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Cement adhesion to the asbestos fiber and its influence on the physicomechanical properties of asbestos cement.

The study of adhesion is at present acquiring great importance in various fields of technology, including the technology of the production of asbestos-cement articles.

The theoretical basis of this comparatively young branch of science was laid by B. V. Deryagin, Corresponding Member of the Academy of Sciences of the USSR.

Already in the very beginning of the development of the shingle industry such characteristics of the asbestos-cement suspension as uniform distribution of the cement in the mass of fibers, absence of perceptible stratification of the solid phase in the suspension even at a small concentration thereof, retention of the structure at intensive stirring, were explained by the strength of adhesion of the cement to the asbestos fibers.

Prof. P. N. Sokolov in 1935 introduced a representation of the elementary structural particles of asbestos-cement consisting of asbestos fibers whose surface is covered by grains of cement. On the basis of this representative he determined the theoretically necessary ratio between fiber and binder in the charge

P. N. Sokolov (1) thinks that the adhesion of the binder increases the area of contact between cement and fiber, increases the strength of attachment of the fiber in the cement stone.

Haidn (2) attributes an even greater importance to the adhesion. Studying the possibility of the employment of mineral and organic fibers in the shingle industry, Haidn came to the conclusion that the ability of the fiber to adhere to the cement in the watery suspension is the decisive factor for judging the suitability of the given fiber.

The theoretical representations of the significance of the adhesion played a great positive role in the development of the technology of asbestos-cement, but they were unable to replace experimental work on determining more precisely not only the qualitative but also and mainly the quantitative indices of this process.

The significance of the adhesion could not be limited to the technological field alone. It was clear that it must exhibit a substantial influence on the whole course of the physicochemical processes in the asbestos-cement; must influence its fundamental physicomechanical characteristics.

A fundamental difficulty at the study of adhesion was the absence of a method for its quantitative evaluation. Many attempts in this direction were unsuccessful. It was impossible to determine (express in numerical values) the degree of adhesion of the cement of one or another composition to the asbestos, the influence of the swelling of the fibers and other factors. It may be for this reason that the works on the physicochemistry of asbestos-cement carried out in the last 15-20 years have failed to attract the attention which they deserve.

The staff of the All-Union Scientific-research Institute for Asbestos-cement in 1950 formulated a method for filtration analysis of asbestos-cement suspensions (3). In this connection there was discovered the possibility of indirect quantitative characterization of the process of retention of the cement by the fiber, and together with this to investigate the influence of the degree of adhesion of the binder on the basis of the technological processes and the physicomechanical characteristics of the asbestos-cement.

T. M. Berkovich and A. I. Vasil'eva (4) investigated the adhesion of the grains of cement of other powdery materials to the asbestos in the water medium with the help of measurement of the amount of sediment in the filtrate obtained at the filtration of the asbestos-power suspension. A defect of this method of investigation, as the authors themselves state, consists in that the amount of sediment is influenced not only by the degree of adhesion of the powder but also by the structure of the film forming in the screen.

In the present article there are presented and discussed the results of the studies of the process of adhesion with the help of filtration analysis carried out in the Institute in the period 1950-1954. There is described the influence of the adhesion on the physicomechanical characteristics of the asbestos-cement and on the productivity of the screen part of the sheet-forming machine.

1. Microscopic investigation of structure of asbestos-cement particles

The structure of the particles of the solid phase of the asbestos-cement suspensions was investigated under the microscope.

For this purpose the fibers of asbestos with the cement particles on the surface were withdrawn from the suspension prepared in the factory hollander as well as from freshly-formed layers and sheets.

For studying the adhesion of the cement of the fibers of various degrees of disintegration, and for investigating the influence of the duration of contact, the velocity of mixing and other factors, some preparations were also produced under laboratory conditions.

At the mixing of the asbestos and cement in the hollander the adhesion of the cement to the fibers occurs under the conditions of intensive stirring of the suspension. For retention of the particles of cement of the surface of the fibers there is necessary a considerably stronger linkage than at the insignificant velocity of movement of the particles. Therefor under the laboratory conditions the cement was deposited on the fibers from a cement suspension of concentration 8%, which was continuously stirred in the mixer at an intensity corresponding to industrial conditions. Into the cement suspension the asbestos fiber was plunged glued on one end of a glass stick. After a certain length of time the fiber was transferred from the mixer to an object glass. Then there was added to the fiber a drop of distilled water taken from the production process (recuperator), and the preparation was covered with the glass. The preparations were examined in reflected light. There were investigated in all 56 preparations.

An observation took 2 hours from the moment of removal of the preparation from the mixer.

Some characteristic microphotographs of preparations are presented in Figure 1.

The visual observation and the microphotography of the asbestos fibers taken from the asbestos-cement suspensions as well as from the freshly-formed layers [illegible]

1. The adhesion of the grains of cement to the fibers under the conditions of intensive stirring of the asbestos-cement suspension occurs very unevenly.

The split asbestos clusters, where the distance between the individual constituent elements of the cluster is less than the average diameter of the adhering cement grains, are covered with cement particles. The density of occupation of the grains on these segments is between 6 and 46 pieces per fiber length of 120 microns, and the size of the grains is about between 25 and 30 microns. At this one grain of cement is in contact with several fibers of the asbestos cluster at several points. This type of adhesion we call provisionally multipointed'.

On the other hand, the non-split asbestos clusters varying in diameter between 25 and 4 microns are nearly clean (compare figure 1a). On their surface the cement grains have a weak hold.

Consequently, the cement particles do not cover with a continuous layer the whole outer surface of the asbestos fibers in the suspension. This cannot be attributed to a deficit of cement grains of the given dispersity, because in the laboratory mixer, when the fibers were mixed, there was a great excess of cement particles of the finest fraction, and nevertheless all the non-split asbestos clusters were not, regardless of the diameter, covered by cement.

The main condition for a strong adhesion and the formation of a dense layer of cement particles on the fibers is the presence of multipointed contact.

The stronger hold of the cement on the surface of the split asbestos clusters may be explained as follows. In each of the points of contact between the cement grains and the fibers there acts a molecular force of attraction of a certain magnitude. The larger the number of points of contact is, the greater is the total value of the force of adhesion.

The possibility of the existence of the multipointed contact on the asbestos fibers is due to the fact that the asbestos fibers in the clusters are not completely split at their treatment on the rollingmill under factory conditions. In the process of further treatment of the asbestos with the hollander, the degree of splitting is increased, and the distance between the fibers of the clusters is increased, although complete disintegration of the clusters does not occur. After the hollander the fibers are united into structural particles. In the process of mixing the suspension such structural particles move as one whole. The components of the fibers are not separated, but retain a certain position relatively to each other. Therefore the cement particles immediately come in contact with certain fibers even in the process of intensive mixing of the suspension.

Figure 1a: Adhesion of cement to asbestos fiber; strong to split cluster at presence of multipointed contact (above); weak to nonsplit cluster (below). Magnification 200x

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Figure 1b: Adhesion of cement to fibers of mineral wool: weak to individual fibers (above); strong to clusters composed of several fibers (below). Magnification 150x

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Figure 1c: Asbestos fibers with hydrated cement grains on surface

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Figure 1d: Unequal adsorption of products of hydration of cement on asbestos fibers. Magnification 150x

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Figure 1e: Surface of asbestos-cement layer. Magnification 90x

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The significance of multipointed contact for a strong adhesion of particles of cement (or another powder) to the surface of asbestos fibers comes out particularly clearly when the molecular attraction of cement grains by asbestos fibers is compared with the attraction of iron balls by a prismatic magnet.

The greater the number of magnets presented to the ball on the same side is, the more difficult ut us ti tear ut iff, If, however, only one magnet remains (one-pointed contact), then the ball can easily be torn off.

Now imagine that the magnets together with the ball begin to move. Here we have two cases.

The first case, where the magnets are strongly united, and do not change their positions relatively to each other during the movement. Then, at movement of the magnets in any direction the ball will be touched by each of them, and will adhere strongly to their surface (like the cement at movement of asbestos fibers united into one particle).

The second case, where the magnets are not united, so that at movement of the one magnet in the one direction it is torn off the ball, of the second magnet in the other direction, etc. until the ball is torn off the magnets. This phenomenon will likewise occur if the number of magnets is increased. Regardless of how many magnets there are, if they are not strongly united the ball will be retained weakly, because at their simultaneous movement the ball can be touched only by one of the magnets. Analogously, the adhesion between the cement particles and the asbestos fibers is destroyed if the latter are united into one structural particle.

Therefore, a remarkable characteristic of asbestos is its particle in the form of a cluster, which, touching the cement particle simultaneously in several places, can hold it strongly to its surface, even when the size of the particle reaches 20 microns and more.

The presence of multipointed contact is apparently a special condition necessary for the adhesion of macroparticles, such as grains of ordinary cement. From this viewpoint there must also beconsidered the question of asbestos clusters. The fiber clusters should be split (separated) in the hollander only to such a degree that there will be possible multipointed contact with the cement particles. If the optimal treating time of the asbestos in the hollander is exceeded, the nonsplit fibers, consisting of clusters must be "separated" to such an extent that the cement grain is unable to come in contact with several fibers simultaneously.

It is precisely to this circumstance that there may be explained the necessity found in the experiments (5) of limiting the treating time on the reconstructed hollander (a) to 5-7 minutes.

The factor of multipointed adhesion must also be taken into account at investigations on the employment of asbestos substitutes.

It is known that the adhesion of cement to the fibers of mineral wool is worse than to the fibers of asbestos (4). If all of the asbestos in the suspension is replaced with mineral wool, its composition is heterogeneous, and it stratifies. One of the reasons for the weak adhesion is that mineral wool does not have clusters. Its fibers are separate. Multipointed contact with the cement particles is impossible.

By creation in the laboratory of clusters of the fibers of mineral wool the adhesion of the cement is significantly strengthened (compare figure 1b).

This experiment shows that at investigations on the employment of mineral wool in the asbestos-cement industry there must be taken into account not only its chemical composition but also the physical characteristics of the binder to the surface of the fibers.

Moreover, it is useful to study the question of the unting of the fibers of the mineral wool into clusters for strengthening the adhesion of the cement.

Despite the weakness of cement to the fibers of mineral wool, its addition to the asbestos-cement suspension can be improved by filtration, which is connected with a considerable increase in the porosity of the obtained layer, because the rigidity of the fiber of mineral wool prevents its compacting by hydrostatic pressure.

2. In the microscope there can be observed the process of the deposit of the product of the hydration of cement on the asbestos fibers.

In 5-8 minutes after bringing the asbestos-cement elementary particles into the water, turbidity is observed around the cement particles.

After the lapse of a certain length of time (40-90 minutes), which depends on the composition of the cement, the quantity of salt dissolved in the water, and the temperature, the asbestos clusters, on the segments where the clearance between the cement grains does not go above 3-4 microns, are covered with a continuous, opaque gelatinous envelope, and acquire the external appearance of a thread of increased diameter in comparison with the original dimensions of the asbestos fibers. On its surface it is no longer possible to distinguish between individual cement grains and individual asbestos fibers (compare figure 1c).

On the segments of the asbestos clusters with fewer cement grains the continuous gelatinous envelop does not form. It exists in the form of individual separate segments (compare figure 1d).

Asbestos clusters with an unequal distribution of the cement grains in their surface in the same state may be deposited not only under laboratory conditions but also at the formation of the asbestos-cement layer. Under these conditions the adsorption of the product of hydration of the fibers will be unequal. The strength of the bonds of the asbestos-cement elementary particles with each other will be unequal. It will be stronger in those points of their contact where a larger number of cement grains was present.

Accordingly the microscopic investigation shows that the adhesion of the cement may have an influence on the mechanical strength of the asbestos-cement.

3. The structure of asbestos-cement (Figure 1e) cannot be regarded as monolithic, but is instead more reminiscent of a network, a rigid skeleton of asbestos-cement elements, more than 50% of whose volume is occupied by pores. The mechanical strength of such a system depends to a considerable degree on the place where the cement grains are concentrated: on the surface of the asbestos fibers or in the intervals between them (in the cells of the network). In the first case, because of the adhesion of the cement to the asbestos fibers, the linkage between the asbestos-cement elementary particles will be stronger than in the second case.

2. Investigation of degree of adhesion by filtration method. Influence of adhesion on characteristics of asbestos-cement

Despite the worth of the microscopic methods of investigation, one of their shortcomings consists in that they enable the study of the adhesion only on individual fibers, and do not enable the characterization of the degrees of adhesion in a given volume of the suspension of different kinds of particles with different kinds of adhesion. Therefore the microscopic method was not employed for estimating the number of cement grains to the asbestos fibers in the suspension.

As the method for determining the number of cement grains adhering to the fibers there were selected the method of filtration analysis. This selection was not fortuitous. The method sedimentometric investigation, or the method of rheology, widely employed in colloidal chemistry, are not employed for the study of the structure of asbestos-cement suspensions. The high velocity of sedimentation of the particles of the asbestos-cement suspension goes far beyond the permissible limits of the employment of the sedimentometer. The necessity of studying the structure at unequal mixing of the suspension is also an obstacle to the employment of either the sedimentometer or the rheological method.

The employment of filtration analysis for studying structure-formation in suspensions was first proposed by W. Ostwald in 1922. Afterward this method was successfully employed in the USSR by I. I. Zhukov, A. V. Dumanskii, P. A. Rebinder and others.

At the present time filtration analysis is employed in the petroleum, the ore-concentration, the food and other branches of industry.

The basis of the employment of filtration analysis for the investigation of the structure of suspensions is the dependence of the velocity of traversal of the liquid through the layer on the average diameter of its pores.

In an asbestos-cement layer (film) the average diameter of the pores depends not only on the size of the particles of the solid phase but also on the disposition of the cement grains relatively to the asbestos fibers.

In figure 2 there are represented diagrammatically two cells of the same size in an asbestos-cement layer at weaker and stronger adhesion of cement to fiber. In a cell a, there are 8 pores of diameter d, in cell b, 1 pore of diameter d and one of diameter 2d.

Figure 2: Diagrammatic representations of elementary cells in asbestos-cement layer: (a) at weaker and (b) at stronger adhesion of cement to asbestos fiber. (1) asbestos fiber; (2) cement particle; (3) pore

If the area of the section of the pore of diameter d is taken at unity, then the area of the pore of diameter 2d equals 4.

From the fact that, according to Poiseuille, the velocity of flow of a liquid in pores (capillaries) is directly proportional with the square of their diameter, it follows that the disposition of the cement grain can be changed from filtration with water.

Take the velocity of flow in a pore of diameter d at unity. At increasing the diameter of the capillary by two times the velocity is increased by four times, and in capillary 2d will be equal to 4. By multiplying the velocity of flow of the liquid by the area of the section of the pore we find the quantity of liquid which filters per unit time through the pores of cells a and b.

Through the pores of cell a there filters:

1 x 8 equals 8 cubic units of liquid.

Through the small pore of cell b there filters:

1 x 4 equals 4 cubic units of liquid.

The large pore of cell b passes:

4 x 4 equals 16 cubic unit of liquid.

In all there filters through the pores of cell b 20 cubic units of liquid instead of 8 cubic unit through the pores of cell a.

Examination of the model shows that with increasing degree of adhesion of the binder there occurs a considerable increase in the flow of liquid. By measuring the velocity of flow at filtration analysis there can be estimated the value of the adhesion.

It is important to notice that the total area of the sections of the pores is in cells a and b the same, and that the difference in the quantities of liquid passing through occurs solely because of the variable diameter of the pores.

Consequently, layers differing only in the degree of adhesion of the binder may have nearly the same porosities.

The variable disposition of the particles in the layer, which has little influence on the magnitude of the porosity, is a particularity of the structure of asbestos-cement in connection with the presence of a network of fibers with such large cells that the cement grains can move freely in them.

The methods and apparatuses for fibration analysis employed in colloidal chemistry are not employed for the study of asbestos-cement suspensions. The All-Union Science-Research Institute for Asbestos-cement has formulated a special arrangement (the chamber filter), with which there is determined the coefficient of resistance to filtration - a magnitude depending on the size of the pores in the layer consisting of particles of solid phase of the investigated suspension. Since the size of the pores likewise determines the degree of adhesion, the coefficient of resistance (Kphi) is employed for relative evaluation of the degree of adhesion of the binder (b).

With this arrangement the sheet is formed in the following manner.

The asbestos-cement layer obtained on the filter is taken off together with the netting and laid on technical cloth. Then the cloth and the layer with netting are pressed on the laboratory press under a pressure of 3 kg/sqcm, which corresponds to the value of the pressure of the squeezing rollers of the sheet-forming machine.

The cloth with the double layer is laid between metal plates and pressed at a pressure of 20 kg/sqcm.

This operation corresponds to the hydration of the layer with the format drum on the sheet-forming machine.

As a result the pressed layer with the netting is transferred to the plate. Then onto the same plate there is in the same manner transferred a second layer, etc. until a sheet of the necessary thickness has been formed.

In this form the chamber filter is suitable for the study of the structural characteristics of the suspension and for the investigation of the physicomechanical characteristics of the sheet formed from this suspension.

With the help of the chamber filter there was determined the influence of the adhesion of the cement on the physicomechanical characteristics of asbestos-cement.

During the experiments for forming the asbestos-cement sheets there was employed suspension of the same composition, but at this there was varied the degree of adhesion of cement as well as the intensity of mixing of the suepension in the mixer.

It was assumed that the adhesion of the cement grains was not so strong as to prevent removal from the surface of the fibers at the corresponding mechanical action.

Actually, as found in an earlier investigation (6) with an increasing number of rotations of the blade in the laboratory mixer there occurs a considerable increase in the coefficient of resistance to filtration of the suspension. This means that some of the cement grains adhering to the asbestos fiber are washed off its surface at intensified mixing of the suspension.

Accordingly, variation of the intensity of mixing of the suspension can vary only the quantity of cement on the fiber at strict constancy of the other indices characterizing the properties of the asbestos and cement.

For the purpose of wholly excluding any influence of the intensity of mixing on the actual process of filtration in the moment of letting down the filter the number of rotations of the mixer was lowered, and was the same in all of the experiments.

In Table 1 there are presented the values of the coefficient of resistance as well as the data characterizing the physicomechanical properties of the asbestos-cement obtained at the investigation with the chamber filter with one and the same composition of the asbestos-cement suspension but with different values of the adhesion of the cement to the fiber. The composition of the charge was: M-5-60 50%; P-6-45 50%. The content of asbestos in the charge was 15%. The cement was Voskresensk Works mark 400. The residue on screen 4900 was 6.5%.

Table 1

Dependence of physicomechanical characteristics of asbestos-cement on value of adhesion of cement to fiber in asbestos-cement suspension. Adhesion evaluated according to value of [illegible]

(1) experiment No.

(2) number of rotations of mixer between filtrations, rpm

(3) number of rotations of mixer in moment of filtration, rpm

(4) K_{phi} of suspension, $(cm/g)^{1.5}$

(5) relative thickness of layer, %

(6) tensile strength of sheet, kg/sqcm

(7) Bending strength of 14-day-old sheet, kg/sqcm

(8) water-absorptivity, %

(9) volumetric weight, grams/cc

1	2	3	4	5	6	7	8	9
1	174	174	311	100	2.8	353	29.9	1.47
2	248	174	350	95	2.35	320	30.2	1.45
3	310	174	415	90	2.02	246	29.1	1.15
4	360	174	545	82	1.70	168	29.7	1.48

The data of the Table show that:

- (a) A suspension which has been subjected to more intensive mechanical action has a greater coefficient of resistance to filtration. This is due to a decrease in the value of the adhesion of the cement, because the other physico-mechanical characteristics of the suspension remain unchanged. Calculation of the thickness of the layer on the netting cylinder shows that this magnitude in this case is decreased 18% at equality of the other technological indices.

Together with this the mechanical strength of the crude sheet is decreased 40%! In the practice this means an increase in the number of rejects of freshly-formed sheets and a lowering of the productivity of the machine.

The found dependence between the filtration characteristics of the suspension and the mechanical strength of the sheet is confirmed by the fact, long known in the practice, of a worsening in the quality of the production at the employment of a poorly-filtering suspension.

(b) The variation of the degree of adhesion of the cement led to a decrease in the bending strength of the asbestos-cement of 50%. In view of the fact that the same raw material was employed in all of the experiments, such a great change in the strength may be explained by the deep influence of the value of the adhesion of binder on the structure of the asbestos-cement.

Similar results were obtained in the other series of the same experiments carried out in the laboratory with different compositions of cement and different marks of asbestos.

(c) Despite such great variations in the strength of the asbestos-cement sheet, its volumetric weight remains practically unchanged (Table 1). This is explained by the fact that at various values of the adhesion (figure 2) the index of porosity of the layer remains constant. At the same time the squeezing out of the water from the layer at better adhesion is improved, because there is increased the size of the pores through which the squeezed-out water flows out of the layer.

With the adhesion of the binder there is apparently connected an influence on the quality of the production of the various marks of asbestos employed in the shingle industry, which differ from each other not so much in the length of the fiber as in the presence of dust, and of the ability of the cement to adhere.

F. L. Davydova (7) compared the strength of asbestos-cement prepared with various marks of asbestos employed for the production of shingles. The content of asbestos corresponded to the Table of mutual substitutability. The asbestoses were of the same degree of clustering. One composition of cement was employed. At the same time with the help of filtration analysis there was measured the index K_{phi} characterizing the value of the adhesion.

From the curve of Figure 3 it can be seen that from the asbestos-cement suspensions containing asbestos with a greater adhering ability (smaller K_{phi}) there are formed stronger sheets.

Figure 3: Dependence between K_{phi} of asbestos-cement suspension and relative strength of asbestos-cement at employment of asbestoses of various marks. As unity there is taken asbestos-cement with asbestos P-5-65. (a) coefficient of resistance to filtration, $(cm/g)^{1.5}$; (b) relative strength of asbestos-cement.

Identification of marks of asbestos

(1) Zh-6-38 in suspension 12.2%
(2) Zh-6-25 in suspension 13.4%
(3) P-5-65 in suspension 11.8%
(4) P-5-50 in suspension 12.4%
(5) P-6-45 in suspension 13.85%
(6) P-6-30 in suspension 14.85%
(7) M-5-70 in suspension 13.55%
(8) M-5-60 in suspension 13.95%
(9) M-6-40 in suspension 16.15%
(10) M-6-30 in suspension 17.30%

The curve convincingly shows that the adhering ability of the binder is an important qualitative index of the fibers employed in the asbestos-cement industry.

3. Establishment of necessary degree of clustering of asbestos on basis of measurement of adhesion of binder

The degree of clustering exhibits a great influence on the value of the adhesion of the cement. Therefore it is important to examine the results of the investigation of the adhesion in suspensions differing by various degrees of clustering of the asbestos.

For the investigations the suspensions were prepared under factory conditions in thereconstructed hollander. The clearance between the drum and the comb in the hollander was 4-5 mm, so that grinding or shortening of the asbestos fibers at the treatment did not occur.

The coefficient of resistance to filtration (K_{phi}) was determined in the chamber filter, in whose mixer there was taken the suspension from the tank of the sheet-forming machine. The variation in the K_{phi} of the suspension and in the physicomechanical indices of the asbestos-cement at various durations of fluffing of the asbestos in the hollander are represented by the curves of Fig. 4.

Figure 4: Dependence of K_{phi} of asbestos-cement suspensions, strength and volumetric weight of sheets on duration of treatment of asbestos in hollander. (1) K_{phi}; (2) strength; (3) volumetric weight. (a) volumetric weight; (b) bending strength, kg/sqcm; (c) duration of fluffing of asbestos in hollander, minutes

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From figure 4 it can be seen that:

(1) With increasing duration of fluffing of the asbestos from 2 to 6 minutes there occurs an increase in the adhesion of the cement, as indication of the decreasing K_{phi}. This fact clearly indicates that the value of K_{phi} depends not on the total surface of the particles of asbestos and cement (because it is precisely in this period that there occurs the most intensive splitting of the asbestos and its total surface is considerably increased), but on the outer surface of the aggregated particles of asbestos-cement.

(2) The highest value of the strength of the asbestos-cement is obtained at the value of the fluffing of the asbestos at which the K_{phi} of the asbestos-cement suspension has its minimal value. A longer duration of fluffing of the asbestos worsens the technological characteristics of the suspension. One of the reasons for this seems to be a worsening of the adhesion due to increasing distance between the fibers of one or another cluster to such an extent that the cement grains no longer contact several fibers simultaneously. Multipointed adhesion becomes impossible.

The experiments showed that the optimal degree of fluffing of the asbestos is reached at a comparatively small increase in the surface of its fibers, which is obtained for 5-7 minutes of fluffing of the asbestos in the reconstructed hollander.

The results of the experiments show that for the technological evaluation of the degree of fluffing it is important to take into account not the total surface of the asbestos fibers but its active part. The active surface of the asbestos fibers with one and the same degree of fluffing will be different for particles having different physicochemical characteristics, different dispersities. Each substance will correspond to its own optimal value of the active surface. Therefore the best method for determining the optimal degree of fluffing will be the method based on the determination of the degree of adhesion (or adsorption) of the fibers with the particles of cement (or other binder) which are employed in the production together with the investigated fibers.

One of the methods for determining the degree of adhesion of the binder is filtration analysis. With its help there is established the degree of fluffing which assures the best adhesion of the binder, which may be regarded as the optimal. This, according to our experiments, corresponds to the minimal value of the coefficient of resistance to filtration of the investigated suspension.

The optimal fluffing assures the best quality of the production and the highest productivity of the machine.

4. Influence of adhesion characteristic of cement on quality of asbestos-cement

In 1952 (8) there was studied the influence of the mineralogical composition of the cement on the value of its adhesion to the asbestos fiber. For the investigation there were taken cements of 12 works of the Soviet Union. On account of the various mineralogical compositions of the cements (at employment of one and the same asbestos) the K_{phi} was varied between 170 and 760 $(cm/g)^{1.5}$.

The variation of the K_{phi} in these limits varies the thickness of the layer on the netting cylinder up to 40% at constancy of the other technological conditions.

The connections between the mineralogical composition of the cement, the degree of its adhesion to the fiber and the physicomechanical characteristics of the asbestos-cement comes out particularly clearly at the investigation of cements differing sharply in composition. There were investigated cements from clinkers produced by the Podolsk experimental works of the Science-research Institute for Cement, whose compositions are shown in Table 2, including a special cement with a very high content of C A (21.07%). The clinkers were ground with an addition of gypsum in the laboratory mill to the same specific surface. The mark of the investigated cements is 400.

The values of the K_{phi} as well as the values of the physicomechanical indices of the asbestos-cement are presented in Table 2. There was employed asbestos of one and the same composition: M-5-60 50%, P-6-30 50%. The asbestos in the mixture was 14.4%.

From Table 2 it can be seen that at the employment of cements of the same mark with nearly the same specific surfaces but with different mineralogical compositions the best strength of the sheet in both the freshly-formed and the hardened form can be obtained with a cement giving an asbestos-cement suspension with a small K_{phi}, that is, with a high adhesion characteristic.

The K_{phi} characterizes only the adhering ability of the cement and cannot be substituted, so that it has nothing to do with the mark and the value of the specific surface of cement, which also influence the physicomechanical characters of the asbestos-cement. It expresses only a supplementary, special requirement of the cement, connected with the particularities of the technology of asbestos-cement, which may be formulated as follows: at the same mark of cement the asbestos-cement with the better physicomechanical characteristics will be obtained at the employment of a cement of a composition which possesses the better adhering characteristic and assures the minimal value of the coefficient of resistance to filtration of the asbestos-cement suspension.

The value of the coefficient of resistance to filtration depends (9) on the value of the specific surface of the cement. Consequently, comparison of the adhering abilities of cement on the basis of the K_{phi} values is permissible only under the condition of constancy of their specific surfaces.

By what is the adhering ability of the cement determined, and how it is connected with the filtration of the asbestos-cement suspension? It has been suggested that the filtrability of asbestos-cement suspensions with cements of different compositions depends on the degree of peptization of the latter. It is thought that with increasing peptization there occurs an increase in the quantity of finely-disperse fraction in the suspension, an increase in the surface of the solid phase and a worsening of the filtrability of the suspension. In particular there is explained in this the poor filtrability of asbestos-cement suspensions with high-aluminate cement, which, as is known, is strongly peptized.

However, the following investigation showed this view of the role of the peptization requires refinement.

For this purpose there were measured the K_{phi} values of asbestos-cement and cement suspensions prepared with employment of various cements. The cement suspension was filtered, and the K_{phi} was determined. The K_{phi} values of the cement suspensions are presented in Table 2.

It is seen that the suspension (cement) of high-aluminate cement No. 3 filters very well, considerably better than, for example, the suspensions of cement No. 1 or No. 2.

However, the asbestos-cement suspension with this cement filters very poorly, and its K_{phi} is 8 times greater than the corresponding **values** for cements Nos. 1 and 2.

Consequently, what is here concerned is not the peptization of the cement particles but their adhering ability.

It must not be forgotten that in a cement suspension there preoceeds besides peptization also coagulation (10). The process of coagulation in a silute suspension of high-aluminate cement seems to proceed very vigorously. One of the reasons for this may be peptization of the particles of the aluminate cement proceeding the process of coagulation. The high coagulation of the particles may explain the low K_{phi} value found for cement No. 3 (compare 3). Therefore in the water suspensions of such cement we have to do with aggregated particles, whose circumfluent surface is smaller than their total surface. Such cement suspensions filter easily.

Table 2

Dependence of physicomechanical characteristics of asbestos-cements on value of adhesion of cements of various mineralogical compositions in asbestos-cement suspensions

(1) cement No.

(2) mineralogical composition

- (a) C_3S
- (b) C_2S
- (c) C_3A
- (d) C_4AF

(3) specific surface, sacm/g

(4) K_{phi} of asbestos-cement suspension, $(cm/g)^{1.5}$

(5) Tensile strength of crude sheet, kg/sqcm

(6) bending strength after 7 days of aging, kg/sqcm

(7) water-absorptivity, %

(8) volumetric weight

(9) K_{phi} of cement suspension, $(cm/g)^{1.5}$

1	2				3	4	5	6	7	8	9
	a	b	c	d							
1	56.59	15.79	3.13	22.65	3381	288	2.20	304	36.0	1.34	444
2	62.89	12.61	8.16	14.59	3265	236	2.25	380	29.2	1.47	179
3	48.64	20.64	21.07	8.14	3291	1755	2.02	19.15	58.0	1.03	51
4	ground sand...............				3600	423*	....	.....	....	....	1320**

*423 is the K_{phi} of the asbestos-sand suspension
**1320 is the K_{phi} of the sand suspension

If the cement particles of coagulated structure are extracted from the suspension by filtration, dried, and the specific surface is measured, there can be found the value of its increase (5) in comparison with the surface before aggregation, because at the drying the aggregates of the particles of a coagulated character disintegrate. Therefore the surface of the aggregated particles in the suspension, which has an influence on the velocity of filtration, will have nothing in common with the surface of the particles extracted from the water after they have been dried.

Until recently some special technological characteristics were attributed to cement. A few years ago it was believed that at complete substitution of the cement with ground sand a sheet could not be obtained in the sheet-forming machine because the suspension would stratify. However, filtration analysis of asbestos-sand suspension carried out by us in 1951 showed that ground sand adheres strongly to the surface of asbestos fibers, and asbestos-sand suspensions are fully technological.

Moreover, cements with a high content of tricalcium of aluminate possesses a much worse adhesion characteristic than ground sand (compare Table 2).

Further experiments on the production of sheets from asbestos-sand suspension on the semifactory machine confirmed this conclusion, which served as the technological basis for the proposal (together with T. M. Berkovinch) to produce shingles with a lime-sand binder.

More detailed data on the characteristics of asbestos-sand suspension will be found in the work (11).

In considering the question of the connection between the value of the adhesion of the binder and the strength of the asbestos-cement there must be taken into account the influence of the concentrated disposition of the clinker grains in the cement paste on the processes of its setting and hardening. V. N. Yung (12) thinks that the formation of flocculating aggregates from colloidal particles in the first minute is the most probable "where the clearance between the individual clinker grains is the smallest".

Further, Prof. V. N. Yung says that in the parts of the mixture where the surfaces of the clinker grains come close together there occurs a more concentrated accumulation of colloidal particles and at the same time they encounter the surrounding medium as well as the finest clinker grains.

The influence of the disposition of the clinker grains on the process of densification of the cement paste can serve satisfactorily to explain the found connection between the degree of adhesion and the strength of the asbestos-cement.

Summary

1. The value of the adhesion is an important factor determining the quality of the asbestos-cement.

2. The greatest ability to adhere to the cement is possessed by those segments of the split clusters of asbestos on which the cement particles come in contact with many fibers (multipointed contact).

On nonsplit clusters of asbestos, regardless of the diameter of the fibers, practically no adhesion of cement is observed.

3. At the setting of the cement the most dense and continuous film of the hydrate new-formation is obtained on the segment of the asbestos with the greater adhesion.

4. Variation of only the degree of adhesion of the cement to the asbestos at constant composition of the raw material and other technological conditions may lead to a considerable variation in the physicomechanical characteristics of the asbestos-cement sheet.

5. The fluffing of the asbestos should be carriedout only until a certain optimal value, which corresponds to the greatest adhesion of the cement to the asbestos fiber, and is determined according to the minimal value of the K_{phi} of the asbestos-cement suspension.

The operating regime of the fluffing apparatus is established with the help of filtration analysis.

6. The mineralogical composition of the cement has an influence on the degree of its adhesion to the asbestos fiber and on the filtration characteristic of the asbestos-cement suspension. By investigation it was established that this influence cannot be explained by an increase in the dispersity of the cement particles in the water suspension as a result of peptization.

7. The concentrated disposition of the clinker grains on the asbestos fiber as a result of the adhesion has great importance for the production of high-quality asbestos-cements. Therefore the ability to adhere, which depends on the physicochemical characteristics of both the binder and the fibrous component, must be taken into account as a fundamental qualitative index in the shingle industry.

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Footnotes

(a) This the hollander operating without the drum, with gaps of 3-5 mm, at which grinding and shortening of the fiber at protracted treatment is impossible.

(b) The method of filtration analysis is known (2), and need not be described here.

(Translated by Carl Demrick)