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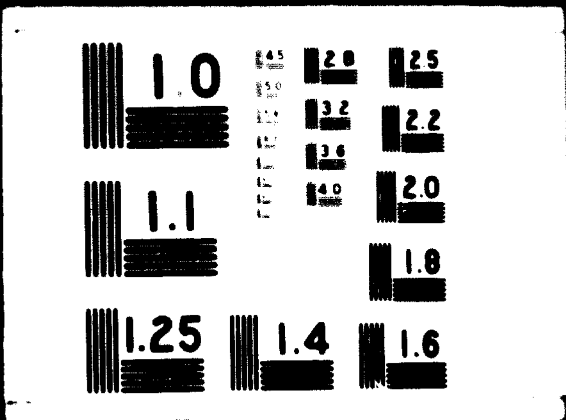

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Fibro-cement Composites

Vienna, 20 - 24 October 1969

AUTOCLAVE METHOD OF PRODUCTION OF ASBESTOS CEMENT SHEETS AND PIPES IN THE USSR 1/

by

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Ministry of Building Materials Industry, USSR

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SUMMARY

THE MANUFACTURE OF ASBESTOS CEMENT SHEET AND PIPING BY THE AUTOCLAVE PROCESS IN THE USSR 1/

by

N.I. Philippovich, Chief, Main
Directorate of the Asbestos Cement Industry,
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INTRODUCTION

Brief details of the history of the development of the autoclave process for the manufacture of asbestos cement goods in the USSR.

I. TECHNOLOGICAL FEATURES OF THE MANUFACTURE OF ASBESTOS CEMENT SHEET AND PIPING BY THE AUTOCLAVE PROCESS IN THE USSR

1. In the Soviet Union there are several production lines for asbestos cement sheet and piping operating on the autoclave process and using sandy Portland cement.

In 1968, about 110,000 tonnes of corrugated asbestos cement sheet and about 35,000 tonnes of asbestos cement pressure piping with a

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diameter of from 100 to 400 mm and pressure resistance capacity of 6, 9 and 12 atmospheres were produced by this method.

2. The theoretical bases for the manufacture of asbestos cement goods by the autoclave process were worked out in the USSR by the Scientific Research Institute for the Asbestos Cement Industry.

As a result of investigations into the structure of asbestos cement suspensions and pastes and the hardening process of asbestos cement at high temperatures, special requirements regarding the quality of the cement and other constituents (clinker, sand), the respective proportions of the constituents, and the particle size of the cement were established.

It was established that finely-ground quartz sand possesses the necessary properties of adhesion to the asbestos fibres, and when it is incorporated in the mix at the rate of 40 per cent of the weight of cement it completely fixes the calcium hydroxide given off in the hydration of the clinker constituent and thus protects the asbestos fibre from corrosion during the autoclave processing.

During the process of chemical bonding of the sand, the highly-basic hydrosilicates of calcium are converted into low-basicity hydrosilicates of calcium.

3. The special features of the technological process used for the production of asbestos cement goods by the autoclave method in the USSR are the following:

- The binder used is sandy Portland cement produced by milling Portland cement clinker together with quartz sand. The proportion of the sand constituent in the mix is 35-40 per cent. For technical reasons, sand with a silicon dioxide content of not less than 86 per cent is used.

- The mineralogical composition of the clinker part of the mix and the fineness of milling of the sandy Portland cement must comply with Soviet standards for Portland cement for use in the manufacture of asbestos cement goods. The autoclave process requires the same amount and type of asbestos as the conventional process for the manufacture of asbestos cement goods.

- In the autoclave process, the preparation of the asbestos cement suspension and the moulding of the asbestos cement sheets and pipes differ from the corresponding operations in the conventional manufacturing process (using Portland cement) in that the filtration parameters for the films on the sheet-moulding machines (Gatchek system) and the operating conditions of the corrugating and trimming machines are different.

- Asbestos cement goods intended for autoclave processing are given preliminary hardening treatment. The freshly-moulded sheets are "soaked" at a temperature of about 20°C for 3-6 hours and then steamed at a temperature of 50-60°C for 4-5 hours. The freshly-moulded pipes are given preliminary hardening treatment on roller conveyors at a temperature of 30-40°C for 6-8 hours.

- The steaming of the sheets and pipes in autoclaves is carried out under the following conditions:

Type of goods	Length of time to reach process temperature and pressure	Length of time goods held at temperature of 174.5°C and pressure of 8 atm.	Length of time taken to reduce pressure to atmospheric level
Sheets	2	6	2
Pipes	1	7	1

- The mechanical treatment of the ends of the pipes is carried out before processing in the autoclaves, but after the preliminary hardening process, when the hardness and strength properties of the pipes are at the best values for such treatment.

4. The physico-mechanical and chemical properties of asbestos cement goods manufactured by the autoclave process differ from those of normal asbestos cement goods in the following respects:

- their bending and tensile strength is 10-15 per cent higher;

- the amount of moisture deformation and the corresponding warping is 2-2.5 times less;

- the resistance of autoclave-processed asbestos cement goods to corrosion by aggressive media is considerably increased because of the fixation of the calcium hydroxide to low-basicity hydrosilicates of calcium.

II. THE TECHNICAL AND ECONOMIC CHARACTERISTICS OF THE AUTOCLAVE PROCESS FOR THE PRODUCTION OF ASBESTOS CEMENT GOODS AND THE POSSIBILITIES OF USING THIS PROCESS IN COUNTRIES DEVELOPING THE MANUFACTURE OF ASBESTOS CEMENT GOODS

5. Analysis of the technical and economic characteristics of the autoclave process for the production of asbestos cement goods and comparison of this process with the conventional method shows that the autoclave process has a number of advantages:

- the consumption of high-quality Portland cement clinker is reduced by 35-40 per cent;
- the length of the production cycle is reduced to 2-3 days, instead of the 7-10 days required for sheets and 12-14 days for pipes under the conventional system;
- the production cost is reduced by 4-5 per cent through the use of a cheaper binder, provided that adequate deposits of quarts sand of high silica content exist near the factory.

6. Plans are now being prepared for the establishment of new enterprises for the production of asbestos cement goods by the autoclave process at places in the USSR where there are deposits of quarts sand.

7. The production of asbestos cement goods by the autoclave process could advantageously be developed in many countries, especially those where the following factors are considered to be important:

- reduction of the consumption of Portland cement;
- improvement of the resistance of tubes and piping to corrosion by sulphatic media;
- improvement of the deformation properties of asbestos cement goods under the effect of high temperatures (hot climates) and variable humidity.

I. INTRODUCTION.

The asbestos-cement building materials industry is developing in the Soviet Union on a large scale. About 50 plants, scattered out over the main economic areas, produce nearly 7,000,000 tons of asbestos-cement materials - a large increase in comparison with other countries which have developed asbestos-cement production. The growth of the asbestos-cement industry in the Soviet Union during the five forthcoming years is expected to increase by over 70%.

The large-scale development of the Soviet asbestos-cement industry is encouraged by the fact that it is the richest and most up-to-date cement industry in the world.

Asbestos-cement plants produce the products assortment, which comprise over 30 articles in accordance with the construction needs. The assortment list includes: corrugated sheets of variable profiles, types and sizes, including coloured sheets; flat sheets for house facing and industrial buildings construction; water and gas pipes of different pressure so that the pipes can also be used for low as well as high pressure conduits.

Apart from this, the asbestos-cement industry produces items for diverse special purposes: fume pipes, metal tubes isolations, large size composite building constructions (wall panels, roof slabs with the infill), etc.

Large-scale asbestos-cement production and the continuous growth of the production bulk volume of these materials in the Soviet Union, cause the necessity for a considerable amount of research to find more effective technological processes and new raw material compositions in order to get asbestos-cement products with different properties which would be possible to meet the needs of users.

In the Soviet Union there is the asbestos-cement research Scientific and Designing Institute "NIIASBESTCEMENT" and Special Engineering Bureau.

The asbestos-cement plants also take part in the experimental work that is conducted by the Institute. This coordination work-system makes it possible to fulfil experimental works on a large industrial scale when it is necessary. Among such experiments is the method of production of autoclaved asbestos-cement sheets and pipes, which is used by two asbestos-cement plants. The autoclaved production technology is based on the use of the ground silica-cement mix. Development of the asbestos-cement production technology on the basis of the partial replacement of cement by ground silica, and the successive autoclaving of the manufactured products, became possible after the fundamental research works on the theory and practice of the autoclaved materials, conducted in the 1940's-1950's (P.P. Budnikov, A.V. Voljynskiy; I.H. Bajenov, Bernall, Kalousen, and others). First steps in this field of scientific developments have been made by M.N. Kitajev as far back as 1936.

Regular research work on the asbestos-cement autoclaved technology problems on an industrial scale have been conducted by NIIASBESTCEMENT in the course of the years 1954-1963.

In the Soviet Union asbestos-cement sheets production on an industrial basis started in 1957 at a specially designed and constructed plant with two technological lines.

In 1963, the second plant was put into operation. Two technological lines of the plant are producing the autoclaved corrugated asbestos-cement sheets, and another two machines produce the autoclaved water pipes.

Yet another project for the manufacture of autoclaved asbestos-cement large size flat sheets for wall panelling, will start production in 1970.

Within the last decade the main questions of the autoclaved asbestos-cement manufacturing technology were successfully settled and technical properties of the manufactured products were also thoroughly investigated.

Analysis of the production costs of the asbestos-cement cured by autoclaving as well as by conventional methods, gave the possibility to find out the optimum economic ways for utilisation of this process of curing.

II. Theoretical basis of the autoclaved asbestos-cement production technology.

The main technological task - that is, to reduce the hardening period - is settled by the process of curing asbestos-cement by high pressure saturated steam at an elevated temperature that sharply intensifies the process of hydration of the binder.

It is well known that the hydration process of cement and materials on a cement base has heterogeneous-diffuse character and is divided into the following stages: the induction stage, which is the initial step of interaction between cement and water. According to the general opinion it starts with the process of dissolving unhydrated minerals, forming saturated and over-saturated solutions, and stops with the beginning of crystallization of newly developed forms from the whole volume of water solution and forming hydrated films over the grains of cement.

The first main period shortly follows the induction stage. It is characterized by the creation of comparatively insignificant stable loose envelopes over the grains of cement consisting of newly hydrated formations of colloidal dispersity.

The volume of uncombined water is sufficient for dissolving waterless clinker minerals and crystallization of newly developed forms, and in this connection the process of hydration is running almost solely through the solution and the kinetics of the process is limited by the water and newly developed formations diffusion through the walls of the envelopes.

The second main stage embraced the period of the further transfer of the binder. The characteristic features of this stage are the formation of the stable dense envelopes over the cement grains and consequent low diffusion of water and the hydrated ions back into solutions.

The diffusion process slowing down is in accordance with the general ideas of the colloidal-chemical character of the cement grains envelopes and connected with the consolidation of the latter. Thus diffusion and hydration velocities are slowing down to a considerable extent during the second stage in comparison with the first stage.

Investigations of the hardening process of the asbestos-cement manufactured on the base of alite (C_3S), the main clinker mineral of Portland cement, showed that under the elevated temperature conditions (170-200°C) in spite of the hydration process acceleration, significant de-creasing of the tensile strength of the material takes place: this occurs especially with the asbestos-cement.

TABLE I

Properties of hardened cement and asbestos-cement stone manufactured on the base of C_3S.

Hardening Conditions	Bending strength kg/cm²	%	Water absorption %	Weight by volume g/cm³
air-damp, 20°				
7 days	274	98	19.8	1.63
the same, 28 days	294	100	20.8	1.60
8 ati, 8 h	248	84	20.3	1.66
15 ati, 8 h	144	49	19.4	1.70
15 ati, 24 h	102	35	21.3	1.74

It is explained primarily by the calcium hydrosilicate phase composition change-over, namely by plate-like hydrosilicates of $C_2SH/A/$, as well as by the intensified corrosion of the asbestos fibres that is caused by high-basic hydrous silicated calcium. The last are educed in the process of hydration of $Ca(OH)_2$, hence the necessity of silica presence in autoclaved asbestos-cement composition became obvious. The best variation of such additives is the silica sand flour. In this case $Ca(OH)_2$ reacts with silica: at the same time the high-basic hydrosilicates change over into low-basic fibrous hydrosilicates CSH(B) - of the higher structure strength. As a result the main task of sharp precipitation of the hardening process without lowering down the tensile strength of asbestos-cement is achieved, and the structural strength of the material has been increased.

TABLE 2.

Influence of fine ground silica addition to the physical and mechanical properties of asbestos-cement on the base of C_3S/8 ati, 8 h/.

Cement Composition % C_3S	SiO_2	Bending Kg/cm_2	Strength %	Water Absorption %	Weight by volume G/cm_3

As one may see the kinetics of the hardening process under autoclaving depends both upon the hydration velocity of Portland-cement clinker materials and on the chemical reaction between silica and lime.

In the SiO_2 bonding process the first main stage goes on at the temperature 164-200°C and stops in 4 hours. During this period 20-35% of silica come into reaction. At the lower temperature (133°C) the first stage finishes after two hours: within this period of time not more than 15% of silica come into reaction. Thus, the higher temperature of the hydration process, the higher degree of the initial components turnover is taking place during the first stage of the reaction (with the higher velocities).

The kinetics of the process within each stage can be determined as the probable velocity constant (K), that would be easily found by the tangence of the gradient angle built by the straights of the hydration kinetics.

TABLE 3.

Kinetics of SiO_2 bond during the hardening of asbestos-cement under autoclaving.

Pressure of saturated water steam (in atm-excess)	Temperature in C°	Constant value during the process / hour $^{-1}$/ first	second
2	132.9	0.00323	-
6	164.2	0.0358	0.0055
15	200.+	0.0855	0.00635

Table 3 shows that within the first period when the envelopes of newly developed hydrate formations are loose and have low diffuse counteraction, their constant values exceed the constant values of the second period in 6-13 times. As it was said before, stable dense envelopes develop during the second period and sharply lower down velocities of straight diffusion of water and backward diffusion of hydrated ions.

To make a long story short, the choosing of optimum phase composition of the new hydrate formations and optimum parameters of autoclaving based on the peculiarities of the cement hydration kinetics, chemical bond of silica and temperature limits that influence all these processes, would be necessary conditions for the manufacture of autoclaved asbestos-cement products.

III. Raw materials for the manufacture of autoclaved asbestos-cement products.

Silica Portland-cement is used as a binder in the manufacture of autoclaved asbestos-cement. The admixture is prepared by combined milling of Portland-cement klincer and silica sand.

Mineralogical composition of klincers meets the requirements of the special Soviet Standard for the Portland-cement used in the manufacture of asbestos-cement products:

- tri-calcium silicate (C_3S) - not less than 50%;
- tri-calcium aluminate (C_3Al) - not more than 8%;
- uncombined lime - not more than 1%.

The main requirement towards the silica sand is a content of silicon oxide which is supposed to be not less than 86%. Clay particles content is limited to 6%. The presence of clay particles (less than 5 mc) is connected with the worsening of the filtration properties of the asbestos-cement slurries if they have significant quantity of the water absorbing clay dirts.

Besides that clay dirts have negative influence over the tensile strength of asbestos-cement products because of the "blocking" effect in the contact zones between the components of the asbestos-cement admixture.

The strength and frost resistance of asbestos-cement manufactured on the base of silica Portland-cement are lowered by alkaline feldspar dirts in silica, the percentage of which in the sum Na_2O+K_2O need not be more than 2-3.

Grains of carbonate rock, which very often happens in silica sands, are in practice inactive additions and do not influence the strength of the finished products if the quantity of additions lies in the limits of 10-12%. Significant content of calcium carbonate in the sand lowers down the content of silica, reduces the activity of the binder and changes for worse the physical and mechanical properties of asbestos-cement.

Composition and fineness of silica-Portland cement mix meet the requirements of special Technical Regulations.

According to the said mineralogical composition of the klincer constituent the content of the sand component in cement is supposed to be in the limits of 35-40%. It is worthy to note that for klincers with the alite content lower than 50%, the quantity of sand in the mixed binder should be decreased.

Under the Soviet norms no other additive besides gypsum is included into the silica Portland-cement or Portland-cement for manufacture of asbestos-cement products. Gypsum regulates setting the period of the binder.

Experiments show that the optimum gypsum content depends upon the content of tri-calcium aluminate in cement and on its fineness. Usually the percentage of gypsum in Portland-cement used in the asbestos-cement manufacture is not more than 3.5% regarding SO_3 quality. In as much as the klincer part of the silica Portland-cement is 60-65% the SO_3 quantity is considered not more than 2.2%.

Required fineness of silica Portland-cement is determined through experiments. On the one hand, the optimum fineness of cement ensures good filtration properties of the asbestos-cement slurry, which results in a high capacity of a sieve cylinder part of machine, and, on the other hand, activates the binder. As a result of this the rest on the sieve N 008 is supposed to be in the limits from 7 to 12%. In this case the surface area of cement accounts for 2400-3200 cm^2/gr (by Tovarov or Blaine).

Types and quantity of asbestos fibre used in the manufacture of autoclaved asbestos-cement products are no different from that of the products which are produced on the base of Portland-cement.

Under the Soviet standards indigenous asbestos of Grade V and Grade VI are used in the manufacture of sheets. Only separate types of sheets for industrial construction with a span of 1.5 m are produced with the addition of 10% asbestos of Grade III or Grade IV (85-90% asbestos of Grade V and Grade IV).

Typical fibre mix of different grades of asbestos is given below:

- 50% II-5-65 or II-5-50;
- 25% II-6-40;
- 25% M-6-40.

Asbestos content in asbestos-cement mix accounts for about 13%.

Pressure pipes are manufactured on the base of asbestos of Grade III and Grade IV with the addition of 10-15% asbestos Grade V. Commonly used is the asbestos admixture of the following content:

40% II-3-70;

45% II-4-35 (or II-4-20);

15% II-5-55.

Asbestos percentage in the asbestos-cement admixture accounts for 15.5%, cement 84.5%.

IV. Method and equipment used for manufacture of autoclaved asbestos-cement products.

I. Asbestos-cement slurry preparation.

In the Soviet Union the major part of asbestos-cement plants are located close to the cement factories. That makes easier the problem of cement transportation. The asbestos-cement plant in AKMJANE, where asbestos-cement products are cured by autoclaving, is a part of a composite cement and slate factory. Sand-silica cement is producing by combined milling Portland-cement klincer and silica sand in cement mills; cement is transported pneumatically from the siloes of the cement plant to the bins and hoppers of the asbestos-cement production line. This method is more economical than railway transportation which is in use on the second line for manufacturing autoclaved asbestos-cement.

Asbestos is delivered by the railway and stored in sacks stacked on supports separately according to the Grades. In case of need asbestos in sacks on supports is brought to the hoppers by accumulatory loaders.

Dosage of asbestos and cement is carried out by automatic weight batch hoppers.

In the Soviet Union much attention is given to the process of "opening" of asbestos fibre. Natural reinforcing properties of asbestos in asbestos-cement composition strongly depend upon the degree of asbestos opening.

The commonly used method of the opening of asbestos fibre is the so-called "wet" method. Experiments have proved that a wet method of opening asbestos fibre in comparison with a "dry" method increases the reinforcing properties of the fibre by 10-15%. The fibre is opened by a double-stage treatment: it is previously treated in a ball mill during 15-20 minutes; each batch weight accounts for the water content of the fibre of 28-32%. Final opening is produced by treating with water in a hollender or in a hydro-turbo opener, which works on the principal of "cavitation". The concentration of the water asbestos suspension is within limits of 3.5 - 4.5%

Adopted flow of asbestos fibre treatment ensures asbestos an opening degree of some 85%-90% and gives the possibility for making asbestos-cement sheets without the use of higher grades III and IV fibres.

Careful fiberization of asbestos is an important element in the production of corrugated sheets on the base of silica sand Portland-cement because the plasticity of the wet asbestos-cement depends upon the degree of fiberization.

The plasticity of a wet asbestos-cement sheet manufactured on the base of silica sand Portland-cement is somewhat lower than that of the products on the base of Portland-cement. It is therefore obvious that the necessary degree of fibre opening is an important factor to ensure shaping a wet sheet without breaks and cracks.

Asbestos-cement slurry is prepared in contact mixers or turbomixers. To avoid stratification of the asbestos-cement slurry all the aggregates in like are furnished with mixing devices. It is especially important when silica sand Portland-cement is used for manufacture of asbestos-cement because sand and cement particles have great difference in their specific weights.

II. METHODS OF FORMATION OF ASBESTOS-CEMENT PRODUCTS.

Asbestos-cement sheets and pipes are manufactured by the Hatchek process with the help of a revolving sieve cylinder. This conventional method has general use in the Soviet Union, and products from the Hatchek process are strong enough and flexible due to the preferred orientation of the asbestos fibre in the planes of asbestos-cement layers.

Experiments carried out by special roentgenograpgy method show that the degree of orientation of the asbestos fibres in the working directions in a body of a product got by the Hatchek process is higher by 10-18% than that of the products manufactured by the Magnani, Marchiolli and other modified methods.

Sheet-making machines for producing autoclaved asbestos-cement sheets have three sieve cylinders with a felt of 1600 or 1200 mm wide.

The pressure loading part of machines consists of two parts.

The pressure is ensured by a forming cylinder and a supplementary press giving roll in the pressure limits from 20 to 50 kg/cm.l. The felt speed is 40-45m/min.

In this case the felt speed is higher than that of the machines working with the slurry on the base of Portland-cement. This phenomen takes place due to the lower water absorption properties of the asbestos-silica Portland-cement slurry in comparison with the slurry on ordinary Portland cement. That in turn prolongs the filtration time to build up necessary thickness of a sheet by 10-15%: hence under the same conditions in the first case the thickness of a layer exceeds that of the second case.

Together with this the higher working speed of a forming machine and the greater thickness of an elementary layer bring somewhat to the worse plasticity of a wet asbestos-cement sheet. In spite of the same thickness of elementary layers, plasticity of the wet asbestos-cement on the base of silica Portland-cement mix is somewhat lower than that of the products manufactured on the base of ordinary Portland-cement.

This is a reason to slightly limit the capacity of sheet-making machines up to 95-100% of the capacity of forming machines working on the base of ordinary Portland-cement.

For the manufacture of asbestos-cement pipes, machines with revolving sieve cylinders are used. The felt is 3, 4 or 6 metres wide.

The 150 mm pipes are produced on 3 m. forming machines. The pipes of other diameters (200 mm and larger) are produced on 4 and 6 m. forming machines. There are no essential differences in the forming processes of all the machines mentioned.

In the Soviet Union wet asbestos cement sheets are corrugated mainly without using templates or moulds. Up till now this method of corrugation has no broad use in the other countries.

The practice shows that the "mouldless" method of corrugation offers distinct technical and economical advantages over the other methods of corrugation.

In a forming plant the mouldless corrugations work in a line with the conveyor (tunnel) for initial setting of sheets where they go in stacks by 15 pieces. The atmosphere inside the conveyor (tunnel) is characterized by very high humidity and temperature about $45-50^{\circ}C$, but in the autoclaved curing this method of setting is not used. The reason is that the initial setting of products on the base of silica Portland-cement mix is carried out at the moderate temperatures ($20-25^{\circ}C$).

There may be a possibility to convey wet sheets manufactured on the base of silica Portland-cement mix from the forming machine directly into the tunnel with the atmosphere of high temperature and humidity but the research and experimental work on this method has not yet finished.

For this reason the sheets on the base of silica Portland-cement are corrugated on steel templates by corrugaters of rolling system.

III. THE HARDENING OF PRODUCTS MANUFACTURED ON THE BASE OF SILICA PORTLAND-CEMENT MIX.

Autoclaved sheets are hardened in two stages:

- first stage - initial setting;
- second stage - final hardening by autoclaving at a saturated steam pressure of about 8 ati.

Before autoclaving, a wet sheet goes through the stage of initial setting. This is inevitable due to the porous nature of a wet sheet. While the pressure in the autoclave is going up the pores full of air are being clogged with condensed water. Partial pressure in the autoclave is lower than that in pores of a wet sheet. For this reason the air in pores aspires to occupy the larger volume and therefore brings pressure against asbestos-cement layers.

But if the bond between layers is strong enough the tendency of asbestos-cement sheet to swell is minimized.

The necessary strength of bond between asbestos-cement layers is achieved through the initial stage of hardening.

Primary bonding of asbestos-cement layers in a wet sheet is ensured by the process of formation of layers on a forming machine and develop during the setting time. Intensity of a wet sheet hardening process is determined by the intensity and deepness of the klincer consistuent hydration process that depends upon cement fineness, tri-calcium aluminate content, on the initial setting time and temperature conditions. If not very dense and poorly set material undergoes autoclaving, especially under quickly changing and uneven temperature and pressure conditions the last may, in places, cause breaks and stratification of a wet sheet and that would influence the resistance properties - namely, frost-resistance - of the manufactured product. Before autoclave curing, asbestos-cement is supposed to have bending strength not less than 60-80 kg/cm^2.

One of the enterprises in our country gives such strength to wet sheets by storing them (staked under a felt cover) in a factory building for 8-12 hours at the temperature of 25-30°C. The piles are then unstacked, liberated from moulds and conveyed to the autoclave for final hardening.

Initial setting of wet sheets may be accelerated by heating them under atmospheric pressure. In this case wet sheets undergo a two-stage initial setting procedure; air seasoning for 3-4 hours at a temperature not less than 20°C in the building of the fabrication detachment and successively steam curing in curing chambers (one of the autoclaves may be used for this purpose) at the temperature of 50-60°C for not less than 2-3 hours.

At the Akmjane plant where this system of curing asbestos-cement wet sheets is used, the initial setting is carried out on the seasoning conveyor with the temperature limits of 25-30°C at the head of it and 50-60°C at its end to take therefore into consideration the conditions of two-stage hardening system.

The distinctive parameters of the initial setting process are to be found solely for each plant considering properties of cement used.

The final hardening of asbestos-cement takes place in autoclaves (diam. 2 mm, length - 18.5 mm) at the temperature 174.5°C and steam pressure 8 ati.

Steam curing of wet asbestos-cement in autoclaves is carried out according to the regime of 2-6-2 (at both plants manufacturing the autoclaved asbestos-cement).

High pressure - up to 8 ati (174.5°C) is reached by feeding saturated water steam to autoclave during the period of 2 hours. This intensity of pressure rise makes it possible to eliminate development of strains in a wet sheet thus to avoid swelling, stratification and cracking of a product. Products are seasoning at 174°C for some time.

The highest strength of slates is reached at the seasoning of wet products under the steam pressure condition in the autoclave and consequent temperature falls are carried out through steam dischargement into the autoclave of a by-side technicological line during a period of 2 hours. This process results in overheating the water inside the pores of asbestos-cement, which is charactorised by heat in activity, as well as intensified water evaporation, that bring the material to the less water content and to the growth of its strength. Too fast pressure dropping would cause the development of termal strains and cracks in a wet sheet.

The autoclaves are equipped with automatic temperature and pressure control device to control the steam curing process parameters.

The hardening of asbestos-cement pipes.

The asbestos-cement pipes hardening process is running in two stages in the same way as that of the sheets: initial setting and final hardening - steam curing in autoclaves.

Initial setting of pipes has two periods: the first period is the initial setting of products on the conveyor (tunnel); the second, seasoning of pipes inside the building of the plant.

The tunnel is a two or three storey chain conveyor, movement of which is ensured by rotating bearing rollers.

Conveyors are equipped with a steam and water feeding system for heating and moisturizing asbestos-cement pipes. The regular cylinder form of pipes is guarded by their continuous rotation while moving with the conveyor belt.

The temperature inside the conveyor is 40-50°C and the relative humidity 75-80%. The setting time does not exceed 8-10 hours, with the result the impact resistance of pipes after the initial setting is 220-250 kg/cm^2 - which is quite sufficient to manipulate them and pile them for storing. The reduction of intensity and time of the initial setting process results in growth of wastage due to the elliptic irregular form and consequent breakage of pipes.

The final hardening of asbestos-cement pipes is carried out either in autoclaves or by seasoning them inside the factory building. A wholly satisfactory hardening system is dependent upon the method of lathe dressing of the pipe ends. The machinery treatment of pipes demands that their crushing strength be not less than 300 kg/cm^2.

Neither the pipes manufactured on the base of silica Portland-cement mix nor those on the basis of ordinary Portland-cement, can achieve the above-mentioned mechanical strength after only the initial stage of curing.

For that reason pipes manufactured on the base of ordinary Portland-cement are advised to undergo mechanical treatment after water seasoning in tanks or hardening on the elongated conveyors. Pipes produced on the base of silica Portland-cement mix get necessary strength only after autoclaving. But mechanical treatment of asbestos-cement in this case becomes more difficult due to the growth of silica stiffness: wear and tear of equipment and tools as well as dusting grow too. The practice demands that asbestos-cement pipes be made to undergo mechanical treatment before steam curing of products. This is the reason why, after the preliminary hardening, pipes are left to season for 16-24 hours at the temperature of 20-25°C inside the plant building. During this period of time their stiffness reaches necessary values for mechanical treatment while their abrasion value is still not so high.

Final curing of pipes is carried out in autoclaves according to the regimen of 1-7-1. In this case pressure rise and fall is brought to one hour, against two for asbestos-cement sheets, due to the greater stiffness of pipes after preliminary hardening. Pipes are subjected to seasoning at the temperature of 174.5°C and steam pressure of 8 ati.

After the pipes are discharged out of the autoclave they undergo necessary tests and are ready for despatch to users.

V. PROPERTIES OF AUTOCLAVED ASBESTOS-CEMENT PRODUCTS.

Corrugated roofing sheets.

The autoclaved asbestos-cement corrugated roofing sheets which are manufactured by the two previously mentioned plants have comparatively small dimensions: Length - 1200 mm; width - 678 mm; pitch of a corrugation - 195 mm.; thickness - 5.5 mm. The sheets are used mainly in agricultural construction.

As it follows from experience slates manufactured on the basis of silica Portland-cement have better resistance properties in comparison with the products on the basis of ordinary Portland-cement.

Table 4 gives data of strength and weight by volume of sheets manufactured on the basis of silica Portland-cement by the Daughel (the width of sheetmaking machine - 1200 mm.) and Akmjane (the width of sheetmaking machine - 1600 mm.) plants. The average data of the same properties for sheets manufactured of the same type but on the basis of ordinary Portland-cement are also included in the Table.

TABLE 4.

Physical and mechanical properties of roofing materials.

Type of sheet-making machine	Bending strength kg/cm^2			Weight by volume g/cm^3		
	ev.	max.	min.	ev.	max.	min.
Silica Portland-cement						
I Narrow	196	253	160	1.61	1.71	1.57
2 Broad	201	253	163	1.58	1.69	1.54
Ordinary Portland-cement						
3 Narrow	162	165	160	1.61	1.64	1.57
4 Broad	166	182	157	1.60	1.67	1.56

Under the Soviet Standards the bending strength of the materials is found by applying the load in the direction of the preferential orientation of asbestos fibres.

Under the Standards the sheets on the basis of ordinary Portland-cement are tested on the 7th day. The strength grows with further seasoning and up to the time of using them in the roof structure the strength of the both types of sheets is almost the same. Weight by volume of them nearly coincides as well. The impact strength of sheets on the basis of silica Portland-cement is by 10-15% lower than that of materials on the base of ordinary Portland-cement. Generally it equals 1.7-1.8 kgcm/cm^2. This happens due to the lower (by 10-15%) tensile strength of the autoclaved asbestos-cement. The essential advantage of autoclaved sheets is in less drying shrinkage and deformative changes which take place in the result of water content changes in the process of use.

Main deformative changes of the asbestos-cement manufactured on the base of silica Portland-cement are connected with the chemical reaction which takes place during the setting time and proceeds in the period of autoclaving. In a monthly period of air-seasoning, drying shrinkage increases only by 0.2 mm/m (20%). The result is that hydro-thermal treatment asbestos-cement produced on the base of ordinary Portland-cement, suffers from deformative changes: the character of the last depends upon the hardening system; the drying shrinkage rises up to 0.5 mm/m and the elongation of the products up to 0.3 - 0.6 mm/m.

During further storage in the air, deformative changes in the asbestos-cement manufactured on the basis of ordinary Portland-cement rise by 80-200%.

After a monthly ageing the moisture deformations of autoclaved asbestos-cement is in 2.7-3.2 times less than that of asbestos-cement cured by conventional methods (Table 5).

TABLE 5.

Drying deformations of the asbestos-cement sheets manufactured on the base of different binders.

Type of binder	Age, in days	Shrinkage mm/m	Shrinkage %	Length Growth mm/m	Length Growth %
Silica Portland-cement	7	2.4	100	1.6	100
	14	4.0	41.7	0.80	57.2
	28	0.78	32.5	0.67	47.7
Ordinary Portland-cement	14	3.0	100	1.98	100
	28	2.3	76.8	1.46	73.6

Shrinkage and length growth data shown in Table 5 have been obtained through the experiments. The asbestos-cement sheets were dried to their constant weights at the temperature of 105° during 48 hours. Before drying the sheets were immersed in water of room temperature for 24 hours.

By their transportability, working and constructing properties, asbestos-cement sheets manufactured on the basis of silica Portland-cement do not differ very significantly from the sheets produced on the base of ordinary Portland-cement.

Asbestos-cement pipes.

The assortment of asbestos-cement pipes manufactured in the Soviet Union is given below in Tables 6 and 7.

TABLE 6

Pipe assortment according to their diameters, mm.

NN	Type of binder	Diameters, mm									
		100	135	141	181	189	235	270	279	368	456
I	Ordinary Portland cement	26.2	0.2	16.8	0.7	13.2	4.4	0.6	12.1	15.2	10.6
2	Silica Portland cement	19.4	4.7	19.4	15.6	20.8	-	12.6	7.4	0.1	-

TABLE 7

Pipe assortment according to the pressure they stand.

NN	Type of binder	Pipe mark, %				
		BT-3	BT-6	BT-9	BT-12	nonpressure
1	Ordinary Portland-cement	0.1	6.5	86.8	0.8	5.8
2	Silica Portland cement	0.6	18.4	55.9	16.3	8.8

Data of tests for tension, bending and crushing strengths of autoclaved asbestos-cement pipes are not worse than those of the pipes manufactured on the base of ordinary Portland-cement. These data are close to ISO Recommendations.

Asbestos-cement materials cured under the autoclave technology possess higher frost resistance if compared with conventially treated asbestos-cement.

A number of Soviet and foreign specialists noticed the elevated chemical resistance of autoclaved asbestos-cement. This fact was confirmed by the investigations conducted in NIIASBEST-CEMENT. These investigations showed that the autoclaved asbestos-cement has proved extremely resistant to the sulphuretted hydrogen, sulphate and magnesium forms of attack.

The following factors have an influence upon the resistant properties of autoclaved asbestos-cement: the part (about 40%) replacement of cement by ground silica, that is practically inactive in corrodable media; absence of unconnected $Ca/OH/_2$ and replacement of highly active calcium hydrosilicates by highly resistant hydrosilicates with lower basicity.

"Tentative recommendations for determination of sulphate and magnesium content in water-media to use them for the design of the underground asbestos-cement mains" have been worked out in NIIASBESTCEMENT. According to the "Recommendations", requirements towards the autoclaved asbestos-cement pipes are 2-3 times higher than in respect of the conventially treated pipes.

VI. ECONOMIC ADVANTAGES OF THE AUTOCLAVED ASBESTOS-CEMENT PRODUCTS.

Economic effects of the autoclaved asbestos-cement technology are manifested in saving of high quality cements, partially (up to 40%) replaced by the silica Portland-cement mix, as well as in liberation of the essential part of working capital. Together with this the shortage of the production time results in the shortage of the plant area.

Production and economy activity of the plants manufacturing autoclaved asbestos-cement proves the profitable use of silica Portland-cement mix clearly enough.

It is impossible to distinguish the economic advantage through the use of the autoclaving process only in as much as other factors influence the factory productivity: (structural organisation and capacity of the enterprise, local prices of raw materials, etc.).

Only analysis of the economic features got from the experiences, together with comparative data of the plants under the project of equal capacities but characterised with the different curing methods and types of cement used, would have given satisfactory results.

We shall begin with the data analysis of the plants under the projects. Advantages of autoclaving technology can be illustrated by comparison of capital cost and working capital furnished for the process of asbestos-cement pipes manufacture.

A standard project for six sheetmaking and two pipemaking machines is chosen as an analogue for this purpose.

Capacity/annum of two pipemaking machines is taken for 3,000 km pipes of con. diameter.

Two features of the manufacturing system of pipes on the base of silica Portland-cement mix are taken into consideration:

1. Transportation of silica Portland-cement from a cement factory;
2. Silica sand milling and preparation of silica Portland-cement mix at the pipemaking plant.

Cost of a main plant building; for pipes manufacturing:

- on the base of Portland-cement	3,140,000 rubles
- on the base of silica Portland cement	3,061,000 rubles
- with sand milling at the plant	3,136,000 rubles.

Capital cost per 1 km. asbestos-cement pipes of con. diam., including capital cost of the main and auxiliary equipment and services, and coupling of factories:

- on the base of Portland-cement 1600 rubles,
- on the base of silica Portland-cement 1574 rubles,
- with sand milling at the factory 1619 rubles.

The autoclaving method of curing asbestos-cement reduces the production area of a warm warehouse but simultaneously tends to somewhat increase the cost of the equipment at the expense of the autoclaves used.

In the first case the capital cost/1 km a.c. pipes of con. diam. is lower than that of the pipes cured by the conventional method by 1.6%; in the second case it is higher by 1.2%.

Manufacturing cost per 1 km. a.c. pipes of con. diam.:

- on the base of Portland-cement 1283.55 rubles,
- on the base of silica Portland-cement 1269.09 rubles,
- with the milling of silica sand 1221.68 rubles.

Manufacturing cost of pipes on the base of silica Portland-cement is lower in comparison with pipes on the Portland-cement base by 1.5-4.5%.

The lower cost of silica Portland-cement makes cheaper the raw materials mix used for asbestos-cement production by 3% (in the first case).

In order to determine the production effectiveness of asbestos-cement pipes on the base of silica Portland-cement it is necessary to compare the capital and working costs of both production systems according to the following formulae:-

$$Э = C + 0.17 K$$

where

C = working cost

K = capital cost

Results are brought to the pipe production per annum, in 1,000 rubles.

TABLE 8

Element of cost	Pipes on the base of Portland cement (production)	Pipes on the base of silica Portland-cement mix (production)	
		Cement from cement factory	Sand milling on the plant
Manufacturing cost	3850.7	3807.3	3665.0
Capital cost	4070.0	3991.0	4126.0
All the expenditures	4233.3	4178.8	4030.4
Economical effect per annum	-	54.5	202.9

The time shortage of a manufacturing cycle of the production in the case of autoclaved asbestos-cement pipes results in accelerated turnover of working funds, which can be determined as follows:

TABLE 9

Article	Unit	Pipes on the base of Portland-cement (production)	Pipes on the base of silica Portland-cement (production)
Time of production cycle	24 h.	14	4.5
Number of cycles per annum	cycle	24	75
Forming machines capacity (per annum)	km pipes of con. diam.	3,000	3,000
Turnover funds requirement	1000 r.	600	200

Acceleration of turning-over the working funds helps to liberate 400,000 r.: that is an additional factor to bring the a.c. production to the higher economic effect.

The practice of autoclaved asbestos-cement manufacture confirms project calculations of the effectiveness of autoclaving over the conventional curing methods.

In 1963 the following data was furnished regarding the activity of the Akmjane and Daughel plants, which used the autoclaving method of asbestos-cement production:

The Akmjane plant:

- 55 mill. con. tiles / ton/ on the base of silica Portland-cement,

- 1430.2 km pipes of con. diam / ton/.

The Daughel plant:

- 43.5 mill con. tiles / ton/, a line productivity / annum :

- for a "broad" type of a forming machine: about 27.5 mill con. tiles (average productivity throughout the industry is 28.5 mill);

- for a "narrow" type of a forming machine: 21.7 mill con. tiles (average data throughout the industry is 21.3 mill).

A day capacity:

- for a "broad" type of a forming machine: 3751 con. tiles (average data: 4012 con. plates);

- for a "narrow" type of a forming machine: 2839 con. tiles (average data: 3088 con tiles).

In the case of production of asbestos-cement pipes on the basis of silica Portland-cement, an average productivity of 3 and 4 m. pipeforming machines accounts for 715.1 km pipes of con. diam. (the average data throughout the industry = 751.9 km pipes of con. diam.). Productivity per hour is 101.4 and 114.4 km pipes of con. diam. correspondingly. Thus in the case of production of autoclaved asbestos-cement, productivity of forming machines is lower than that in the case of production asbestos-cement on the base of Portland-cement.

In 1968 the manufacturing cost of 1,000 con. plates of sheets on the base of silica Portland-cement was 37.78 r., which is 10.5% less than the average manufacturing cost of sheets on the base of Portland-cement throughout the industry.

The manufacturing cost of 1 km pipe of con. diam on the base of silica Portland-cement came to 1186.28 r., which is 8.7% less than the average data throughout the industry.

In other words, the practice confirms essential savings in the manufacturing cost of asbestos-cement produced on the base of silica Portland-cement mainly at the expense of raw materials.

In 1968 the profit of the Daughel plant amounted to 39.9%, which was 13% higher than the average throughout the industry. Although this data has a "synthetic" character, it undoubtedly has summed up the results of the acceleration of turning-over the working funds and somewhat saving the capital cost at the expense of the plant area cut.

The productivity index of the plants where the autoclave curing of the asbestos-cement is used coincides with that of the industry as a whole. In general the Akmjane and Daughel plants would rank among the profitable enterprises which effectively used the advantages of this method.

By now some new projects for the manufacture of autoclaved asbestos-cement pipes are under design in the Soviet Union. This work includes geological mapping of silica sand occurrences. It is desirable to go in for construction plants on sites close to the silica sand occurrences and transporting lines. It is necessary to take into consideration other local economical factors.

The manufacture of autoclaved asbestos-cement is advisable for a number of countries where there is a keen need for building materials.

The autoclave curing of asbestos-cement should interest countries for which the economy of Portland-cement is of great importance, as capital cost and working capital for manufacturing ground silica sand are far lower than for the cement production. When using a production method it would be advisable to take into consideration the specific properties of the asbestos-cement products on the basis of silica Portland-cement. For instance, in countries with a hot and damp climate the working properties of the autoclaved sheets are far better in comparison with the same characteristics of the sheets manufactured on the basis of Portland-cement: it happens due to the reduced drying shrinkage of the autoclaved asbestos-cement.

Higher deformative resistance of the autoclaved asbestos-cement is of paramount importance for large-size sheets production.

Manufacture of autoclaved asbestos-cement pipes is advisable in the case of the extreme sulphate and magnesium ground aggression in locations where the underground mains are planned to be constructed.

Autoclaved asbestos-cement pipes have also proved resistant to aggressive liquids.

14. 3. 72