CEMENT ASBESTOS PRODUCTS COMPANY

WOODWARD, ALABAMA

PLAINTIFF'S EXHIBIT

CAP-231

MAKING ASBESTOS-CEMENT PIPE

Introduction

Asbestos-cement, as the product is called, is made from three principal ingredients: asbestos fibre, cement, and silica. Mixed in preset proportions, the ingredients are consolidated under pressure to form pipes having dense, uniform walls. After formation, the pipes are subjected to a steam-curing process that improves their stability and structural strength. The resulting product is a strong, corrosion-resistant pipe suitable for underground piping and industrial lines. For example, such pipes are used for water and sewer systems, irrigation, electrical conduit, ducts, vents, flues, and stacks.

In 1904 when asbestos-cement was introduced in the United States, it was in its simplest form, a plain gray slate, cured under natural room conditions, but it has since progressed from this simplicity.

Most people who use asbestos-cement products consider them as a masonry product, but the manufacturer of asbestos-cement knows that there are two major classifications of asbestos-cement products--normal cure and autoclaved or steam cure-- and two distinct manufacturing processes--the wet method and the dry process--which give definite characteristics and determine where the asbestos-cement products are used. The method used by Capco is the wet method for pipe forming and then autoclaving or steam curing.

Composition and Basic Materials

In normal curing the product, as it comes from the manufacturing machine, is allowed to air cure at atmospheric pressure or in a moist chamber. There are those who have the mistaken idea that the cement has to dry in order to cure. The opposite is true, not only for asbestos-cement but also for all products made with hydraulic Portland cement. It is necessary at all times to keep masonry products moist to hydrate the cement for at least 28 days, a period at which the composition has approximately 90 per cent of its theoretical strength. In work done at the Portland Cement Association it goes even further and states that in atmospheres of under 50 per cent relative humidity cement fails to hydrate.

In normal cure manufacture asbestos-cement pipes leave the machine with a water content of 20 to 25 per cent, thus insuring adequate water for hydration.

In concrete work subjected mainly to compression, only about 15 per cent cement is required, but with normal cure asbestos-cement as much as 75 per cent cement is used for the strength that is required for these relatively thin members.

For an autoclave product the formula is similar to a normal cure product except that silica, 200 mesh, replaces part of the Portland cement in a silica/cement ratio of .6; or, the silica is 40 per cent of the total weight of the cement and silica.

The other difference of an autoclave mix is the cure; an autoclave mix must be autoclaved at high steam pressures. After forming, the autoclave product is precured first in moist heat oven for one to one and a half hours, next air cured for four to eight hours, and then steamed in an autoclave at 100 - 150 p.s.i., about 350 degrees Fahrenheit for eight to sixteen hours, depending on the pressure in the autoclave and also on the pipe being manufactured. Usually thicker pipes require longer steaming.

The quantity of asbestos in the mix has a bearing on the strength of the product. Each pipe size and service may require a different percentage of fibre, determined from experience and the strength necessary for a satisfactory performance.

For many years it was thought that long-length fibre was necessary for good strength and that the longer the length the better the product. For pipe this is partially true, but openness, degree of fiberization, and freedom from grit are more important than just length alone.

The strong asbestos fibres behave similarly to the steel bars used in reinforcing concrete.

The fibres used involve Groups 4, 5, and 6 of the Canadian classification. These grades of chrysotile asbestos are generally classified as medium length fibre; they are used extensively in the manufacture of asbestos-cement pipes.

One basic requirement for the asbestos is that it must be fully fiberized prior to mixing it with cement in order to obtain the best properties in the final product. It is also important to remove or minimize such impurities as dust and grit.

The mixing of the asbestos and cement slurry is highly important in the wet mechanical process, because the slurry must be distributed to form a thin film across the entire width of the machine. The open fibres from Kollergang are combined with the cement and mixed with water in a turbopulper fitted with rotors in order to open remaining clusters of fibres. The relatively heavy paste mixture in the turbopulper is delivered to a stirring

vat where it is pumped into overhead containers for delivery to pipe machine or recirculated to this mixer. It is important that agitation be constant and effective in order to prevent separation and settling of the solids in the slurry.

The slurry flows to cylinder vats of pipe machine which are fitted with paddle agitators to prevent settling of the stock. There are two of these vats on the machine. Each vat contains a horizontal cylinder covered with a fine wire mesh screen and fitted with seals at its ends so that flow can occur out of the vat and only through the wire, thus leaving a thin, even film of stock deposited on its surface while removing the major part of the water. The thickness of the film depends on the slurry level in the vat, its consistency, and the speed of rotation of the cylinder. The machine is usually operated so that the film deposited is approximately .002 to .010 inches thick.

The continuous woven felt travels above these cylinders with its hairy side toward them; it is kept in firm uniform contact with them by heavy rubber-covered rolls. At the contact surface, the film of stock is transferred to the felt and some water is removed. Each cylinder adds its film thickness to the web of stock on the felt. Additional water is drawn from the web by means of a vacuum box placed under the felt as it travels toward the cast iron or steel mandrel. There is a vacuum box between the vats to seat the stock web firmly on the felt.

As the web of stock passes under the mandrel, it is transferred to the mandrel in a continuous operation until the pipe is built up to the desired thickness.

The water removed during this operation is returned to the mixing area of the machine. This water contains a small quantity of asbestos and cement from the stock that has passed through the screens and the felts. It is first retained for a period of time in settling tanks to clarify it. In addition the water very rapidly becomes saturated with soluble materials from the Portland cement. This latter operation is generally beneficial because it eliminates further leaching of lime from the cement as the process continues. The solids separated from the water in the settling tanks are returned to the mixing chambers separately from the clarified water.

When the felt is returned toward the vats, it is cleaned by means of shower sprays and vacuum to remove any adhering stock particles. It is subjected to considerable strain and wear; usually it has an effective life of only six to twelve days. Similarly, it is necessary to prevent the cylinder screens from clogging. They are cleaned continuously during operation with a shower spray immediately after the film of stock has been released and before it is dipped into the vat for a new film.

The process needs to be controlled closely. Attention to cleanliness is important; otherwise, there may be clogging of the cylinder screens and the felt, and an inferior product may result.

CAPCO KIN 0000499

The experimental manufacture of asbestos-cement pressure pipes was started in Italy in 1913. Progress was rapid, and by 1921 asbestos-cement pipes had been accepted in Europe. At that time the British Ministry of Health approved the use of the pipe for watermains. They provided for loans for these pipes with a repayment period of thirty years; this period represented the same period allowed for cast iron pipes.

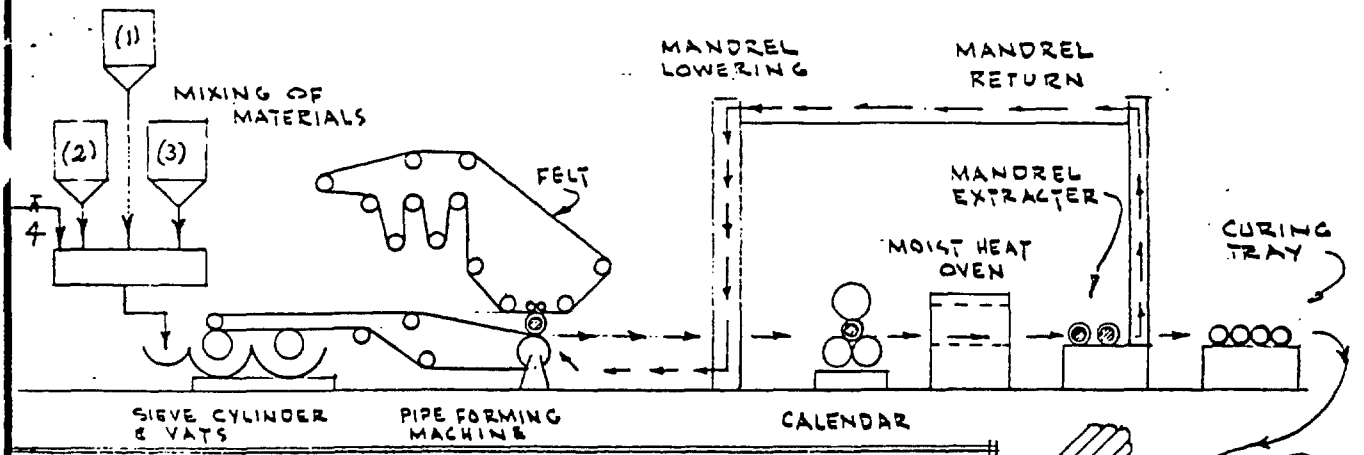
This type of pipe gradually superseded both metal and ceramic piping in a large number of applications because of the fact that they are resistant to corrosion, impervious to and free from electrolytic action when buried in the earth, light-weight, elastic, strong, resistant to compression, economical to install, and unaffected by temperature changes.

Tests have been conducted on pipes after thirty years in service with the conclusion that they had retained their original properties. These pipes have a smooth, glossy, cylindrical internal surface, and offer very low hydraulic frictional resistance to the flow of liquids. The Italit Mazza asbestos-cement pipes manufactured by Eternit, Genoa, Italy, are still in operation throughout the world. Their experimental data shows that the carrying capacity of pipe is on an average of 25 per cent greater than that of new cast iron pipes and 30 to 60 per cent greater than that of old cast iron pipes, all being of the same internal diameter.

Asbestos-cement pressure pipes are manufactured on costly and complex machines which are automatically operated by means of hydraulic and electrical controls. The pipes are built up of a continuous, uniformly thin and highly compressed film of asbestos-cement.

The Mazza process is the most important commercial process used in the manufacture of pipes. The diameter of mandrels varies from three to fifty inches. Because of their weight, the larger diameter mandrels are more difficult to handle. These large mandrels are usually mounted in pairs, one attached to each side of the machine. The machine permits wrapping on one mandrel as the previously wrapped pipe is withdrawn from the other mandrel.

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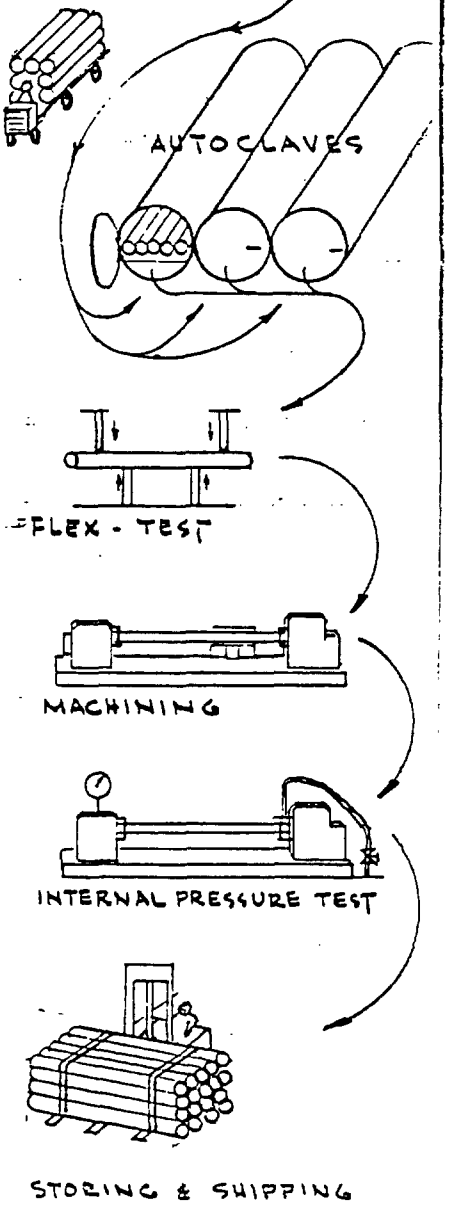


(1) Asbestos Fibers
(2) Cement
(3) Silica flour
(4) Water

Flow diagram illustrates major equipment items used in forming asbestos-cement pipes. A mixture of asbestos fibers, cement, silica, and water is formed on metal mandrels in pipe forming machine. After calendering to loosen pipe from mandrel, pipe and mandrel then move through an oven for precuring, then to a mandrel extractor. From the extractor, mandrels are returned by conveyor to the pipe forming machine, and pipe are stacked in curing trays.

The pipe stacked in curing trays are moved to auto-clave area and allowed to air dry for several hours. The pipe on curing trays are then placed in auto-claves which are high pressure steam curing vessels.

After curing in the auto-claves the pipe are first subjected to a bending or flexural test, then machined on each end, then tested with internal water pressure and finally packaged for storing and shipping.



CEMENT ASBESTOS PRODUCTS CO. RAGLAND, ALABAMA	DIAGRAMATIC OF PIPE MANUFACTURE.			
DRAWN: TC	APPROVED:	SCALE: —	DATE: 4-13-65	DWG. NO. A- 9

CAPCO KIN 0000501

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Cement Asbestos Pipe Company

Asbestos Cement Pipe Manufacture

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SUMMARY

Cement, silica flour, and asbestos fiber are batched by weight and mixed in water to form a slurry. This slurry is pumped into the two vats of the pipe machine, where two cylinders covered with a fine mesh screen are mounted. Because the cylinder ends are sealed, the water pressure forces the slurry through the immersed screen, thereby depositing asbestos fibers - which in turn trap a cake of cement and silica flour. In a way closely analogous to pouring slurry into a bucket having only a wire screen for a bottom, the thickness of the film on the wire will vary with the pressure head, the consistency and viscosity of the slurry, time, the compressibility of the cake, and the number of fibers available to close the openings in the screen.

Over the top of the cylinders passes a cloth belt made of a woven felted material containing wool and nylon. The felt is held tightly against the cylinder by weighted rolls so that the felt drives the cylinders as it moves. Because of water's surface tension the wet film is picked up by the smoother felt from the rough wire. After the felt picks up both stock films

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to form a sheet, it passes over a suction box which partially dewaters the sheet prior to roll-up.

The sheet is rolled up to the required pipe wall thickness on a metal pipe or mandrel in a press which consists of a large roll underneath and a pair of smaller, hydraulically loaded rolls above the mandrel. Between the mandrel and the upper press rolls is a second felt which prevents transfer of the sheet to the top rolls and which has voids in the weave for acceptance of water pressed from the pipe wall.

After roll-up is completed, the felts are stopped, the upper press rolls are raised and the old mandrel is replaced by a new, bare mandrel for the next roll-up cycle.

The newly formed pipe is then loosened from the mandrel, or calendered, by blowing compressed air under the pipe wall next to the mandrel and rolling to complete the loosening.

Next the mandrel with pipe is conveyed through a heated tunnel where a combination of curing and drying hardens the pipe enough to permit stripping without damage. After stripping, the pipe are loaded by vacuum cups into a metal tray.

In these trays the pipe are stored in a warm room where overhead spray showers return moisture lost in the pre-cure

tunnel. From the wet room the trays are transferred to autoclaves for final curing. At approximately 350°F the high pressure steam brings about an accelerated cure of the cement and causes unstable products of hydrated cement to combine with the free silica to form a strong bond around the reinforcing strands of asbestos.

I Mixing Plant

A. Raw Materials
1. Cement
a. Properties
(1) Set time: The cement should be designed to set as rapidly as possible after roll-up in order to minimize mandrel inventory and wet-end handling damage. If the cement sets before roll-up, water retention increases, build-up occurs in the wet portion of the operation, and strength is lost.

(2) Strength: The ultimate strength of the cement is affected by the chemical composition, the fineness of grind, and the water retention.

(3) Fineness of grind: While a finer grind improves early strength in concrete, the increase in water retention in the pipe wall associated with a fine grind may result in an overall weakening of the pipe.

(4) Importance of uniformity: In order to produce pipe of consistent quality, it is mandatory that the cement properties remain constant. For a uniform cement, other manufacturing variables may be adjusted to give optimum results.

2. Silica flour
(a) Chemical requirements: The silica should be in a pure crystalline form.

(b) Physical properties: Chemical reactivity in-

creases with fineness, but at the expense of higher water retention.

3. Asbestos Fiber

(a) Chrysotile or white fiber: In general as fiber grade or length increases - strength increases, filtering time decreases, water retention is relatively constant, and bulk increases. As a particular grade is opened to a higher surface area - strength increases moderately, filtering time decreases but with more water retained, and bulk increases moderately.

(b) Crocidolite or blue fiber: For a given grade of blue fiber, additional opening results in - considerably increased strength, reduced filtering time, considerably increased water retention, and a rapid increase in bulk.

4. Reclaimed scrap pipe

(a) Method of preparation: After primary crushing the scrap is fed to a closed circuit consisting of a hammermill and screen. Above the screen an air suction duct lifts the fine reclaim product while the oversize is returned to the hammermill.

(b) Benefits: The reclaim reduces material costs and improves filtration by rendering the stock less compressable.

(c) Limitations: The reduced compressability of the

stock results in lower pipe density.

B. Fiber Preparation

1. Kollergang

The Kollergang, which is an edge-runner, opens the crude bundles of fiber and mixes the blue and white fibers. A small amount of water is added to aid in opening the blue and to reduce dust.

2. Turbopulper

The turbopulper has a horizontal shaft turning a pair of vertical discs having radial slots which open into curved scoops. When water and fiber are violently agitated in the pulpers, final mixing and opening is achieved. Fiber opening is a function of time and slurry viscosity.

C. Batch weights

Fiber and reclaim are weighed in a hopper on beam scales controlled by electric eye scanners at the scale head. At present, the cement and silica are weighed on belt scales but beam scales will replace them when delivered.

D. Mixing

The turbopulper serves to mix the entire batch into a slurry as well as to open the fiber.

E. Process water

Process water variables which influence pipe manufacturing are temperature, which influences cement set time

and filtering - and disolved minerals, which alter cement reactions. Process water is recirculated in a closed system in order to conserve water and to maintain stable water properties. To prevent too fast a set of the cement when starting up with fresh water, hydrated lime is added to raise process water alkalinity.

F. Stock feed to the machine
After each batch is mixed a pump transfers it to a holding chest containing a ribbon agitator. A small stock pump constantly pumps stock from the holding chest to a small stock chest. When a tapered plug in the small stock pump is raised, the stock flows to the machine; when lowered, the stock overflows back into the holding chest.

In the piping to the machine, a tee mixes process water with the stock to dilute the slurry. This thinned slurry discharges into a mixing cone and overflows into three troughs to the vats.

II Pipe Machine Operation

A. Vats and molds
In the bottom of both vats are two flat-bladed agitators which maintain the solids in suspension and aid in aligning fiber circumferentially around the molds - thereby giving the

hoop strength needed in pressure pipe. The paddles must turn fast enough to provide a uniform slurry consistency but not so fast that the film is swept from the mold wire.

The mold is covered first with a spirally wound wire, next a ten mesh stainless wire cloth and finally a 30 or 40 mesh stainless face wire. The wire weave is normally "wrong way" which means the crimped wires run axially across the face. The 30 mesh screen provides a more rugged cover than the 40 mesh and the larger openings do not seem to affect strength adversely.

Variables which affect the thickness of the film on the cylinder wire are as follows: (1) The thickness of the film increases as the proportion of asbestos increases - first because without the asbestos the cement and silica would pour through the wire and second because the asbestos reduces the compressibility of the film, thereby leaving voids for the passage of more water.

(2) The thickness increases for an increase in slurry temperature, since slurry viscosity drops rapidly as the temperature rises.

(3) The thickness decreases as the consistency or

viscosity of the slurry increases. For a given blend the consistency increases as the concentration of solids increases. For a given blend and concentration, the consistency increases as the asbestos surface area increases.

(4) The thickness of the film increases with time, but at a decreasing rate. There are two times to consider: First, the time that a given part of the screen is under the slurry while the machine is running - an inverse function of felt speed; second, the time that the machine is stopped, a direct function of mandrel change time.

Although the formation of the film on the mold gives the appearance of being elementary, the precentage, types, and degree of opening of the asbestos fibers charged into the vats is vital to the machine operation. The production rate of the machine may be determined by the rate of film pickup on the molds, but a high production rate is costly unless the fiber strength and opening is balanced with cement and silica properties to produce a sheet which the pipe machine felts, vacuums, and press can sucessfully convert into a sound pipe wall.

In general, as asbestos fiber is progressively opened,

the strength increases, the filterability decreases, the bulk increases (thereby decreasing density), and the water retention increases. As compared to white fiber, the blue asbestos exhibits a more rapid increase in strength but also a much higher water retention increase.

As an aid to the agitators in maintaining uniform vats, an overflow system is in use. The flow over a weir toward the front of the machine flows down a trough to a pump which returns it to the mixing cone at the rear of the machine. A high volume overflow may also aid in aligning fiber for greater hoop strength. Because of the mixing which takes place with the overflow in the cone, water may be allowed to flow into the machine during mandrel changes to replace the water lost from the vats through the molds.

For some random alignment of fibers to increase flexual strength, a rake having long blades immersed in the slurry next to one of the molds is slowly oscillated. There is some question about the rake's effectiveness, but if it does promote flexual strength it should not be used for hydro pipe i.e., 10" or larger pipe, which requires no flexual strength test.

The film width is controlled by applying an adhesive

or other coating to fill the face wire openings outside the desired film width - these coated areas are known as deckles and are 13'-2" apart.

B. Bottom felt and vacuum de-watering boxes
After the bottom felt passes over the first cylinder mold it passes under a vacuum slit box which pulls the stock into the felt and partially dewaters both the felt and the sheet before the second mold. After the second film is picked up, the two-layered sheet is carried back toward the front of the machine with the sheet still on the outside but now on the top instead of the bottom of the felt loop. Sheet and felt are again dewatered while passing over a larger vacuum box pulling from 10 to 16 inches of mercury. The flow of air varies as the square root of the pressure difference across the felt - so that increasing the vacuum 50% only changes the air flow by 22% with other conditions constant.

The moisture remaining in the sheet will vary as follows: The moisture decreases as fiber content increases, as temperature increases, and as the sheet thickness decreases; the moisture increases as a given content of fiber is opened, as cement and silica fineness increase, and as water contact time with the stock increases.

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Also, affecting moisture release are the dust content of the fibers, the degree of hydration of the cement, and the design and cleanliness of the felt. There is a limit to what can be accomplished with higher vacuums because as the vacuum increases the accompanying increase in felt tension tends to reduce the felt weave openings.

C. The Press

The roll-up of the sheet on a mandrel is probably the most critical operation in pipe making - for at this point the thin, tender sheet must be compacted into a dense, thick mass to form the pipe wall. High densities and strength require low moisture content after roll-up, and it is the press which must reduce the moisture to an acceptable level. While increasing the press roll loading will squeeze out more water, pressures cannot be increased beyond a point which causes the pipe wall to shift or tear. Once shifting or tearing occurs, the bond between the plies or between fiber and cement is permanently weakened.

The factors limiting pressures are water content of the sheet, sheet thickness, drainage capacity of the felts, the lubricity or slipperiness of the stock, and the uniformity of

pressure across the mandrel.

For a given pressure curve the moisture in the pipe wall will vary as follows: Moisture will decrease as temperature increases, as water contact time decreases, and as sheet thickness decreases; moisture will increase with more opened fibers, with finer grind cement and silica and with faster setting cement.

Blue fiber as compared to white permits the use of higher pressure but retains more water and reduces density.

D. Bottom felt cleaning devices

After leaving the bottom press roll, an inside, high volume shower floods the felt immediately before an inside worm roll. The left and right hand helixes on this roll knead and stretch the width of the felt and at the same time force shower water through the weave to flush out the imbedded stock. Next a face shower is directed 45° into the felt travel direction to wash the loosened stock away. The final shower is inside the felt at a right angle and again drives solids to the lower face. Next a whipper turning against the felt travel strikes the felt with a series of sharp raps to jar away remaining solids - much like the action of a rug beater.

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Finally, before reaching the first mold, the felt passes over a fan suction box which pulls out the soiled washing water.

E. Top Felt

The top felt transmits and cushions the press roll forces to the pipe wall. Since the press forces are spread over more pipe area than on the bottom felt, and since the sheet carrying job is reserved to the bottom felt - the physical wear and filling is far less a problem on the top felt. Consequently, cleaning on the top felt is limited to three worm rolls, a single intermittent spray shower, and a single slit vacuum box.

The DC drive speed control permits the operator to set the top felt speed at a ratio greater than one to the bottom felt - this is termed overdrive. By using a slight amount of overdrive the top felt drive carries an increased share of the press power load and is thought to assist in rolling up a tighter pipe.

F. The press hydraulic system

At the present time, the two press rolls are moved up and down by hydraulic cylinders connected to the press roll bearing housings and guided by a pair of four parallelogram

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linkages connected with two torque tubes. In order to compensate for deflection in the center of the rolls, a pair of dolly rolls transmits force from two other cylinders. When a bare mandrel is loaded in the press, a closed center hydraulic valve shifts to move the outboard and dolly roll cylinders down against the press rolls to load the mandrel at a preset pressure. When the proper pressure is reached, the fill valve centers and the pipe machine is started.

During roll-up the hydraulic circuit is isolated from any oil source. The pressure curve is controlled by a cam operated relief valve - which drains excess oil to sump as the cylinder pistons are pushed up by the increasing wall thickness.

Physically the press should impart smooth, uniform, and reproducible pressures across the pipe wall and should permit a rapid mandrel change.

By keeping mandrel change times low the excess build-up of stock on the molds during machine pauses will be minimized. This heavier mold pickup is termed a slug and may be positioned in the pipe wall by varying layer thickness and felt speed.

G. The Calender

At the calendering station, an air lance is inserted

between mandrel and pipe wall to open a gap across the pipe. By subsequent rolling the pipe is loosened around its circumference. Although a pressure roll is sometimes used on small pipe, over-opening may result.

If the mandrel is too smooth, the compressed air cannot easily penetrate across the pipe. Accordingly, the mandrels are periodically sand or shot blasted to leave a textured surface.

Every effort should be made to prevent over-opening, since an increase in pipe diameter weakens the bonds between fiber and cement. Resistance to over-opening increases with lower moisture content and with higher fiber level. The tendency to over-open increases as pipe diameter and wall thickness increase.

III Pipe Curing

A. Pre-cure Oven

The purpose of the pre-cure oven is to harden the pipe enough to permit stripping the mandrel as quickly as possible for return to the pipe machine - thereby reducing mandrel inventory. The hardening can result from cure of the cement or from drying the pipe. Ideally, all the hardening should be derived from curing rather than drying, but in practice

drying predominates.

When a pipe is rolled up in the press, some air is trapped in its wall, primarily between layers. As the pipe is rapidly heated, this blocked air expands more than the solid phase and causes the pipe to swell. As compaction or density decreases, the swelling increases rapidly and can greatly weaken the pipe.

Wetting the newly rolled up pipe will also result in destructive swelling, but as the pipe is allowed longer curing times before wetting the damage decreases. In fact, after enough strength is obtained to prevent swelling, an increase in strength will result because of the additional water available for hydration.

B. Wet Room

Pipe is placed in the wet room after pre-cure in order to replace moisture lost through drying in the oven. This room is heated and sprinkled by overhead showers, which provides uniform cement hydration regardless of outside temperature and humidity. Regulating the minimum hold time in the wet room assures that pipe will be strong enough to withstand rapid autoclave heating.

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C. Autoclaving

There are two important advantages to an autoclave cure as compared to a normal cure. First, greater strength is reached by autoclaving for a day than by normal curing for a month. This greatly reduces in-process inventory and allows flexibility in scheduling production to meet shipments.

Secondly, autoclaving imparts improved resistance to chemical attack in the ground by sulfate salts, aggressive Co_2, soft waters, and acid. At the high pressure and temperature in the autoclave, calcium hydroxide - a vulnerable hydration product of cement - combines chemically with silica flour to form a stable calcium silicate hydrate called tobermorite.

Properties which are not improved by autoclaving are permeability, brittleness, and stiffness. These undersirable tendencies may be minimized by holding curing temperature at approximately 350°F, by an adequate pre-cure, and by avoiding too rapid an increase or decrease of pressure.

The reactivity of silica increases rapidly as the particle size decreases and the strength falls sharply for particles coarser than 200 mesh (74 microns). For this

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reason silica flour should be 98% passing 200 mesh - which would be equivalent to a 3500-4000 Blaine.

Scientific studies indicate that the maximum strength will be obtained with a 70:30 or 65:35 ratio of cement to silica flour but a slightly higher proportion of silica may be used to reduce uncombined calcium hydroxide or to compensate for too low a water to cement ratio in the pipe wall.

Cement Asbestos Pipe Company

Asbestos Cement Pipe Manufacture

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SUMMARY

Cement, silica flour, and asbestos fiber are batched by weight and mixed in water to form a slurry. This slurry is pumped into the two vats of the pipe machine, where two cylinders covered with a fine mesh screen are mounted. Because the cylinder ends are sealed, the water pressure forces the slurry through the immersed screen, thereby depositing asbestos fibers - which in turn trap a cake of cement and silica flour. In a way closely analogous to pouring slurry into a bucket having only a wire screen for a bottom, the thickness of the film on the wire will vary with the pressure head, the consistency and viscosity of the slurry, time, the compressibility of the cake, and the number of fibers available to close the openings in the screen.

Over the top of the cylinders passes a cloth belt made of a woven felted material containing wool and nylon. The felt is held tightly against the cylinder by weighted rolls so that the felt drives the cylinders as it moves. Because of water's surface tension the wet film is picked up by the smoother felt from the rough wire. After the felt picks up both stock films

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to form a sheet, it passes over a suction box which partially dewaters the sheet prior to roll-up.

The sheet is rolled up to the required pipe wall thickness on a metal pipe or mandrel in a press which consists of a large roll underneath and a pair of smaller, hydraulically loaded rolls above the mandrel. Between the mandrel and the upper press rolls is a second felt which prevents transfer of the sheet to the top rolls and which has voids in the weave for acceptance of water pressed from the pipe wall.

After roll-up is completed, the felts are stopped, the upper press rolls are raised and the old mandrel is replaced by a new, bare mandrel for the next roll-up cycle.

The newly formed pipe is then loosened from the mandrel, or calendered, by blowing compressed air under the pipe wall next to the mandrel and rolling to complete the loosening.

Next the mandrel with pipe is conveyed through a heated tunnel where a combination of curing and drying hardens the pipe enough to permit stripping without damage. After stripping, the pipe are loaded by vacuum cups into a metal tray.

In these trays the pipe are stored in a warm room where overhead spray showers return moisture lost in the pre-cure

tunnel. From the wet room the trays are transferred to autoclaves for final curing. At approximately 350°F the high pressure steam brings about an accelerated cure of the cement and causes unstable products of hydrated cement to combine with the free silica to form a strong bond around the reinforcing strands of asbestos.

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I Mixing Plant

A. Raw Materials
1. Cement
a. Properties
(1) Set time: The cement should be designed to set as rapidly as possible after roll-up in order to minimize mandrel inventory and wet-end handling damage. If the cement sets before roll-up, water retention increases, build-up occurs in the wet portion of the operation, and strength is lost.

(2) Strength: The ultimate strength of the cement is affected by the chemical composition, the fineness of grind, and the water retention.

(3) Fineness of grind: While a finer grind improves early strength in concrete, the increase in water retention in the pipe wall associated with a fine grind may result in an overall weakening of the pipe.

(4) Importance of uniformity: In order to produce pipe of consistent quality, it is mandatory that the cement properties remain constant. For a uniform cement, other manufacturing variables may be adjusted to give optimum results.

2. Silica flour
(a) Chemical requirements: The silica should be in a pure crystalline form.

(b) Physical properties: Chemical reactivity in-

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creases with fineness, but at the expense of higher water retention.

3. Asbestos Fiber

(a) Chrysotile or white fiber: In general as fiber grade or length increases - strength increases, filtering time decreases, water retention is relatively constant, and bulk increases. As a particular grade is opened to a higher surface area - strength increases moderately, filtering time decreases but with more water retained, and bulk increases moderately.

(b) Crocidolite or blue fiber: For a given grade of blue fiber, additional opening results in - considerably increased strength, reduced filtering time, considerably increased water retention, and a rapid increase in bulk.

4. Reclaimed scrap pipe

(a) Method of preparation: After primary crushing the scrap is fed to a closed circuit consisting of a hammermill and screen. Above the screen an air suction duct lifts the fine reclaim product while the oversize is returned to the hammermill.

(b) Benefits: The reclaim reduces material costs and improves filtration by rendering the stock less compressable.

(c) Limitations: The reduced compressability of the

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stock results in lower pipe density.

B. Fiber Preparation

1. Kollergang

The Kollergang, which is an edge-runner, opens the crude bundles of fiber and mixes the blue and white fibers. A small amount of water is added to aid in opening the blue and to reduce dust.

2. Turbopulper

The turbopulper has a horizontal shaft turning a pair of vertical discs having radial slots which open into curved scoops. When water and fiber are violently agitated in the pulpers, final mixing and opening is achieved. Fiber opening is a function of time and slurry viscosity.

C. Batch weights

Fiber and reclaim are weighed in a hopper on beam scales controlled by electric eye scanners at the scale head. At present, the cement and silica are weighed on belt scales but beam scales will replace them when delivered.

D. Mixing

The turbopulper serves to mix the entire batch into a slurry as well as to open the fiber.

E. Process water

Process water variables which influence pipe manufacturing are temperature, which influences cement set time

and filtering - and disolved minerals, which alter cement reactions. Process water is recirculated in a closed system in order to conserve water and to maintain stable water properties. To prevent too fast a set of the cement when starting up with fresh water, hydrated lime is added to raise process water alkalinity.

F. Stock feed to the machine
After each batch is mixed a pump transfers it to a holding chest containing a ribbon agitator. A small stock pump constantly pumps stock from the holding chest to a small stock chest. When a tapered plug in the small stock pump is raised, the stock flows to the machine; when lowered, the stock overflows back into the holding chest.

In the piping to the machine, a tee mixes process water with the stock to dilute the slurry. This thinned slurry discharges into a mixing cone and overflows into three troughs to the vats.

II Pipe Machine Operation

A. Vats and molds
In the bottom of both vats are two flat-bladed agitators which maintain the solids in suspension and aid in aligning fiber circumferentially around the molds - thereby giving the

hoop strength needed in pressure pipe. The paddles must turn fast enough to provide a uniform slurry consistency but not so fast that the film is swept from the mold wire.

The mold is covered first with a spirally wound wire, next a ten mesh stainless wire cloth and finally a 30 or 40 mesh stainless face wire. The wire weave is normally "wrong way" which means the crimped wires run axially across the face. The 30 mesh screen provides a more rugged cover than the 40 mesh and the larger openings do not seem to affect strength adversely.

Variables which affect the thickness of the film on the cylinder wire are as follows: (1) The thickness of the film increases as the proportion of asbestos increases - first because without the asbestos the cement and silica would pour through the wire and second because the asbestos reduces the compressibility of the film, thereby leaving voids for the passage of more water.

(2) The thickness increases for an increase in slurry temperature, since slurry viscosity drops rapidly as the temperature rises.

(3) The thickness decreases as the consistency or

viscosity of the slurry increases. For a given blend the consistency increases as the concentration of solids increases. For a given blend and concentration, the consistency increases as the asbestos surface area increases.

(4) The thickness of the film increases with time, but at a decreasing rate. There are two times to consider: First, the time that a given part of the screen is under the slurry while the machine is running - an inverse function of felt speed; second, the time that the machine is stopped, a direct function of mandrel change time.

Although the formation of the film on the mold gives the appearance of being elementary, the precentage, types, and degree of opening of the asbestos fibers charged into the vats is vital to the machine operation. The production rate of the machine may be determined by the rate of film pickup on the molds, but a high production rate is costly unless the fiber strength and opening is balanced with cement and silica properties to produce a sheet which the pipe machine felts, vacuums, and press can sucessfully convert into a sound pipe wall.

In general, as asbestos fiber is progressively opened,

the strength increases, the filterability decreases, the bulk increases (thereby decreasing density), and the water retention increases. As compared to white fiber, the blue asbestos exhibits a more rapid increase in strength but also a much higher water retention increase.

As an aid to the agitators in maintaining uniform vats, an overflow system is in use. The flow over a weir toward the front of the machine flows down a trough to a pump which returns it to the mixing cone at the rear of the machine. A high volume overflow may also aid in aligning fiber for greater hoop strength. Because of the mixing which takes place with the overflow in the cone, water may be allowed to flow into the machine during mandrel changes to replace the water lost from the vats through the molds.

For some random alignment of fibers to increase flexual strength, a rake having long blades immersed in the slurry next to one of the molds is slowly oscillated. There is some question about the rake's effectiveness, but if it does promote flexual strength it should not be used for hydro pipe i.e., 10" or larger pipe, which requires no flexual strength test.

The film width is controlled by applying an adhesive

or other coating to fill the face wire openings outside the desired film width - these coated areas are known as deckles and are 13'-2" apart.

B. Bottom felt and vacuum de-watering boxes
After the bottom felt passes over the first cylinder mold it passes under a vacuum slit box which pulls the stock into the felt and partially dewaters both the felt and the sheet before the second mold. After the second film is picked up, the two-layered sheet is carried back toward the front of the machine with the sheet still on the outside but now on the top, instead of the bottom of the felt loop. Sheet and felt are again dewatered while passing over a larger vacuum box pulling from 10 to 16 inches of mercury. The flow of air varies as the square root of the pressure difference across the felt - so that increasing the vacuum 50% only changes the air flow by 22% with other conditions constant.

The moisture remaining in the sheet will vary as follows: The moisture decreases as fiber content increases, as temperature increases, and as the sheet thickness decreases; the moisture increases as a given content of fiber is opened, as cement and silica fineness increase, and as water contact time with the stock increases.

Also, affecting moisture release are the dust content of the fibers, the degree of hydration of the cement, and the design and cleanliness of the felt. There is a limit to what can be accomplished with higher vacuums because as the vacuum increases the accompanying increase in felt tension tends to reduce the felt weave openings.

C. The Press

The roll-up of the sheet on a mandrel is probably the most critical operation in pipe making - for at this point the thin, tender sheet must be compacted into a dense, thick mass to form the pipe wall. High densities and strength require low moisture content after roll-up, and it is the press which must reduce the moisture to an acceptable level. While increasing the press roll loading will squeeze out more water, pressures cannot be increased beyond a point which causes the pipe wall to shift or tear. Once shifting or tearing occurs, the bond between the plies or between fiber and cement is permanently weakened.

The factors limiting pressures are water content of the sheet, sheet thickness, drainage capacity of the felts, the lubricity or slipperiness of the stock, and the uniformity of

pressure across the mandrel.

For a given pressure curve the moisture in the pipe wall will vary as follows: Moisture will decrease as temperature increases, as water contact time decreases, and as sheet thickness decreases; moisture will increase with more opened fibers, with finer grind cement and silica and with faster setting cement.

Blue fiber as compared to white permits the use of higher pressure but retains more water and reduces density.

D. Bottom felt cleaning devices

After leaving the bottom press roll, an inside, high volume shower floods the felt immediately before an inside worm roll. The left and right hand helixes on this roll knead and stretch the width of the felt and at the same time force shower water through the weave to flush out the imbedded stock. Next a face shower is directed 45° into the felt travel direction to wash the loosened stock away. The final shower is inside the felt at a right angle and again drives solids to the lower face. Next a whipper turning against the felt travel strikes the felt with a series of sharp raps to jar away remaining solids - much like the action of a rug beater.

Finally, before reaching the first mold, the felt passes over a fan suction box which pulls out the soiled washing water.

E. Top Felt

The top felt transmits and cushions the press roll forces to the pipe wall. Since the press forces are spread over more pipe area than on the bottom felt, and since the sheet carrying job is reserved to the bottom felt - the physical wear and filling is far less a problem on the top felt. Consequently, cleaning on the top felt is limited to three worm rolls, a single intermittent spray shower, and a single slit vacuum box.

The DC drive speed control permits the operator to set the top felt speed at a ratio greater than one to the bottom felt - this is termed overdrive. By using a slight amount of overdrive the top felt drive carries an increased share of the press power load and is thought to assist in rolling up a tighter pipe.

F. The press hydraulic system

At the present time, the two press rolls are moved up and down by hydraulic cylinders connected to the press roll bearing housings and guided by a pair of four parallelogram

linkages connected with two torque tubes. In order to compensate for deflection in the center of the rolls, a pair of dolly rolls transmits force from two other cylinders. When a bare mandrel is loaded in the press, a closed center hydraulic valve shifts to move the outboard and dolly roll cylinders down against the press rolls to load the mandrel at a preset pressure. When the proper pressure is reached, the fill valve centers and the pipe machine is started.

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G. The Calender

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between mandrel and pipe wall to open a gap across the pipe. By subsequent rolling the pipe is loosened around its circumference. Although a pressure roll is sometimes used on small pipe, over-opening may result.

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Every effort should be made to prevent over-opening, since an increase in pipe diameter weakens the bonds between fiber and cement. Resistance to over-opening increases with lower moisture content and with higher fiber level. The tendency to over-open increases as pipe diameter and wall thickness increase.

III Pipe Curing

A. Pre-cure Oven

The purpose of the pre-cure oven is to harden the pipe enough to permit stripping the mandrel as quickly as possible for return to the pipe machine - thereby reducing mandrel inventory. The hardening can result from cure of the cement or from drying the pipe. Ideally, all the hardening should be derived from curing rather than drying, but in practice

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Wetting the newly rolled up pipe will also result in destructive swelling, but as the pipe is allowed longer curing times before wetting the damage decreases. In fact, after enough strength is obtained to prevent swelling, an increase in strength will result because of the additional water available for hydration.

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Secondly, autoclaving imparts improved resistance to chemical attack in the ground by sulfate salts, aggressive Co_2, soft waters, and acid. At the high pressure and temperature in the autoclave, calcium hydroxide - a vulnerable hydration product of cement - combines chemically with silica flour to form a stable calcium silicate hydrate called tobermorite.

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