolith structure are easily available and are furnished as white powders, which must be stocked in a closed flask or other container. The advantage of these products is that the binding of water is a reversible process and bonded water may be removed by heating the powder for several hours to about 300° C. This may be executed in a laboratory stove. In practice it is preferred to mix these dry powders with a certain amount of hydroxide compound to a paste which is not so sensitive to the air humidity and avoids that the new dry powder may become ineffective by absorption of water from the air. As a hydroxide compound castor oil is very suitable to give a mix of about 50 % solid content with the sodium aluminium silicate.

When preparing the surface coating composition of polyurethane resins, an amount of about 5 % of the water catching agent must be added, calculated on the weight of the polyhydroxide compound + isocyanates. As the weights of the polyhydroxide compound and the isocyanate are calculated stoichiometrically according to the chemical equation of the reaction between hydroxide groups and isocyanate groups. the amount of castor oil or similar compounds present in the water catching paste must be considered.

The addition of the drying paste ensures the formation of a well adhering, troublefree surface coating.

The choice of the hydroxide compounds for the coating mass depends on the desired nature and aspect of the surface. The chemical industry offers a range of synthetical hydroxide compounds of the polyether or polyester type, which react normally with an isocyanate to hard and strong final products. In some cases, however, a more flexible layer is required, and therefor- the addition of castor oil is a very cheap manner to obtain the desired effect according to the amount of exchange. On the other hand also industrial hydroxide compounds with flexible properties are available. Concerning the details of the formulation, a large number ofstandard type mixtures are recommended in the technical leaflets of the Industry. Because of the alkaline reaction of asbestos cement polyether hydroxide compounds should be preferred, as polyesters are not so stable against the saponifying effect of alkaline.

The inorganic components of polyhydroxide isocyanate reaction mixtures may be chosen in the same manner as in the case of unsaturated polyesters. In contrast to the polyesters, glassfibre reinforcing is not usual for polyurethane. Quartz powder, fine sand, calcium carbonate or other well-known fillers as well as inorganic pigments may be used in a well dried state. Also for this a large scale of basic formulations are recommended.

It must be considered that in the moment of mixing the two components hydroxide compound and isocyanate, reaction between them takes place. The velocity of the hardening reaction depends on the chemical nature of hydroxide compound and isocyanate, on the filling grade of the mixture and particularly on the temperature of the starting conditions. For technical reasons the isocyanate is mostly a derivate of an aniline-formaldehyde condensation product with a middle chemical activity. The commonly used polyether and also castor oil effect with this type of isocyanate an average reaction velocity of about 45 minutes to one hour for 100 grams of mixture by starting at room temperature. Fillers, pigments and so on may lengthen this time a little, but one of the most important effects are changes in the starting temperature. It is an advantage of the polyurethane reaction mixtures that hardening is also possible still at temperatures of about 5° C. On the other hand rising of the temperature of about 25 and more °C causes a considerable acceleration of the reaction velocity, which may become troublesome if too large amounts of mixture are prepared and must be worked in 20 to 30 minutes. Normally some preliminary tests are made to establish the best conditions for working.

It is only a question of custom to establish a well working production line in surface coating of asbestos cement with polyurethane resins by means of painting, brushing or spreading. There are some difficulties to execute the surface coating by spraying with a two-component gun. The first reason is that the polyhydroxide compound and isocyanate must be mixed in a very exact manner. This cannot be done by the spraying gun described under [illegible] because the two components would join only on the surface of the asbestos cement. In the case of polyurethane other mixing guns are available, which conduct the two components firstly into a mixing chamber, where they are mixed in the necessary relationship, then shed as a mixture against the surface. Guns of this kind are used to spray polyurethane foams as it will be described in the chapter [illegible]. But the second and more important reason is that the very small droplets of resin mixture would be loaded with [illegible] between the gun mouth and the surface. The amount of water catching agent present in the mixture would not be enough to avoid trouble in the layer.

Concerning the question of hygiene solventless polyurethane resins do not contain any substance with toxic vapours, but on the other hand the isocyanate groups may attack mucous membranes of the human body (eyes, lips and so on). In the liquid state the components of polyurethane resins, provided that the above mentioned isocyanate is used, are practically not toxic to the skin. To avoid some dark, but harmless spots on the skin, caused by the isocyanate, it is recommended to wear gloves or to handle with care.

3.1.2.2 Surface coating with solvent containing polyurethanes

The application of solvent containing polyurethane coatings can be treated in this paper only from the view-point of certain plastic effects, which are different from normal, even coatings or paintings. It is curious that the formulations required for these special effects are relatively complicated. Therefore it is a principal question whether the executing service, which coats the asbestos cement sheets, shall prepare also the different reaction mixtures. It is particularly to recommend to co-operate with a well experienced formulation service, which may ensure a continuously good quality of the mixtures and may be able also to change colours, viscosities, softness and so on if required. Also in the developing countries there is already established a certain industry for varnishes and lacquers, which may be very suitable to furnish ready-for-use mixtures for this coating.

For this reason it is not possible to give detailed descriptions of working, because the fabrication conditions differ highly according to the special requirements.

As particularly interesting effects two methods of coating may be briefly outlined:

The hydroxide compounds are mixed with typical varnish solvents containing ketones, esters and so on and pigmented in the desired colour. Thickening agents are added, which cause a thixotropic behaviour of the mixture. These thickeners are preferably chosen from the class of very finely divided silicium dioxides. To this pre-mix a solution of isocyanates is added and the whole composite is coated onto the surface of asbestos cement, which has been coated before with a highly diluted composition of a wash primer. The hardening time of these solvent containing coatings is much longer than in the case of solvent-free compositions. Therefore there is time enough to model the surface of thick, thixotropic and still wet layers. This may be executed by rolling, embossing or other suitable methods known in the painting practice. If the surface is dry, it is preferable to complete with a briliant or mat finish also on the base of polyurethane solutions. Picture 2 gives an idea of the very various and nice effects of such coatings, which may cause real refining of asbestos cement as a contruction material. Particularly for bath-rooms and so on it is possible to apply ceramic or tile appearance.

The second principle possibility to produce special effects is to apply two layers of polyurethane coatings in different colours and with different weakness. The different shrinkage in drying of these two layers causes tearing and bursting of the surface and leads to bi-coloured aesthetical effects as shown in picture [illegible]. It is obvious that particularly this method requires skill and aptitude and cannot be explained here in a more detailed manner.

The isocyanates used in the solvent containing mixtures are normally different from those in the solvent-free ones. In most cases it is a pre-polymer of diisocyanate or toluene with low molecular glycols, glycerine and so on. It does not contain low molecular isocyanate compounds with considerable vapour pressure, but also in this case no danger is given by irritating isocyanate traces in the air. As regards the inorganic solvents, the normal presciptions for solvent working surfaces must be followed.

In contrast to the foregoing, the water sensitivity of the non hardened reaction mixtures of solvent-free compositions is very low. Water molecules from the air, which penetrate into the liquid phase of the mixture may be eliminated by a slow distillation of the low boiling solvents. Therefore the addition of water catching agents like sodium aluminium silicates is not necessary in the case of solvent containing polyurethanes.

1.3 <u>Coating of asbestos cement with epoxide resins</u>

As mentioned above in chapter [illegible], epoxide resins are widely used for surface coating in the construction industry, because of their mechanical and chemical properties, which are extremely high. But for the most purposes with asbestos cement their elevated price is relatively seldom justified by their technical advantages. Only to complete the description of application methods for the three resin types some remarks may be given also for epoxide resins:

The application of these resins is effectuated principally in the same manner as unsaturated polyesters and polyurethanes. Reinforcing of the layer by glass fibres is not usual. Solvent-free coating mixtures are mostly filled by quartz powder and pigments, which are applied by washing, spreading or other normal coating operations. Spraying by guns is relatively seldom applied.

Since the epoxide resins are mostly to thick viscous products, the hardeners based on polyamine or amido-amine compounds are commonly more liquid ones. Solvents for the thinning of the coating mixtures may be used. Particularly aliphatic polyamines as hardeners must be handled carefully by reason of their toxic effects not only in liquid state but also by traces of vapour which may be in the air. The hardeners on the base of amido-amines, which are often used in coating processes, are less toxic, but in every case it is necessary to observe the prescriptions given by the furnishers. Then it is easily possible to execute coating with epoxide resins in a successful manner without damage.

3.2 Composites of asbestos cement with plastic foams

The following chapter treats of one-piece-composites of asbestos cement with plastic foam.

In the practice the use of asbestos cement sheets for the siding of buildings is often combined with a separated application of foam sheets or plates as heat insulating material in the construction of the outer wall built up in a conventional manner by concrete, tiles and so on. In this case the asbestos cement sheets form a ventilated fore--façade of the total construction. These systems are not object of this paper.

However, real composites lead to newer developments in housing particularly for light-weight and quick-built structures and offer therefore enlarged importance of asbestos cement.

The main purpose of the production of composites between asbestos cement and plastic foam is to join the hardness and solidity of the inorganic material to the high thermal insulation power of the plastic foam. As a principal fact it must be pointed out that the heat conductivity of plastic foams is extremely low. Particularly in the case of polyurethane foams it reaches the lowest values known in all classes of heat insulating materials. On the other hand the calorific capacity of plastic foams is very limited by reason of their light weight, which means that heat cannot be stored up in the same manner like by a thick stone masonry.

The normal way for the production of asbestos cement/plastic foam composites is the manufacture of sandwich structures with foam cores. While the one-side covering of asbestos cement with a layer of foam is an exception as will be described below, the two-side sandwiches may comprise either two sides in asbestos cement or also only one, the other side being formed by another product like plaster, aluminium foils, metallic sheets and so on.

The production of these sandwich structures may be executed in two ways:

a) The plastic foam material is available in a finished state as expanded plates. In this case the three components are glued together in an appropriate apparatus with suitable glues.

b) The siding plates are ranged in a supporting mould or in another suitable machinery as will be described below, and the foaming reaction mixture will be injected in a liquid state. The rising foam glues itself to the inner surface of the side plates so that a sandwich structure is formed in situ. This process is normally called "filling-construction-method".

The first method is particularly applied if polystyrene foams are used, because this material is easily available in pre-cut plates. The filling-construction-method is particularly suitable for the use of polyurethane foams and allows also technical variations in the foam formulation and also the filling of spaces between profiled plates like corrugated or undulated asbestos plates.

3.2.1 Junction of asbestos cement and plastic foams by adhesives

This method of fabrication is nearly self-explaining and will be executed in the normal manner of glueing as it is known in the furniture industry and so on. As mentioned above in chapter 2, the glues used in this treatment must be free from organic solvents if polystyrene foam is chosen as a sandwich core. Principally other foams may also be used in plates or sheets to be connected with asbestos cement by glueing. That may be polyurethane and phenol formaldehyde foams. These foams are stable against organic solvents, but by reason of their wide-spread availability polystyrene foam plates are mostly worked in this case.

The facility of the glueing process is one of its greatest advantages. On the other hand particularly this method requires still a considerable amount of man work and its variability is limited by the dimensions and densities of foam plates, which are available. Changes in the size of the sandwich construction cause naturally remarkable waste of foam. Nevertheless it must be indicated that the production of foam core sandwich structures with asbestos cement by glueing the components is a useful and cheap process, which is practically executed. The picture 4 shows some applications of these plates using polystyrene foam as a sandwich core.

3.2.2 In situ forming of foam cores between asbestos cement plates

The above mentioned filling-construction-method and similar processes on the base of in situ foaming are nearly in all terms the contrary of the first method of glueing:

Instead of the technical simplicity of the first method in situ foaming requires a certain technical equipment. On the other hand, the limitation to fixed sizes and qualities of foam has changed to a high variability in foam densities, plate sizes and special technical features like the embedding of installation tubes, electric cables and so on in the foam core. Also profiled respectively corrugated asbestos cement sheets may be connected with foam by this manner.

In contrast to the first method the production service for the sandwich structure does not buy the ready foam plates, but raw materials of the desired foam and executes the foaming process and the fabrication of sandwichs at the same time.

The most used foam system for the in situ foaming is surely the polyurethane foam. Principally also the polyurea/formaldehyde foams may be produced in situ. But this process is only introduced by the heat insulation of installation channels, roofs and so on, and since urea-formaldehyde foams are cheap and well insulating, their mechanical properties are relatively low, so that they cannot be used for the formation of sandwich cores, which may suffer a certain mechanical load. As pointed out in the introduction chapter [illegible], polyurethane foams are produced by mixing of polyhydroxide compounds (for example Desmophen types) with polyisocyanates (Desmodur) in the presence of certain additives and foaming agents. The machinery needed for it consists essentially in tanks for the raw materials, exactly working piston pumps and a very small-sized reaction chamber into which the components are continuously introduced in an exactly dosed weight relationship, mixed and continuously ejected. The working of this machinery may be guided by hand or by an automatical system, which allows the dosage of exactly calculated quantities. One of the technical features of this minimised reaction chamber is that there is nearly no quantity of reacting mixture enclosed when the flow of raw material is stopped. This avoids waste and difficulties of cleaning. Such machines, the principle of which is described in picture 5, is fabricated with different foam capacities and available all over the world. A view of the Hennecke UK type is shown in picture 6.

The continuously ejected foaming mixture may be filled into a prepared mould or projected onto a conveyor belt as will be shown below. Changes of pressure, formulation or of the shape of the mouth cause different rising times for the foam, various densities and lesser or greater porosity.

The isocyanate mostly used in this process is the same as described above in the chapter of surface coating with solvent-free polyurethane resins. The polyhydroxide compounds vary according to the desired quality and density of the foam. Details for the choice of the different compounds are given in the leaflets of the suppliers.

For the production of foam sandwich structures according to the filling-construction-method the two outer plates must be put into a supporting mould, which may consist in the simple case of two even plates or a frame construction, which is solid enough to neutralize the pressure produced by the rising foam. The pressure forces, which must be overcome, depend on the formulation used for the foam mixture. In normal cases for densities of about 40 to 80 kg/m^3, they may be in the range of up to 2 atmospheres. This requires a supporting framework, which must be able to withstand several tons of total pressure.

It is obvious that also the sides of the desired sandwich structure cannot remain open, and therefore a frame must be made in the thickness of the planned foam core. For this reason all elements made by the filling-construction-method are very solid in long-term use and may also be equipped with inner reinforcements or electric cable installations and so on. As materials for these frames wood may be preferred. In most cases the wall element to be constructed is put into a particular supporting structure, so that on one edge of the short side of the frame a hole may be made to introduce the foam mixture. If the length of the element is relatively important, a tube may be introduced before, which contains several slots to eject the foam mixture. The part of the frame, which shall be situated on the upper side in the support may be also equipped with some holes to allow the evacuation of the air. According to the results of preliminary tests, the quality of the foam mixture has to be calculated in such a manner that the space between the asbestos cement plates will be fully filled by foam of the required density and only a little excess of foam will get out through the upper holes. The principle of this work is given by the picture 7.

The plates of asbestos cement used for this process need no special treatment, but naturally their sufaces must be cleaned in the same manner as described in the chapter on surface coating. The adhesion of the foam is normolly very good, so that no problems arise concerning the splitting off of the different parts of the sandwich. It is clear that not only pure asbestos cement plates may be used, but also those which are already surface coated on the outer side. On the other hand surface coating or painting or another surface treatment may be executed in a following working stage.

The filling-construction-method is a typical non-continuous process. The relatively high requirements as to technical equipment may appear expensive in comparison with the simple glueing method. However, the solidity and durability of the sandwich structures obtained by the two processes is very different too. Surely the above described production method furnishes wall elements of the highest quality, which can be obtained by all possible methods.

Another and continuously practicable method for the productior of sandwiches uses the principle of a foaming process, which became very important for the manufacture of light-weight sandwich elements for heat insulation in flat roofs. For this purpose a machine has been developped, which allows the one-step-production of polyurethane foam plates covered on both sides with paper, metallic foils and other thin covering materials. The principle of this machine is shown in picture 5.

A large sheet of paper, roofing felt, metallic foil or similar material is conducted from a coil over a roll-system to a conveyor belt, which passes through an exhausting channel. On the way to the conveyor belt the borders of this thin material may be edged to form a very flat trough. In a short distance before the conveyor belt a mixing chamber for polyurethane foams is posed above this support and moved to and fro crosswise to the direction of the paper. The foaming mass projected by the mouth of this reaction chamber begins to rise and adheres to the inferior surface of another paper or foil, which is conducted from a second coil and bent by several rolls to the same direction like the first, but at a distance of about 1 to 5 cm above the first. A second conveyor belt ensures that the distance between the two covering sheets may be always the same. Thus a sandwich structure is formed during the passage through the foaming channel and at the end of the machine rigid foam plates may be continuously obtained, which are cut to the desired length. A view of such a technical equipment for a pilot plant production is given in picture [illegible]. This double conveyor belt system has become very important for the production of light-weight polyurethane plates and is installed in numerous specimens in various countries. It is obvious that this method of production is very simple, cheap and effective, and therefore it has been the second step to develop this system to the manufacture of sandwich elements with more stiffened sidings. In this sense, a German manufactory works on a large-scale production line with steel sheet coils. In a continuous way the steel sheet is cleaned, surface coated on the outer sides, edged on the border, filled with foam, connected with the other sheet and passed through the channel, cut and finished to the one-step production of wall elements for industrial buildings. Picture .... shows the principle of the construction of these wall elements, which may be composed to store houses, work-shops, garages and so on.

Since in the case of steel sheets the covering material is still to bend to a certain extend, asbestos cement plates are absolutely rigid. However, a short time ago it was possible to construct a modified double conveyor belt system, which can work also with absolutely rigid cover plates. This has become very important for the use of asbestos cement, and the first of these machines serves also for the production of wall elements with asbestos cement siding with polyurethane foam cores. There was not only the difficulty to overcome the problem of the rigidity of the plates, but it must also be ensured that the ends of the upper plate are always in the same position as those of the inferior plate. These problems have been dissolved, and therefore there is now no difficulty to produce asbestos cement sandwiches with polyurethane foams by the continuous conveyor belt method. Picture 10 shows this modified machinery system, the first specimens of which have been installed in Spain.

The relatively strong framework needed for the non-continuous process of the filling-construction-method is not necessary in this case. The expansion of the foam over the side borders of the plates may be avoided by planking or other appropriate means. Naturally the continuous process does not allow the insertion of inner reinforcing structures, electric cables, installation tubes and so on. However, the wall elements obtained by this method may be manufactured in a very economic manner, and as there is the possibility of variations in thickness, foam density and also profilation of the covering sheets, the double conveyor belt system is very interesting particularly for developing countries, where only one installation should be able to produce as many different types as possible.

Although the continuous production of such wall elements appears to be particularly important for developing countries, there are also other systems, which may be interesting:

3.2.3 Sandwich structures of asbestos cement and light-foam concrete

As mentioned above in chapter 2, the pure plastic foams may be modified by incorporation of inorganic, light-weight fillers. One of the most interesting systems is the combination of foam with blown clay or blown glass. These fillers, available in small balls of about 1/2 to 3 cm in diametre, may also be exchanged against similar products, such as blown mica or other light-weight materials available in the country. In the present state of technique, the production of such compounds with foam and asbestos cement cannot be executed in a continuous manner. Therefore the filling-construction-process is used as described above except that before introduction of the foam the space between the two layers of asbestos cement is filled with blown clay, blown glass and so on. After closing of the system the foam may be injected and fill out the spaces between the balls. In this case beside polyurethane foams, also foams on the base of unsaturated polyester resins may be used. The advantage of the latter is the very simple production method, which is possible because of the slow foaming rate and the low foaming pressures of the polyester system. Therefore the polyester mixture may be prepared in an open vessel and stirred into the open form among the ball filling. It is time to close the mould and to wait for the rising of the foam. Polyurethane foam, however, needs here also a foam producing machinery like in the other process and the moulds must be stronger by reason of the higher foam pressure. The cost for the material is rather the same in both cases, because a denser foam is required in the case of unsaturated polyester resins (about 100 to 120 kg/m³), which neutralizes the cheaper price of this material. The final choice of the foaming system is due to the manufactory conditions as well as to the technical requirements of the sandwich element, which has to be produced. If a polyurethane foaming machine is available, this foaming system should be preferred because of the higher production rate and variability. Otherwise the polyester resin foam is particularly advantageous for beginners in this production.

The production of wall elements of light-foam concrete with sidings of asbestos cement plates may be carried out in a one-step process. But it is also possible to mould the light-foam concrete in pure form and to glue it together with the siding materiel. This may be of a certain importance if only one layer of asbestos cement is required, while the other side may be covered with rough cast plaster and so on. As described with the filling-construction method, inner reinforcements of wood and steel as well as sanitary or electric installations may be embedded in the mould before filling with blown glass and so on and foaming.

The particular advantages of these heavier composites are the extremely high fire resistance and the considerable sound absorption so that they can be used as separating walls between apartments and in the construction of sleeping rooms, bathes, WC's and so on.

The particular high fire resistance, which reaches values of about 90 to 120 minutes according to the German norm 4102, is due to the content of inorganic materials. When a flame coming from one side has broken off the covering plate of asbestos cement, the superficial foam will first burn and form together with the glass balls an insulating layer of coke and charred decomposition products from the foam, which are a strong hindrance for the fire to penetrate into the composite. Pictures 11, 12 illustrate articles made in practice by this method and picture [illegible] also shows a sample of foam-light concrete after a burning test. It is to believe that foam-light concrete covered with asbestos cement shall become an important construction material, particularly for housing in developing countries.

3.2.4 One-side covering of asbestos cement with foam

The reaction between isocyanates and polyhydroxide compounds together with the additives may be accelerated by catalysts in such a measure that it becomes possible to jet the reaction mixture against the surface, where the foam rises and solidifies in the same moment. By this method foam layers on floors, walls or ceilings may be applied. The same process is also possible with gun-sprayed urea-formaldehyde foams. So it is also possible to cover asbestos cement plates

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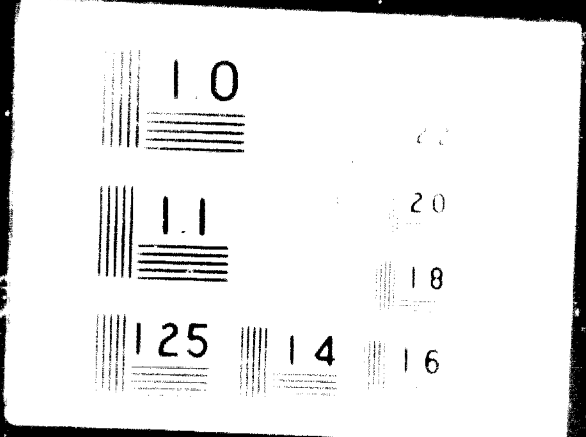


with a one-side layer of foam-plate by glueing.

The reason for such a process is for example to avoid condensation water dropping from the ceiling of a large hall, which is covered with corrugated asbestos cement sheets. This condensation water may be formed when the hall has been heated during the day and a cool night lowers the temperatures of the roof. It is obvious that this process is particularly important for tropic countries.

The execution of this process is self explaining. Spray guns for foam have been constructed for both systems. In the case of polyurethane foam practically the same equipment is used as described above, with the exception of the mouth of the reaction chamber. For the projection of urea-formaldehyde foams also suitable machines are available.

The thickness of the foam **layer** applied by the spray process may range from 1/2 to about 2 cm according to the special climate conditions. A thin layer can be applied with one spray jet , but a thicker foam may be more successfully obtained by several layers of sprayed foam. As the rising foam becomes immediately solid, it is not necessary to wait a certain time. The adhesion of the different layers one upon the other is extremely good, and the high weathering resistance of polyurethane foams allows to renounce surface coating.

4. <u>Composites of asbestos fibres and synthetic resins</u>

As asbestos cement is a connection between asbestos fibres and cement, it is principally possible to exchange the cement against an organic resin. Practically that means impregnation of asbestos fibres with an unsaturated polyester resin, epoxide resin and so on. This method has already been realised, and mats of asbestos fibres have been bonded and hardened with the above mentioned resins to plates, sheets and otherwise shaped articles. It must be pointed out that these products cannot be antagonists to asbestos cement, but they are materials with special properties made particularly for technical purposes.

From the viewpoint of material these products are more similar to the glassfibre reinforced plastics than to asbestos cement articles. In spite of the fact that there are some attempts to use sheets of this kind for the construction of barracks, garages or other little buildings the greatest importance of asbestos fibre reinforced resins is in this time the manufacture of special articles for the electric industry, for machine pieces, special tubes and so on.

In comparison with glassfibre mats, asbestos fibre mats are denser and not so easy to impregnate with the resin. Therefore resins must be chosen of low viscous types, which is relatively easy in the case of unsaturated polyesters, but more difficult in the case of epoxy resins.

In view to the actual technical state, asbestos fibre reinforced plastics cannot be compared yet with asbestos cement and may be considered a possible substitute only in the future.

5. <u>Total substitution of asbestos in [illegible]</u>

Finally it is necessary to show in a general way the possibilities in the plastics field to substitute asbestos cement as a construction material.

As has already been mentioned in the summary and in other chapters of this paper, there is no reason for an antagonistic competition between the well introduced inorganic material and the plastic materials. But naturally, if for example a hall is constructed with asbestos cement sheets and covered with corrugated plates, it is always desired that light may penetrate into the hall. Here is already a possibility for the introduction of plastic materials as a completion for asbestos cement: a part of the corrugated roofing plates from asbestos cement may be replaced by glassfibre reinforced polyester plates of the same shape. On the other hand, glassfibre reinforced translucent wall elements may alternate with compact prefabricated sandwich structures with foam cores and asbestos cement side plates. Also in this way the building may be enriched by special archetectural features.

As shown by a series of the following pictures 14 - 18 glassfibre reinforced plastics in a translucent or fully pigmented state may be entirely used as construction material. To avoid the difficulties caused by the low elasticity modulus of plastic materials, such constructions may be curved and formed in domes, cupolas and so on. Of course, this construction has nothing more to do with constructions possible with asbestos cement. Here a real alternative is given, and the choice may be made always in the direction of the plastic material, if the desired building should have a special aspect, particularly for exhibition or reception pavillons or other representative constructions.

Also pure polyurethane foams are able to be used as a construction material, as shown in picture 19. Here domes and cupolas are obtained by spraying numerous layers of foam against the mould. The obtained igloo-like housings can immediately be used and may serve in cases of emergency like earthquakes, natural catastrophes and so on, as also for expeditions camping centres in desert countries, for fugitives and so on. The greatest advantage is that only compact barrels with raw material in liquid form must be transported and a relatively small mechanical equipment may serve to jet the foam reaction mixture against a support to form such housing. Surely these hand-made foam buildings are nothing to dwell in, but under certain circumstances they could aid people to have a first hiding place.

6. Conclusion

It has been shown in the present paper that plastic materials may advantageously be used for the completion of asbestos cement.

The main ways to connect asbestos cement with plastics are:

a) the surface coating

b) the combination with plastic foams.

Both possibilities can be joined together.

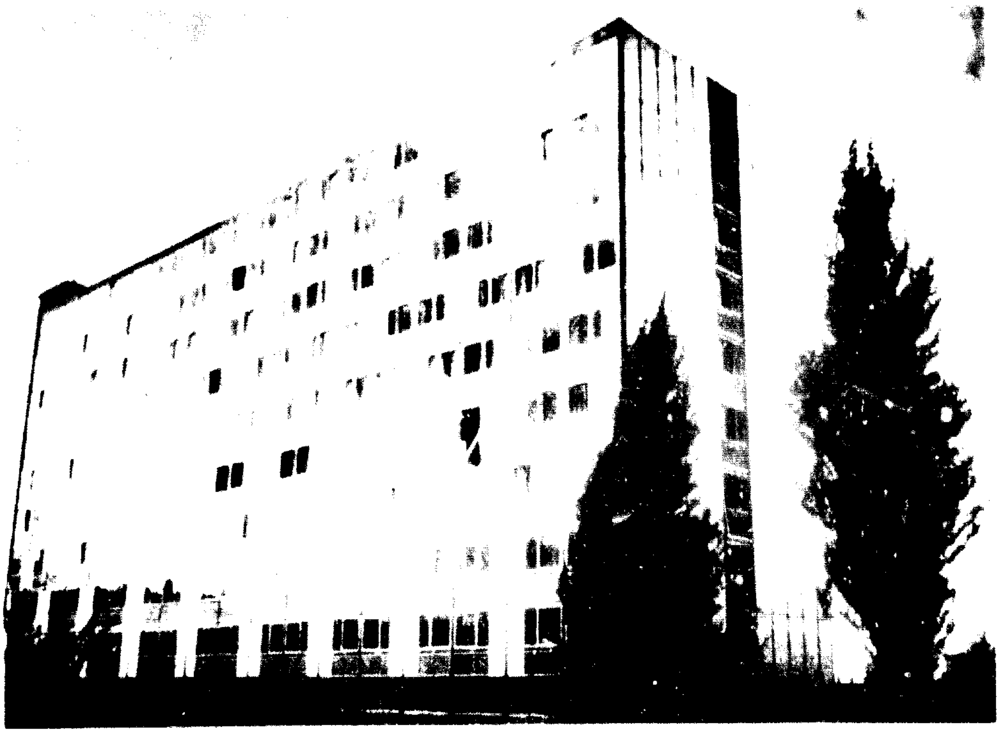
All these mentioned composites enlarge the application range of asbestos cement and render this material more variable in the construction industry.

All applications described in this paper are still in the beginning technical phase. It can be foreseen that these combinations will become more and more important in the future. Particularly for light housing and the manufacture of pre-fabricated construction elements sandwich structures with plastic foams are very interesting also for developing countries.

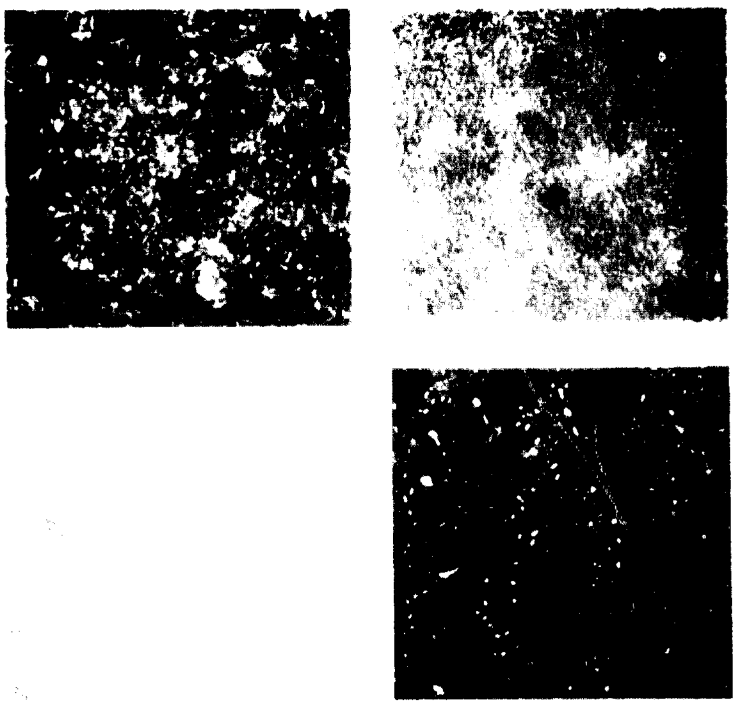
Substitution of the cement in asbestos cement by thermosetting resins is principally possible, but leads to materials with other properties and with applications in different industrial sections. They cannot be used as a real alternative to normal asbestos cement.

Substitution of asbestos cement by plastic materials is possible and may be carried out in all cases where light transmission is required or buildings with more complicated shapes are to be constructed.

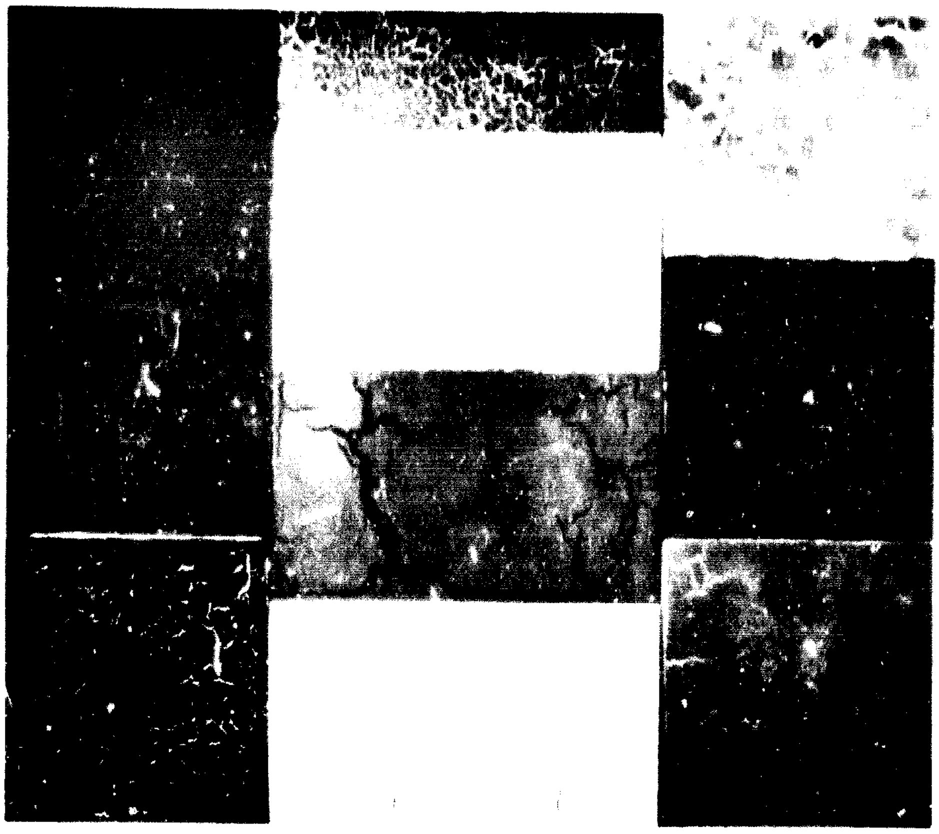
ANNEX



1. Youth hostel, [illegible] [illegible]ted by [illegible] [illegible] (page [illegible])

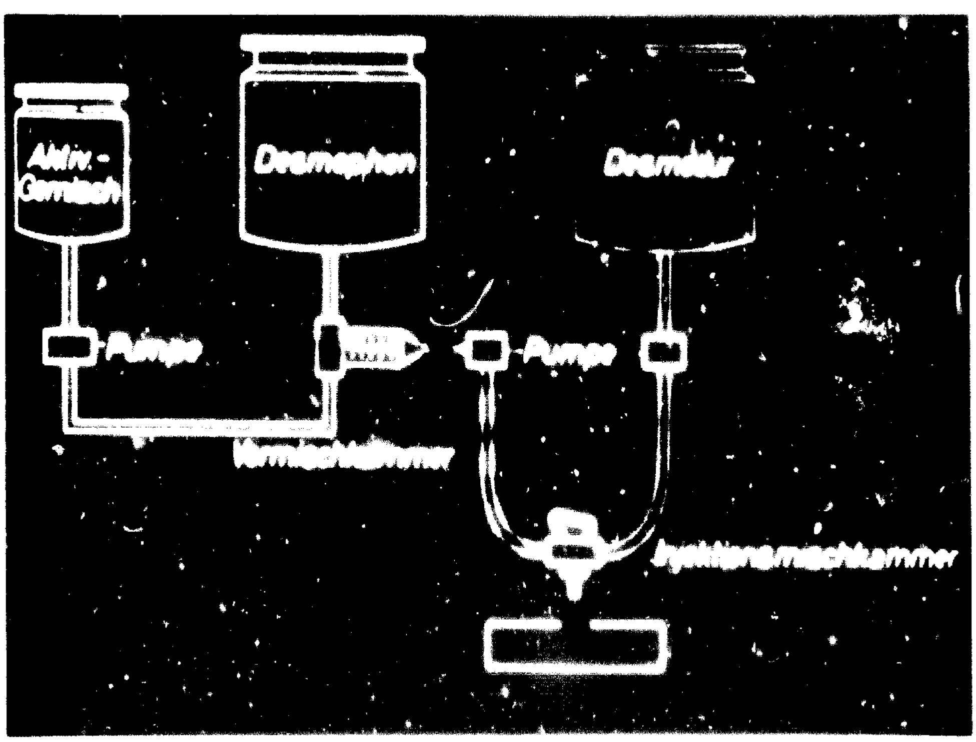


2. Surface-coating of asbestos-cement. Plastic-coat by polyurethance-resin. (page 30)

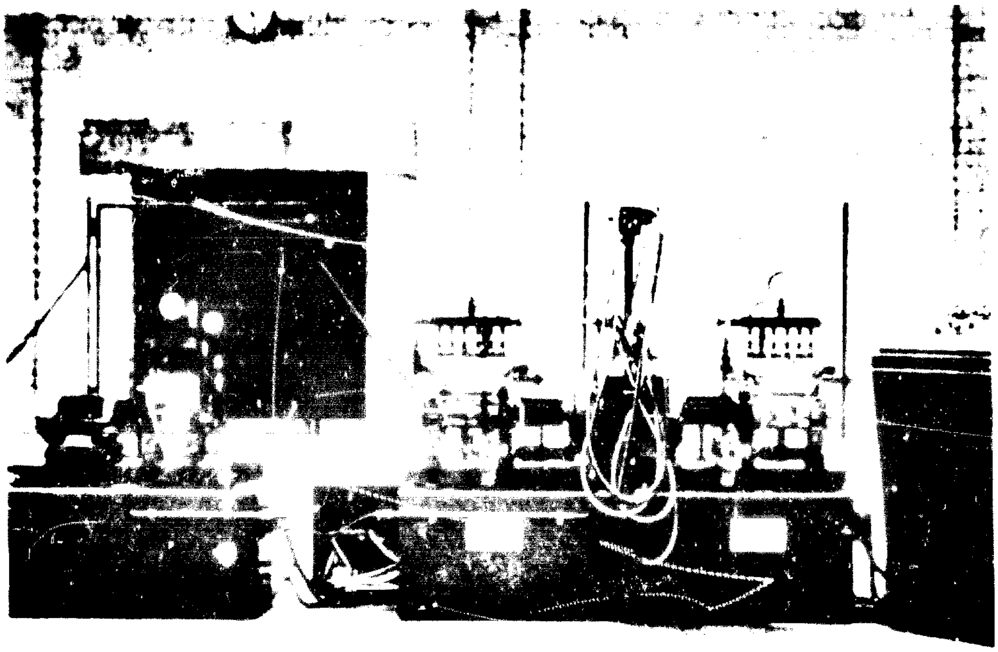


3. Surface-coating of asbestos-cement "two-layers-system" by polyurethane-resins. (page 31)

4. **Sandwich-structures of wall elements.** Composition of asbestos-cement and polystrene-foam. (page 35)



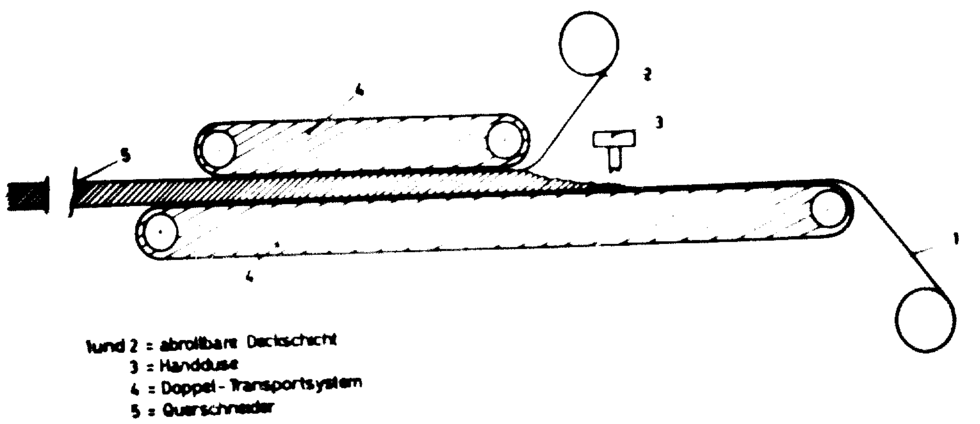
5. Polyurethane-foam pr[illegible]



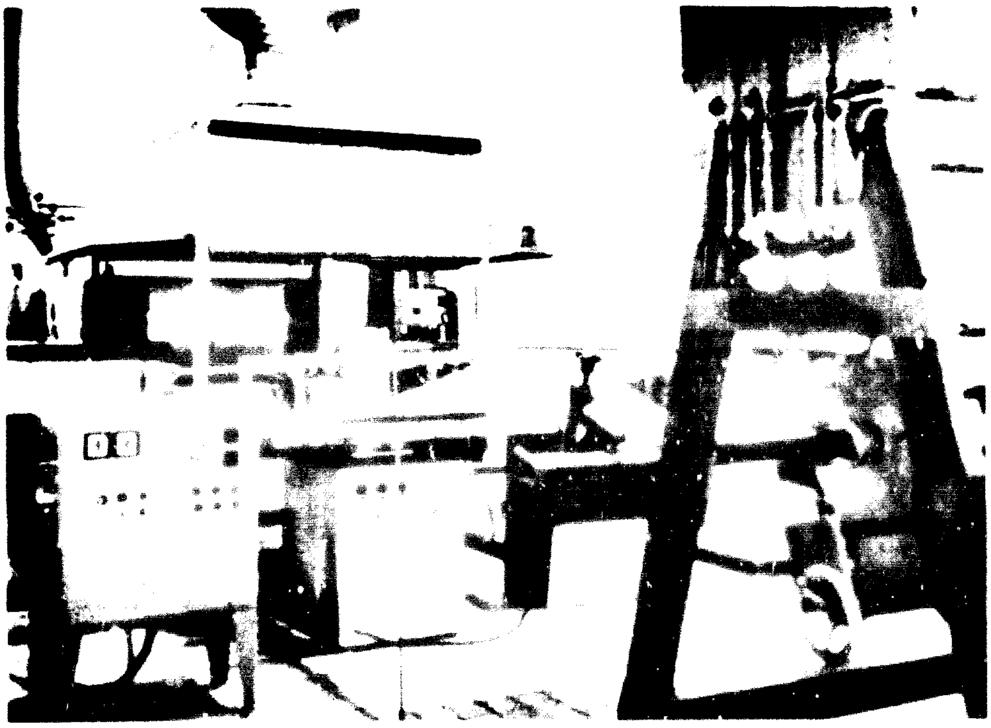
6. Polyurethane-foam production set HK-Machine. (page 36)

7. Sandwich-structures with polyurethane-foam. Production of wall-elements with asbestos-cement according to the "filling method". (page 38)

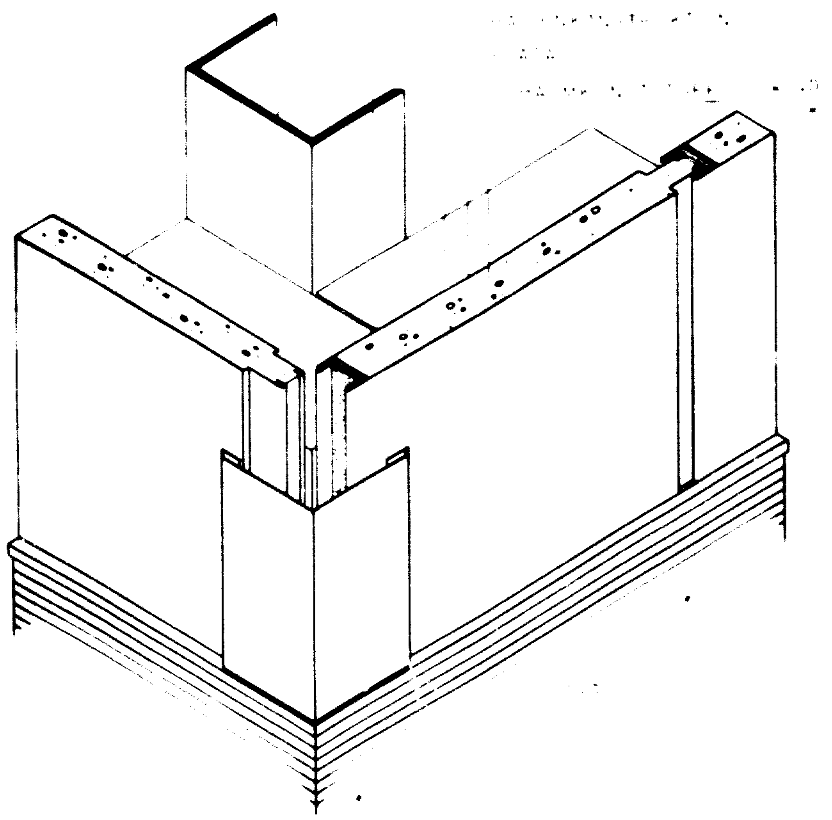
8. Example[illegible] (A, [illegible]
(page 38).



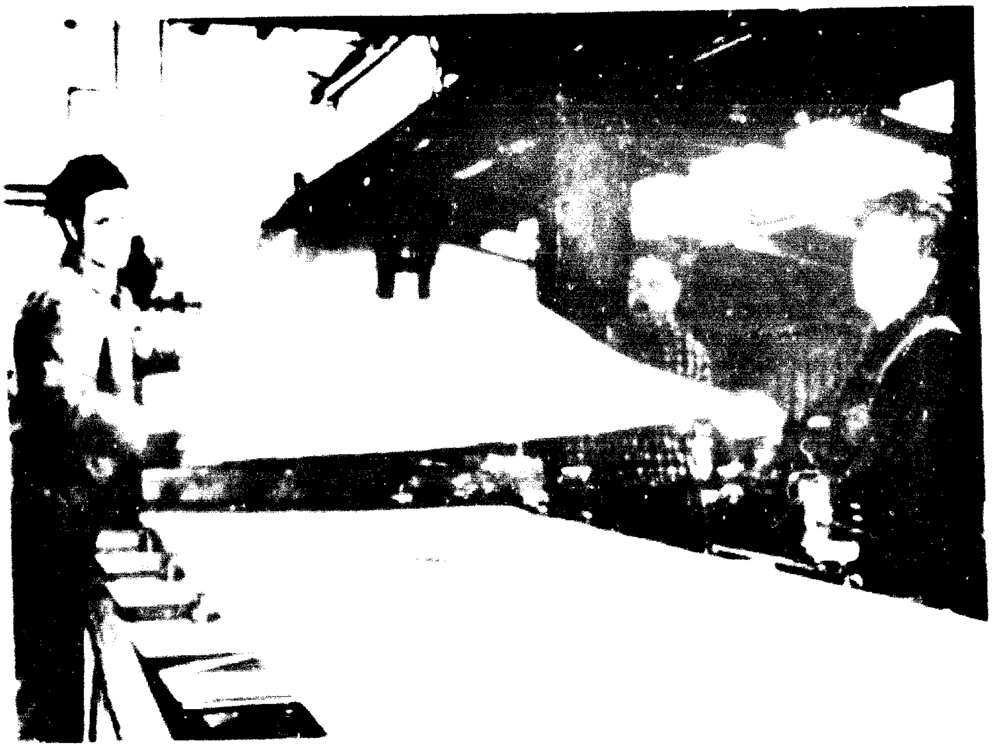
9. Production of polyurethane-foam sandwiches by the double-conveyor-belt-machine scheme. (page 39)



10. Pilot plant [illegible]

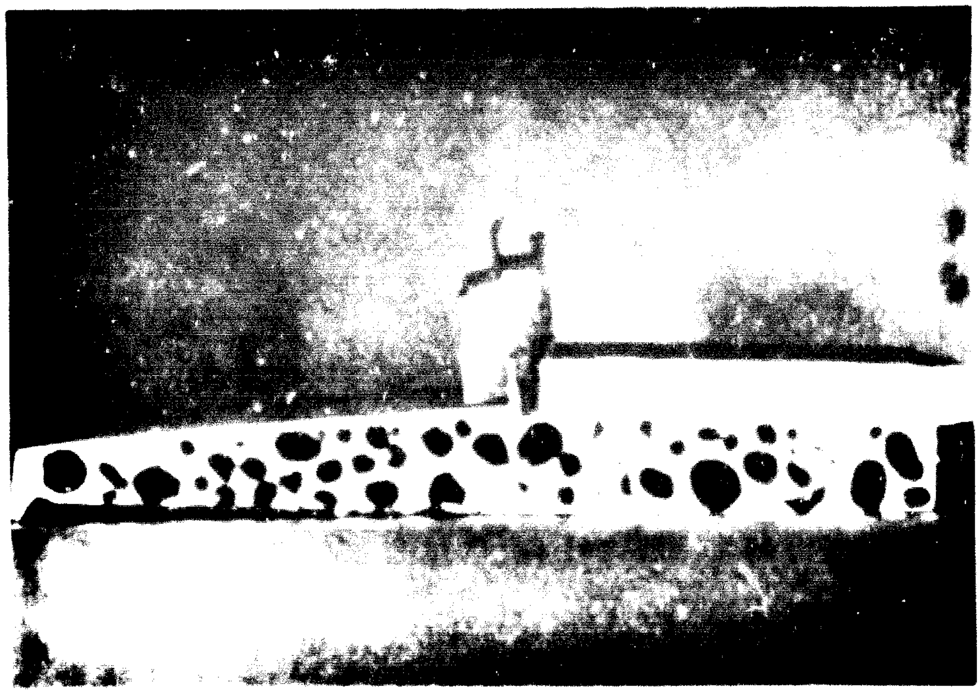


11. Construction scheme of a hall built by polyurethane-wall-elements with steel-sheets, fabricated according to the double-conveyor-belt system. (page 40)

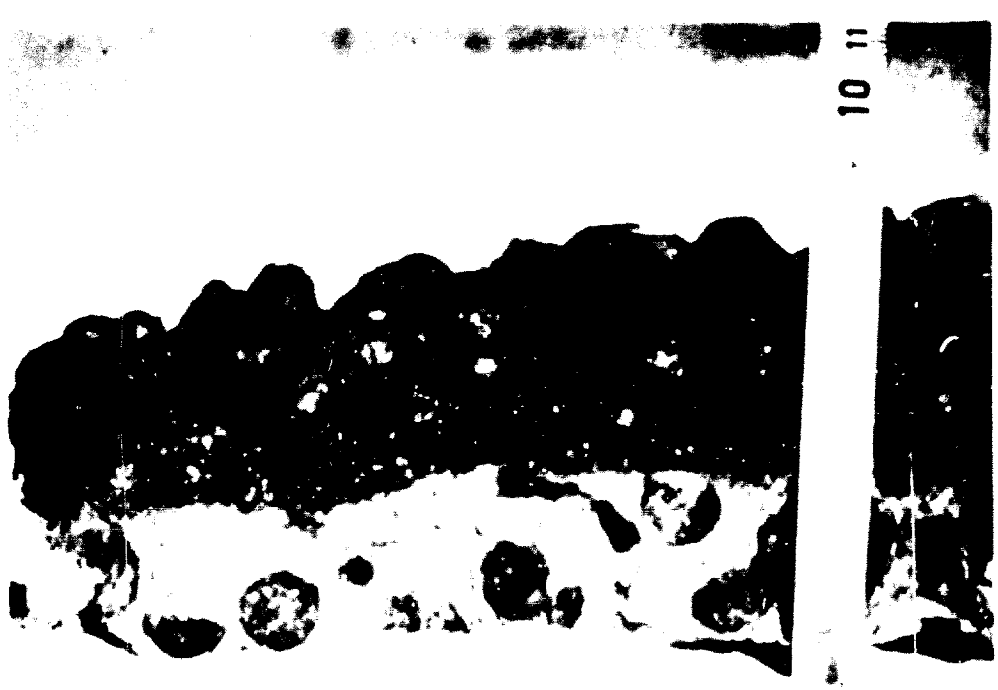


12. Moi.fie[illegible] conveyor-belt-machine for use of asbestos-cement-plate[illegible] [illegible]erin[illegible] material. (page 41)

13.- Polyurethane-foam fight-concrete. Cut of a wall-element. (page 44)



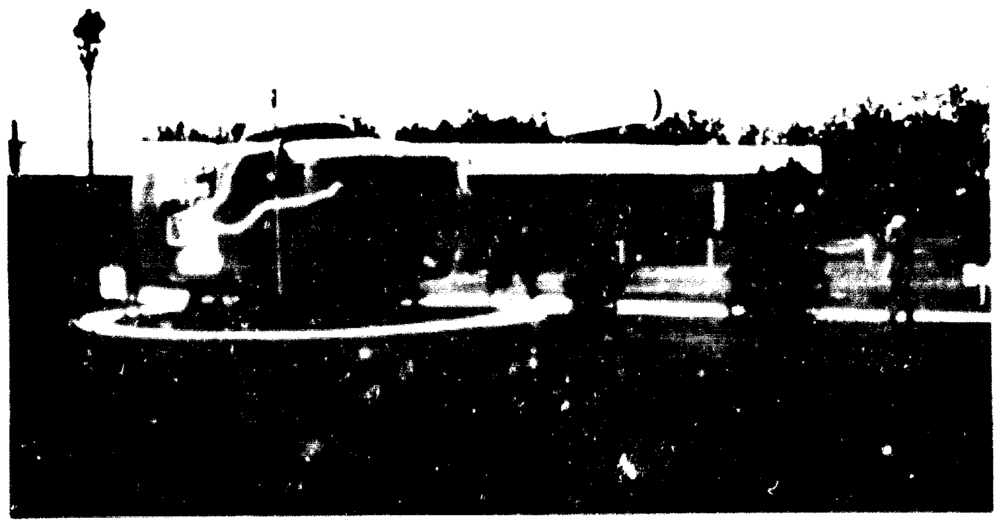
14. Polyurethane-[illegible]



15. Polyurethane-foam light-concrete. Sample after burning-test. (page 44)

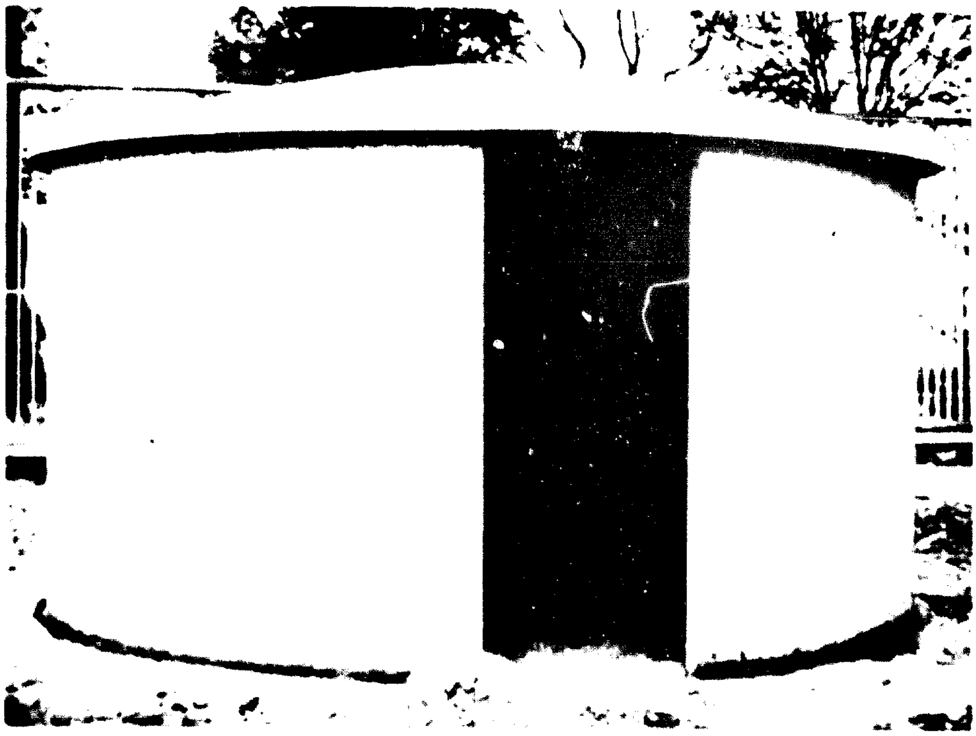
16. **New York World's Fair '65.** **Pavillon constructed by** wall-**elements with galssfibre-reinforced polyester-resin sandwich structures.** (page 47)

17. Shoe factory, **Massachusetts**, [illegible] .A. [illegible] glassfibre-reinforced [illegible] (GRP). (page 47)



18. [illegible] sandwi[illegible] "[illegible]le-six-[illegible]", [illegible] leisure-house). (page 47)

19. [illegible] translucent cupola [illegible] 47.



20. Emergency-shelter, fabricated by spraying of polyurethane-foaming mixture against a support of thin plywood. Nine years old in open air without any damage. (page 43)

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