abrasion, reduction of crazing tendencies, and higher flexural and compressive strengths as shown in Fig. 1 to 5, inclusive. It was obvious that the improvements in concrete qualities resulted from reduction in the water-cement ratio at and near the surface to provide a "case-hardened" effect[4] [5].

The problem of developing and fabricating a suitable material on a commercial basis was made possible through the splendid cooperation of several manufacturers of wallboard products. The use of fabric facing was soon abandoned as special chemical treatments to eliminate sticking and at the same time provide some control of the initial rate of absorption by the board proved more practical and economical.

Large-scale field tests were conducted in October 1939, on the downstream face of Grand Coulee Dam. Twenty-two different linings, furnished by four manufacturers, were tried under normal job conditions. Although the results were mediocre as compared to the results that are now being obtained, the field test at Grand Coulee Dam indicated that surfaces formed with wallboard lining were superior both in quality and appearance to those formed with wood or metal forms.[3] [6].

Friant Dam, where lining was first used on a practical basis, became a proving ground for many of the facts known about form lining today. Manufacturers were given an opportunity to demonstrate their products after potential effectiveness had been demonstrated in the laboratory. Practical handling and installation techniques have been developed and desirable performance characteristics established from the Friant Dam experiences[10].

Other construction agencies, notably the Tennessee Valley Authority [9], U. S. Corps of Engineers, and the Wyoming State Highway Department[8], became interested in absorptive form lining and conducted independent field and laboratory investigations or actually used form lining in construction. Johnson has presented an excellent report[9] on the investigations and experiences at Kentucky Dam. An important conclusion stated, in part, that: ". . . It is also highly probable that by increasing the water-cement ratio and reducing the cement content, the surfaces produced will still be considerably better than we are obtaining today with lower water ratios and higher cement contents . . . "

Laboratory studies are being continued for the purpose of establishing the fundamental, physical characteristics most desirable for a form-lining material, and the exact processes by which the indicated improvement in the quality of the surface concrete is effected. These studies have established the fact that absorptive form-lining materials now in use effects measurable decrease in water-cement ratio of the concrete to a depth of approximately one inch from the surface, depending on the

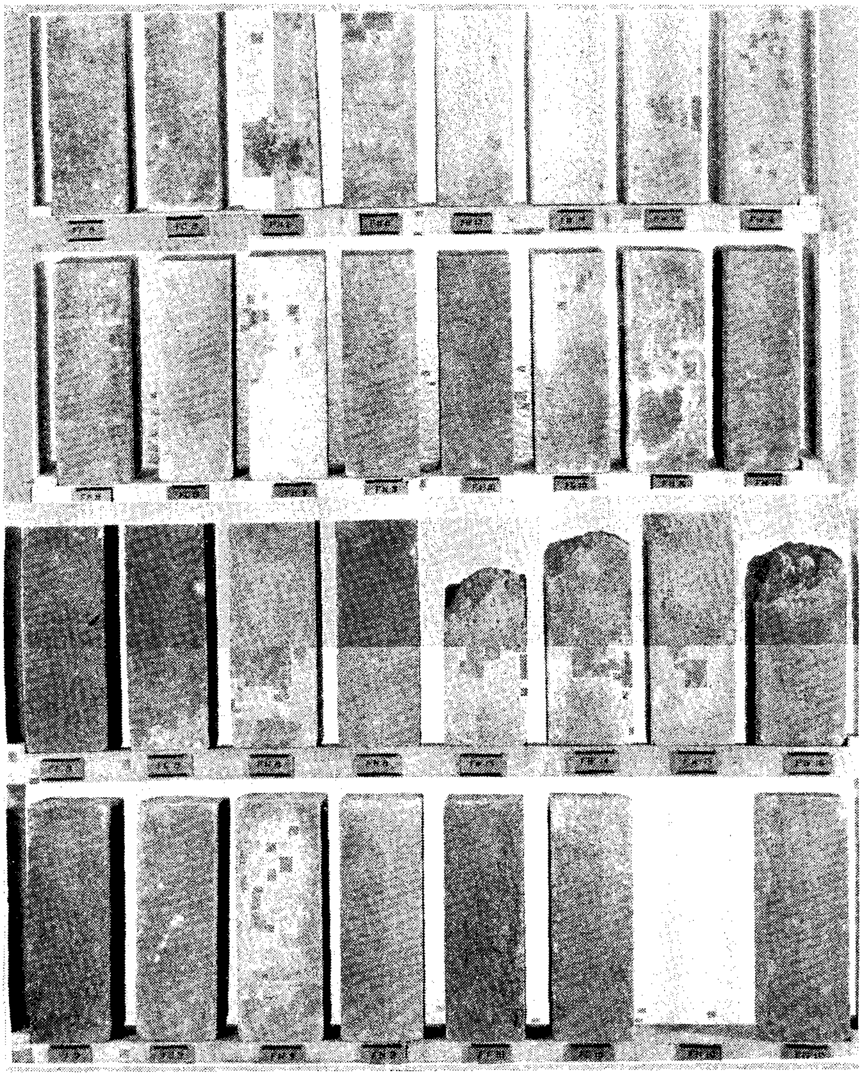


Fig. 1—Durability test on 3 x 3 x 9-in. concrete blocks formed by various types of lining as compared to wood-formed blocks (marked F W). The latter failed at approximately 110 cycles of freezing and thawing. Two top rows, 60 cycles; two lower rows, 100 cycles; two top rows, opposite page, 260 cycles.

The symbols designating specimens in the two top rows (after 60 cycles) are:

top row FF8, FC8, FH8, FN8, FW13, FW14, FW15, FW16
2nd row FF9, FC9, FH9, FN9, FF10, FC10, FH10, FN10

There is an identical sequence in the 3rd and 4th rows (100 cycles) and on the opposite page the 5th and 6th rows (260 cycles).

Fig. 1 Continued—See opposite page.

lining. The water-ratio decrease was the greatest at the surface, progressively reducing toward the interior as shown in Fig. 6.

This information was based on tests made by sampling sand mortars, two hours after placing, at varying depths from the linings and oven-drying each sample, to determine the water content. The reduced water contents near the surface are attributed to the absorptive action of the form lining.

SPECIFICATIONS

Specifications issued by the Bureau of Reclamation for the purchase of the wallboard type of form lining(7) were based principally on the physical properties (strength, absorption, adaptability for field use, etc.) of the board itself and a performance test in which a formed 3- by 5-ft. concrete slab was cast on a 0.7 to 1 slope. The physical properties were based on tests of boards which had functioned most satisfactorily in the previous tests. The purchase specifications also stipulated:

> The form lining shall be capable, through its absorptive capacity, of eliminating, to the extent specified, voids, pits, and other common defects from the surface of concrete placed against it. The form lining shall be highly absorptive to air and water and possess surface characteristics resulting in a satisfactory surface texture of the hardened concrete and a minimum amount of sticking upon removal of the forms. The lining shall be readily adaptable to cutting, fitting, and any other operation necessary in connection with its use. The lining itself, and any coating or treatment employed *in its manufacture*, shall be such as will not create discoloration or interfere with normal chemical reactions of the cement in the concrete.

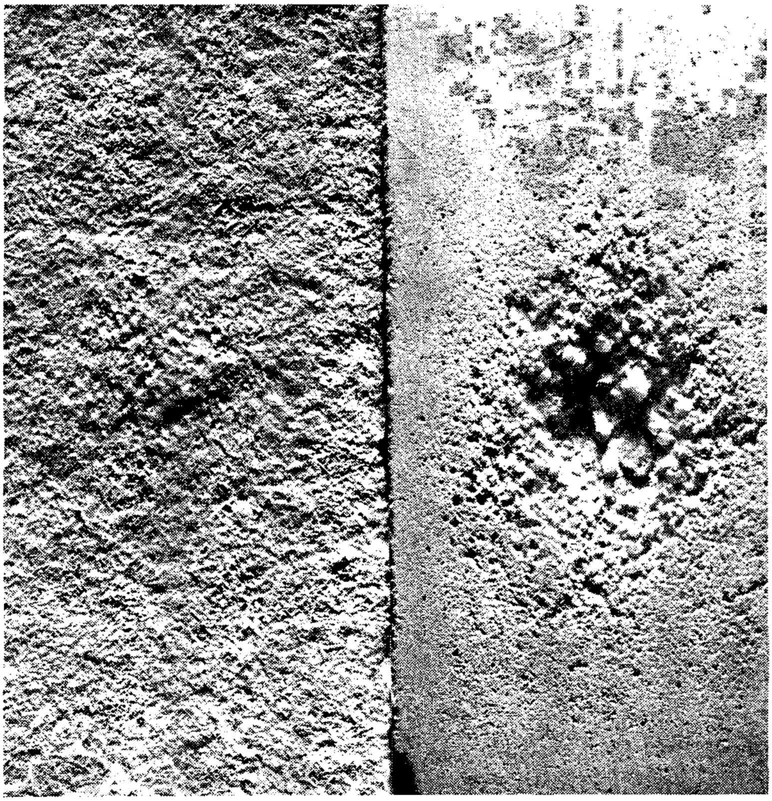


Fig. 2—One minute abrasion test. The surface of the wood formed concrete (right) was completely eroded in this test leaving nothing but the coarse aggregate to withstand the wear. The absorptive formed surface, (left), was only slightly affected by like treatment.

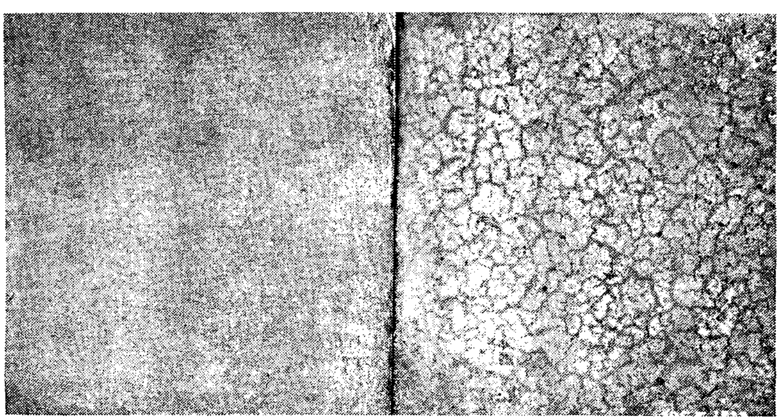


Fig. 3—The concrete surface produced against a wood form (right) crazed much more than the surface produced against an absorptive lining (left).

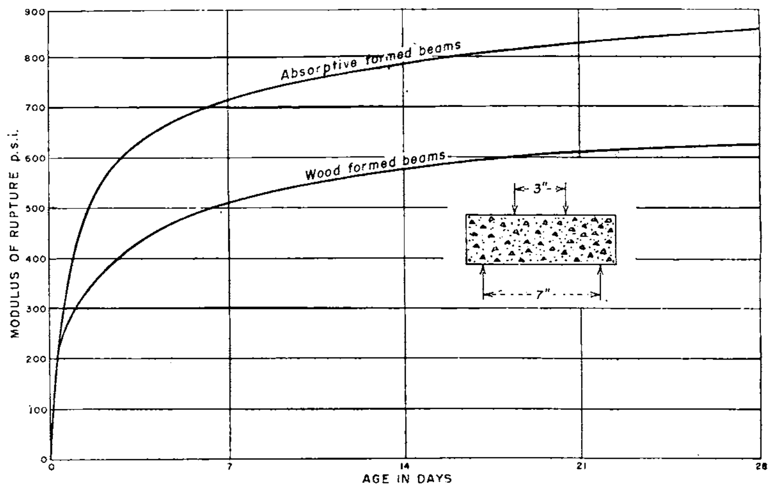


Fig. 4—Modulus of rupture of wood formed and absorptive formed beams.

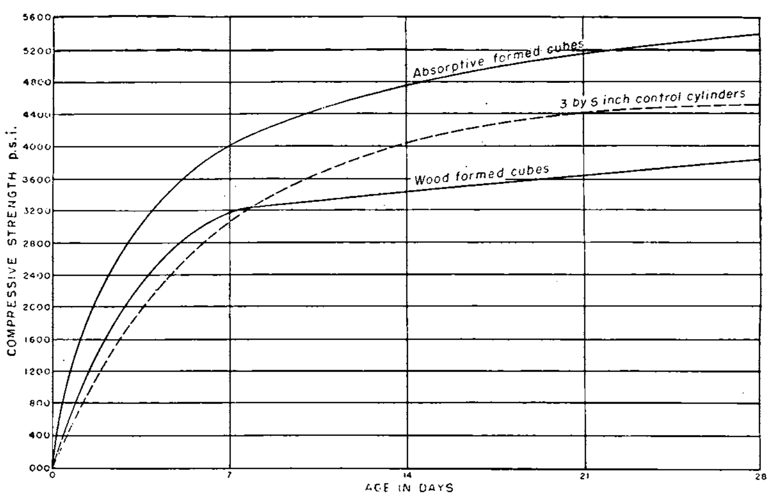


Fig. 5—Compressive strength of absorptive formed and wood formed modified cubes.

It was required that bid samples be furnished to determine conformance of the proposed material. Provisions were included to control the size of bundles in shipment to simplify handling operations.

After accidentally installing sheets backwards on some of the early work, the specifications were revised to provide for appropriate markings in every square foot of each sheet. The reverse side of form lining, in general, does not function in the manner desired.

Recently, attention and study have been directed to a different type of lining which consists of a thin absorptive paper-pulp sheet faced with

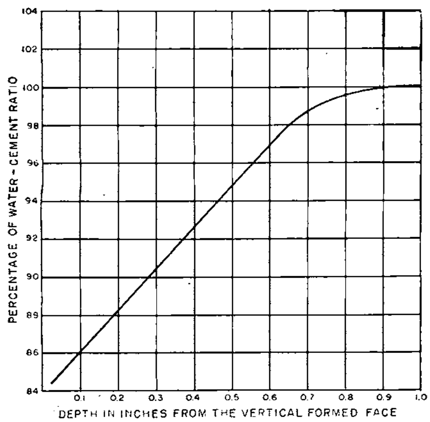


Fig. 6—Typical curve showing reduction in water - cement ratio of mortars formed against absorptive form lining.

muslin. The composite sheet is less than ⅛-in. thick and has been effective, both in the laboratory and in the field as a form-lining material.

FIELD EXPERIENCES IN THE USE OF ABSORPTIVE FORM LINING

During the last 18 months, several million square feet of the wallboard type of absorptive form lining have been used on a variety of Reclamation structures, including a large concrete dam, spillways and outlet works for earth dams, control houses, and power and pumping-plant buildings. The objectives have been to obtain: (1) Improvement in hydraulic characteristics and increased resistance of the concrete to cavitation resulting from high velocity water flow; (2) increase resistance to freezing and thawing and surface checking and crazing; (3) improvement in architectural appearance.

The results have been generally very satisfactory and the cost reasonable. The improvement in surface appearance has been striking, with practically all air voids, sand streaks, and other common defects eliminated (Fig. 7). Marked improvement in construction joints with the use of absorptive lining is also obtained, although when architectural considerations are of primary importance, special joint treatment, as discussed later, should be employed. While laboratory tests conclusively demonstrated the superiority in weathering resistance of absorptive formed over ordinary formed concrete, service histories are too short as yet to indicate the corresponding behavior under field conditions.

The delivered cost of the wallboard type of lining has varied from 3½ to 5 cents per square foot. The gross handling and installation costs vary with the particular job conditions involved, from 8 to 15 cents per square foot. In some cases a large part, if not all, of this over-all cost is offset by direct construction savings in the initial cost of forms, form cleaning, oiling and maintenance, curing and protection, and special surface finishing.

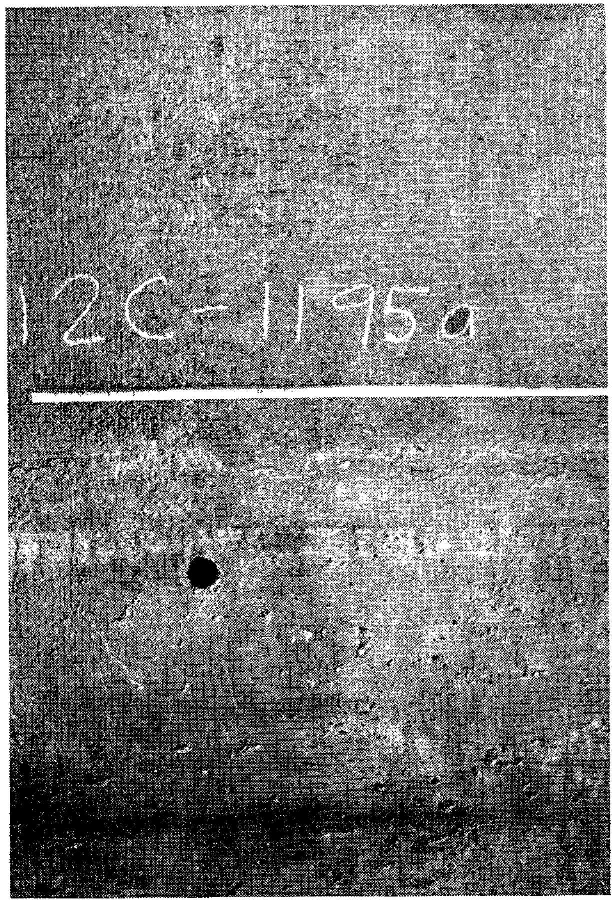
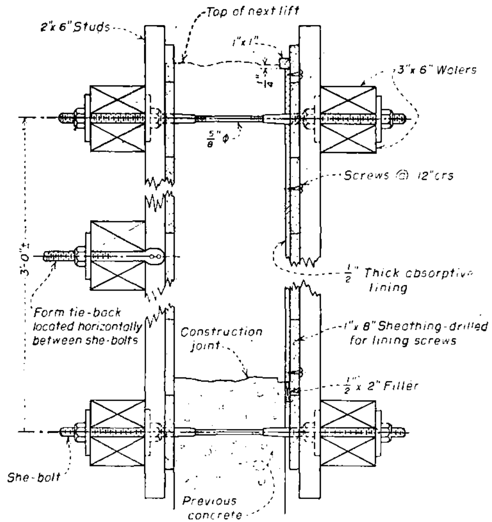


Fig. 7—Downstream face of a dam comparing surface formed by absorptive lining above with that produced below against ordinary wood lagging.

HANDLING WALLBOARD FORM LINING

Wallboard lining is normally supplied in sheets ½ in. thick by 4 ft. wide and 8 ft. long. Special sizes cut to predetermined lengths can be obtained readily but widths other than even factors of 12 feet usually require special manufacturing provisions or waste. A 4- by 8-ft. sheet has sufficient structural strength to permit ready handling by one man. Longer lengths can be obtained but they are somewhat awkward to handle and are more susceptible to damage during installation. The structural strength of lining boards now available limits the length which can be handled to about 12 ft. The boards should be obtained in bundles of six, wrapped in strong waterproofed paper for protection in handling



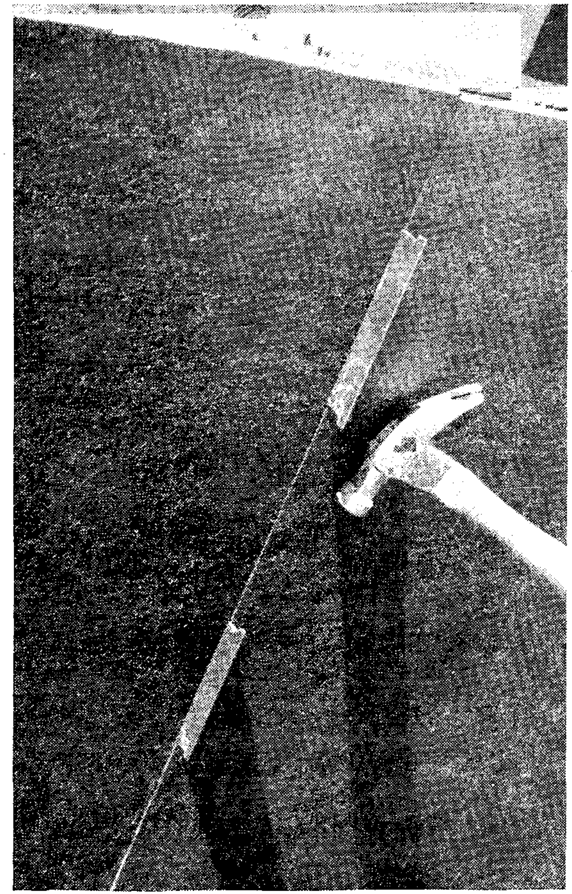


Fig. 8 (above)—Example of form construction proposed and used for thin wall structure. If desired nails from the lining could have been used in place of the screws.

Fig. 9 (right)—Metal shims for proper spacing of form lining sheets.

and from the elements until they are used. "Dog houses" or special crates should provide storage on the job for working supplies of boards.

INSTALLATION

On complicated work, layout diagrams showing the location and identification number of each board will be found advantageous. The sheets can then be cut to dimension in the carpenter shop or yard and quickly installed in the forms without confusion or delay after transportation to the work in the special crates or skips. Cutting can be satisfactorily accomplished with ordinary power saws. Holes can be drilled with common wood bits, or a cutter similar to a cork borer driven by a power hand drill has been found useful for drilling tie-rod holes. Other special cutting tools are available or may be devised and made where expedient.

Forms should be constructed in the usual manner with proper allowance in dimensioning for the liner sheets. Lagging need not be as smooth as for forms which are not to be lined. The lining should not be counted on to supply any structural strength or handling stability. Backing for the lining (lagging) should be of solid wood and reasonably free of irregularities. Fastening the lining to the form panels should be the last operation before final alinement and clamping the forms in place. Even then, care must be exercised to prevent damage to the lining in the final stages of preparation for actual concrete placing.

Fourpenny casing nails, driven just flush with the board surface, have been found adequate for fastening the lining to the forms. The nails should be spaced on 3- to 6-inch centers around the edges and on 12- to 18-inch centers over the balance of the lining surface. Nails with larger heads will leave imprints in the concrete. On one job involving thin walls, the lining was fastened with wood screws from the back side of the forms (Fig. 8). Form spreaders should be used sparingly and where used should be provided with large bearing plates to prevent compressing the lining. Absorptive lining expands considerably on absorbing moisture and the sheets should be spaced about 1/16 in. apart to prevent buckling. Metal shims (Fig. 9) of proper thickness have been used effectively for spacer gages. With proper attention to the spacing detail, joints between lining sheets are hard to detect on the hardened concrete.

It is impractical to place absorptive lining during heavy rains but during light rains or after installation, protection with canvas has proved practical. Slightly damp lining can be dried after it has been installed by portable warm-air blowers which are available on the market.

The absorptive lining should overlap the old concrete about two inches at a plain construction joint. A filler strip of hardwood should be tacked to the form lagging just below the lining to provide bearing against the

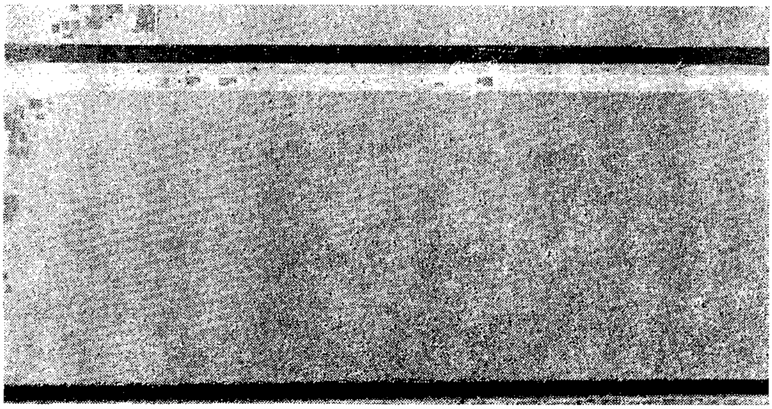


Fig. 10 (above)—Successful use of 1 - inch deep architectural grooves. A horizontal construction joint is located in the lower groove. Note the excellent surface texture of the concrete wall.

Fig. 11 (left)—Probably an extreme example of the resulting concrete surface when the fiber lining was damaged by contact with carelessly handled vibrator.

old concrete when the forms are tightened in place. The thickness of the filler strip will vary somewhat with the job conditions, rate of placing, and consistency of the concrete. The thickness should be such that the pressure of the fresh concrete will just balance the swelling tendency of the lining board as it absorbs moisture, and thus prevent bulging or an underlip at the construction joint. For dry concrete in massive sections where an appreciable interval elapses between placing successive layers, the filler strip should be the same thickness as the lining. For thin walls involving more rapid rate of vertical progress in placing the