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A Rapid-Set Cement Suitable as a Molding Sand Binder for Small Ferrous Castings

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A RAPID-SET CEMENT SUITABLE AS A MOLDING SAND BINDER FOR SMALL FERROUS CASTINGS

by

S. D. Sanders,[1] E. D. Scott,[2] and G. V. Sullivan[3]

ABSTRACT

Goals of the Bureau of Mines include utilizing readily available minerals as substitutes for scarce mineral commodities and minimizing occupational hazards associated with mineral processing occupations. Therefore, the Tuscaloosa Research Center investigated using rapid-set cement as a suitable molding sand binder for small ferrous castings; currently petroleum-based binders are used. Substitution of a rapid-set cement would eliminate organic vapors associated with the petroleum-based binders; these vapors constitute occupational hazards and environmental pollutants.

A binder containing 60 percent white portland cement (WPC) and 40 percent calcium aluminate (CA) would be an acceptable and economic substitute for petroleum-based binders where the foundry requirements are compatible with its limitations. It produced a set time and a pattern strip time of less than 1 hour. Cement, sand, and water mixtures developed compressive strengths from about 40 to 75 psi after 2 hours and from 120 to 130 psi after 24 hours. Tensile strengths of 18 to 22 psi were obtained after 2 hours, increasing to 30 to 35 psi after 24 hours.

The addition of about 1 percent polyphosphate to the sand-cement-water mixture doubled the compressive strength and increased the tensile strength about 50 percent after 4 hours, but also increased the set time from 30 minutes to 1 to 1-1/2 hours. Polyvinylacetate (PVA) resin latex additions resulted in rapid strength development.

When castings were poured into the cement-bonded molds, the surface finish was fair to good on gray iron castings, but some areas of burn-on were present on steel castings. Using a graphite wash on the cement-bonded molds produced good surfaces on gray iron castings.

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INTRODUCTION

Cement is probably the most economical self-hardening binder available. For this reason portland-cement-bonded sands have been used for many years in the United States and Europe in the production of large molds and/or cores for iron, steel, and bronze castings. Because production schedules for smaller castings generally call for shorter set times than are obtained with such cement binders, organic binders, usually synthesized from petroleum products, have usually been used for small castings. The development of a rapid-setting cement to bond foundry molding sand could result in the replacement of organic binders. As part of its effort to minimize the requirements for minerals through conservation and substitution, the Bureau of Mines has conducted research to improve current foundry practice by developing such a rapid-setting cement. Cement constituents are widely available, and in use, do not burn or evolve noxious fumes that pose occupational or environmental hazards.

Sano and Kinoshita (6)[4] reported on the use of fluidizers and hardeners for portland-cement-bonded sands which could be poured directly onto a pattern to form a complete mold in a short time. The molding mixture contained 8 to 10 percent portland cement, 0.1 percent polyoxyethylene additive to improve flowability, and 1 to 3 percent polyphosphate or aluminum salt to improve setting properties. A set time of 2 hours was reported for this mixture. Cola and Sarti (3) used a fluid-sand process with about 8 percent alumina cement as a binder, lithium chloride as a wetting agent, and small additions of foaming reagents to provide fluidity. The LiCl accelerated the setting reaction of the alumina cement so that a set time of less than 5 minutes was achieved. Robinson (4) studied the characteristics of mixtures of portland and high-alumina cements. He attained set times of a few minutes for ratios of high-alumina to portland cements in the range of 40:60 to 85:15.

This investigation focused on mixtures of portland cement and high-alumina cement binders for molding sands. The effects on set time and strength of the resulting mold of the quantity of water and the ratio of portland cement to calcium aluminate were determined. The use of several other additions was evaluated with regard to decreased set time and increased mold strengths. Finally, gray cast iron and steel castings were produced using the cement-bonded molds to verify that the mold strength and casting surface finish were satisfactory.

[4]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

BINDER EXPERIMENTS

Cement Mixes

Commercial grades of calcium aluminate (CA) cement and white portland cement (WPC) were used to determine the effects of various mixtures on the set times and strength. Typical analyses are shown in table 1.

TABLE 1. - Typical chemical analyses of cements tested, wt-pct

	CA[1]	WPC[2]		CA[1]	WPC[2]
Al_2O_3............	79.0	5.0	CaO..............	18.0	67.6
SiO_2............	.15	23.5	MgO.............	.4	.7
Fe_2O_3............	.3	.3	SO_3..............	ND	1.8
Na_2O............	.5	ND	Loss on ignition.	1.5	1.5

ND Not detected.

[1]Calcium aluminate information obtained from product data booklet entitled "Alcoa Calcium Aluminate Cement CA-25," Aluminum Co. of America, Chemicals Division, 1501 Alcoa Building, Pittsburgh, Pa. 15213.

[2]White portland cement information obtained from General Portland Cement Co., 1545 West Mockingbird Lane, Dallas, Tex., 75247.

The set times were determined using the procedure detailed in ASTM standard C-266-74 (2). The cement mixtures were blended dry in a paddle mixer for 2 minutes; then 33 percent water was added, and mixing was continued for an additional 3 minutes. Samples were prepared, following the ASTM standards, and stored in a humidity cabinet (temperature 30° C and relative humidity 100 percent) until tested to improve their strengths (1, 4). Both initial and final set times were determined using the standard Vicat needle penetration test. The results of these experiments, shown in figure 1, indicate final set times of less than 30 minutes with initial set times as low as 10 minutes for WPC-CA ratios in the range of 60:40 to 40:60. Since WPC is cheaper than CA, cement mixtures with a WPC-CA ratio of 60:40 were used in the remainder of the test work.

Compressive Strengths and Set Times

Measurements were made to determine the effects of H_2O on the compressive strength and set times of sand-cement mixtures. The mixtures were composed of 90 parts sand, 10 or 12 parts cement, and 5 to 25 percent water. The compressive strengths reported were the average of three tests measurements made on 2-inch cube specimens prepared by hand-ramming and tucking the molding mixture into a metal mold. The set times were determined using the method described in ASTM standard C-266-74 (2).

The results for the 90 parts sand and 10 parts cement mixture are shown in figure 2. The set times were minimum when additions of about 15 percent water were used. The compressive strengths at both 1 and 2 hours were nearly constant in the range of 10 to 15 percent H_2O.

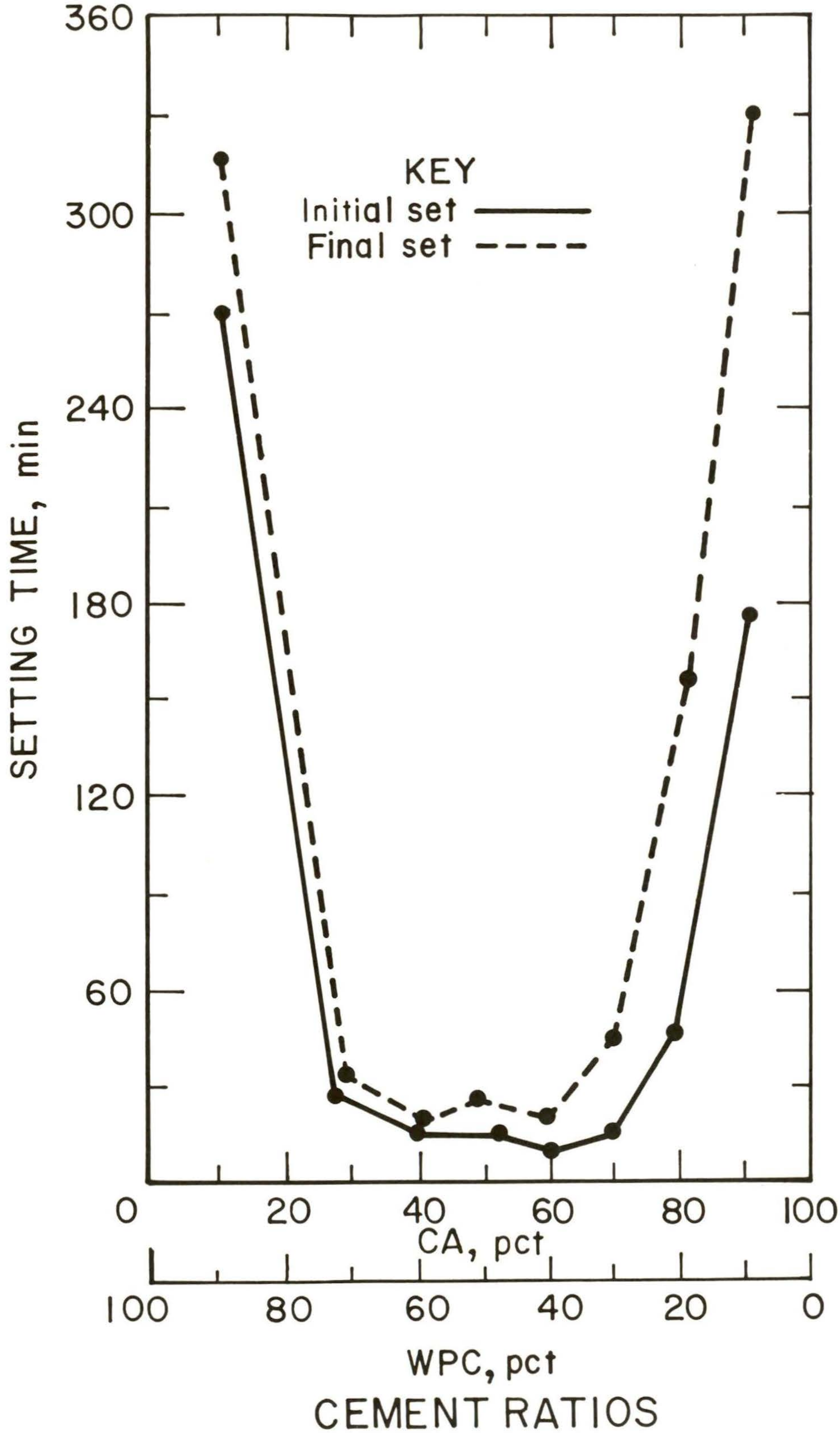


FIGURE 1. - Setting times versus WPC-CA ratio.

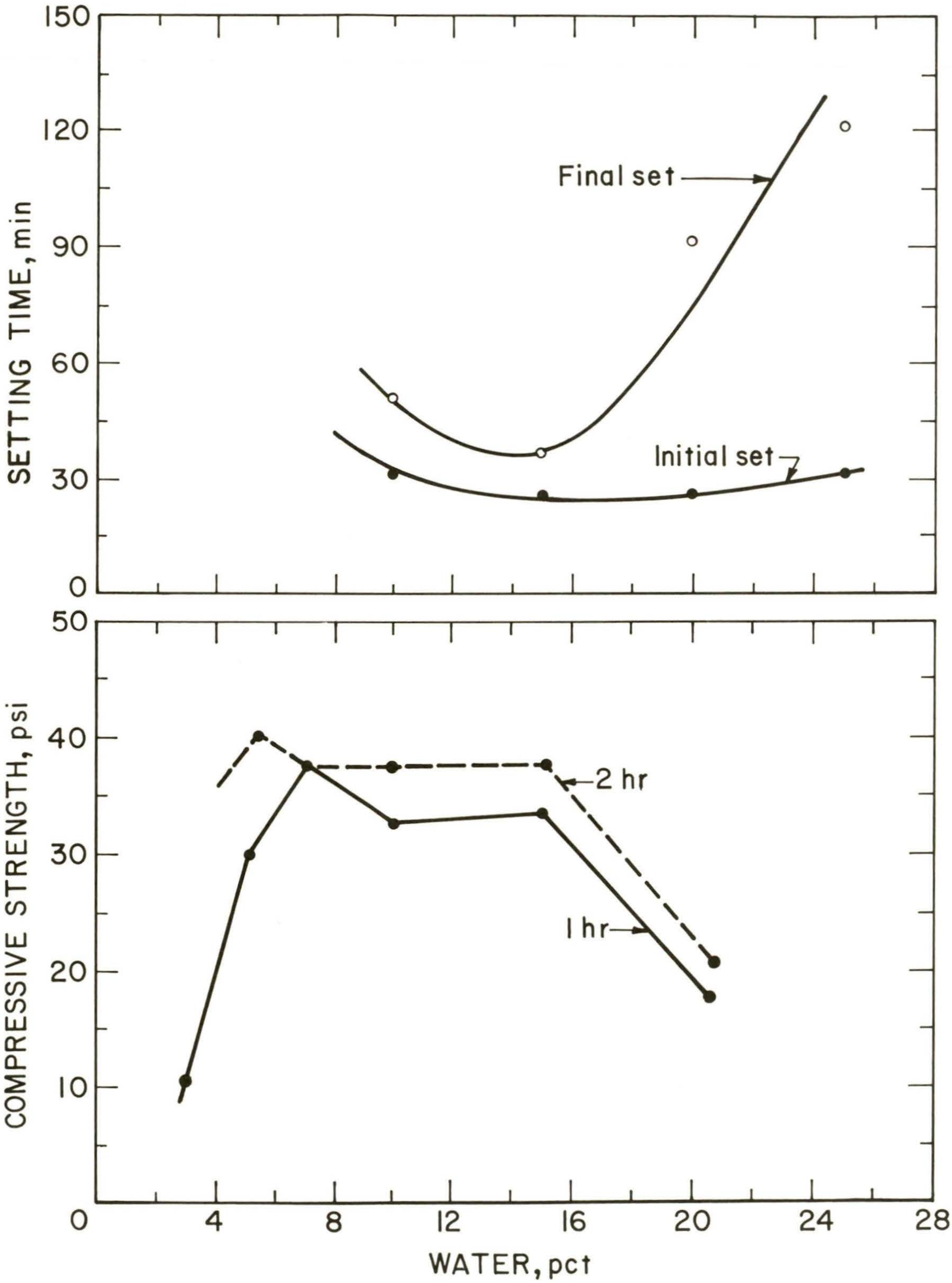


FIGURE 2. - Effect of water on setting times and compressive strengths for 90 parts sand and 10 parts cement mixtures.

Preliminary tests indicated that increasing the cement in the mixture would increase the strength. The cement was increased to 12 parts by weight. Tests for compressive strengths were repeated, varying the water content. These results, shown in figure 3, indicate that the compressive strengths were higher for the mix with the 12 parts cement. The data further indicate that for both cements, using between 7 and 15 percent water, the compressive strengths would be more than adequate for stripping most patterns after 1 hour.

Tensile Strengths

The American Foundrymen's Society's (AFS) tensile specimens were made by hand-packing the molding sand mixture into molds. Three of these specimens were broken using a universal sand testing machine, and the average value was reported. Sano and Kinoshita (6) assumed that a tensile strength of about 7.1 psi was required to withdraw patterns from cement-bonded molds.

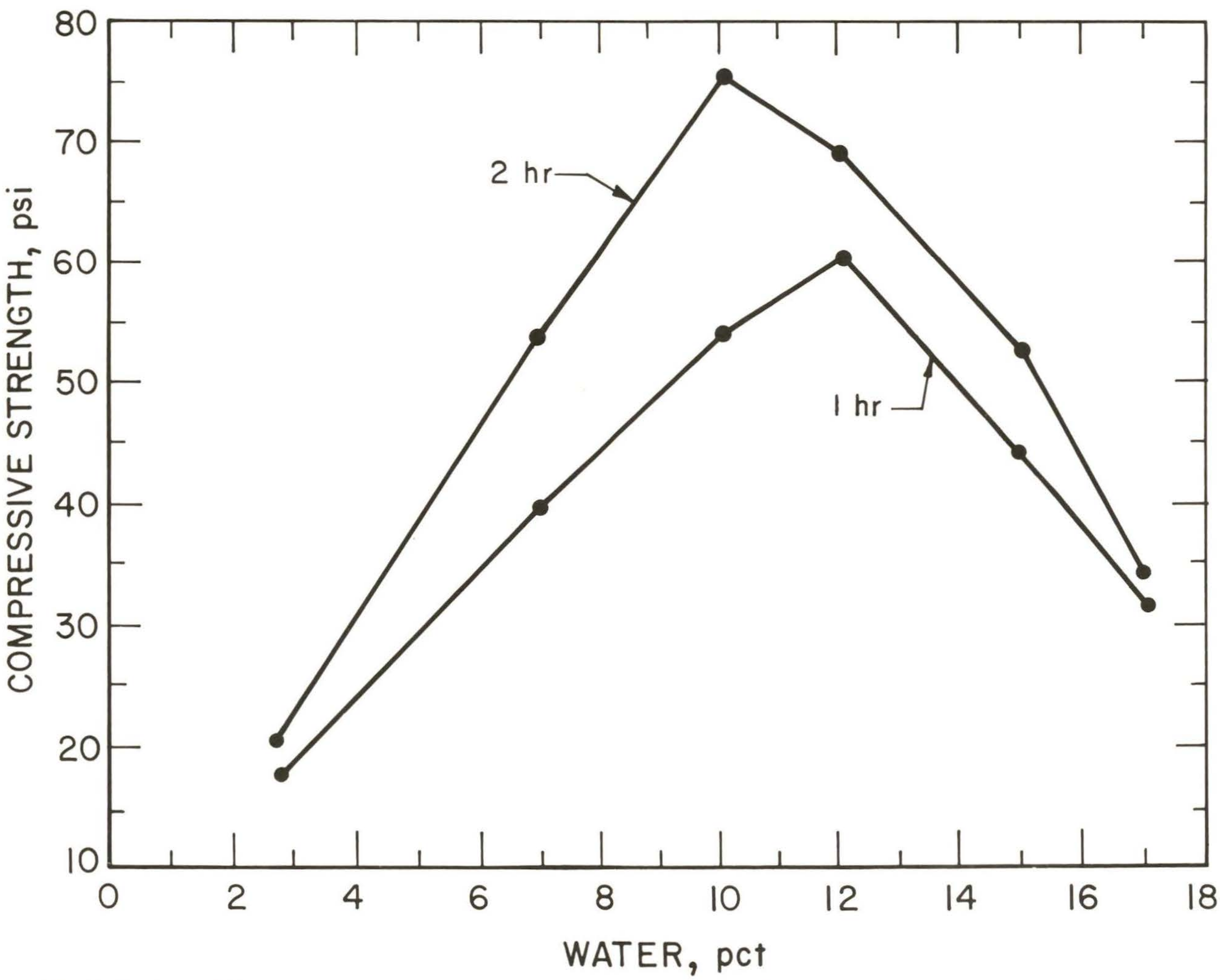


FIGURE 3. - Effect of water on compressive strengths for 90 parts sand and 12 parts cement mixtures.

Tensile strengths were determined initially for the sand-cement mixture of 90 parts sand and 12 parts cement with water levels varying from 7 to 12 percent. The results, presented in table 2, indicate that the tensile strengths were almost independent of water content, and the 7.1 psi assumed by Sano and Kinoshita was exceeded in 1/2 hour.

TABLE 2. - Variation of tensile strengths with time and percent water

Percent H_2O	Tensile strength, psi			
	1/2 hour	2 hours	4 hours	24 hours
5	-	17.5	22.5	35.0
7	17.5	20.0	25.0	32.5
10	10.0	20.0	22.5	37.5
12	17.5	20.0	22.5	35.0

However, it was later felt that a lower water content would improve the surface finish of the castings by reducing the amount of steam produced during casting. Therefore, tensile strength versus time was determined for 5 percent moisture. These results are also shown in table 2. These data closely match the data obtained at higher moisture levels, although no measurement was made at 1/2 hour.

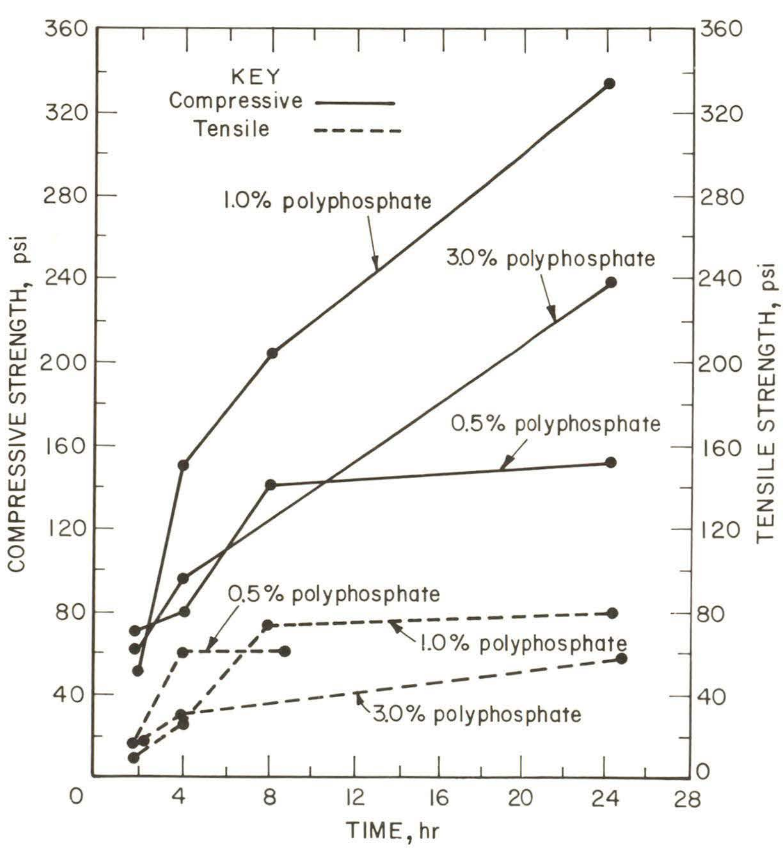


FIGURE 4. - Effect of time on tensile and compressive strengths for varying quantities of polyphosphate.

The tensile strengths increased with time and after 2 hours were about 60 percent as great as they would be after 24 hours. Significant increases in the tensile strengths were obtained with this cement binder by using a hardening agent.

Polyphosphate

The literature (6) indicated that polyphosphate increased tensile and compressive strengths when added to cement binders. To evaluate the effect of polyphosphate, tensile and compressive strengths were measured on mixtures containing 0.5 to 3.0 percent polyphosphate, 0.1 percent polyoxyethylene, 90 parts sand, 12 parts cement, and 10 percent H_2O. Polyphosphate gave considerably higher strengths after 4 hours, as shown in figure 4. One percent polyphosphate gave the highest strength. However, the set time increased from about 30 minutes to 1 to 1-1/2 hours.

Flowability

The flowability of a molding sand relates to the ease with which a flask can be filled with sand. Molding materials with good flowability require little ramming or packing. Polyoxyethylene ranging from 0.1 to 0.3 percent has been used to increase the flowability of conventional cement-bonded molding sands (3). Several tests were performed to measure the effect of polyoxyethylene. Polyoxyethylene was added both in the dry state and as an aqueous solution. The flowability of the sand was measured by placing sand in an open-ended core box. After about 3 minutes, the box was removed. The degree of slump, which is the decrease in height of the sand, was taken as a measure of flowability. No effects were noted for polyoxyethylene in the sand-cement-water mixtures.

Latex Resin

A commercial latex-resin, polyvinylacetate (PVA), was tested to determine its effect on the strength of a cement-sand mixture. The water-based latex also supplied the water required to set the cement. Compressive and tensile strengths were measured on mixtures of 90 parts sand and 12 parts cement. The PVA ranged from 0 to 10.0 percent and water from 10.0 to 0 percent such that the total combined water and PVA was 10 percent. The compressive strengths are shown in figure 5. The mixture containing 6.7 percent PVA and 3.3 percent water gave the highest compressive strength, which was about 1.6 times the strength of the 10-percent-water mixture.

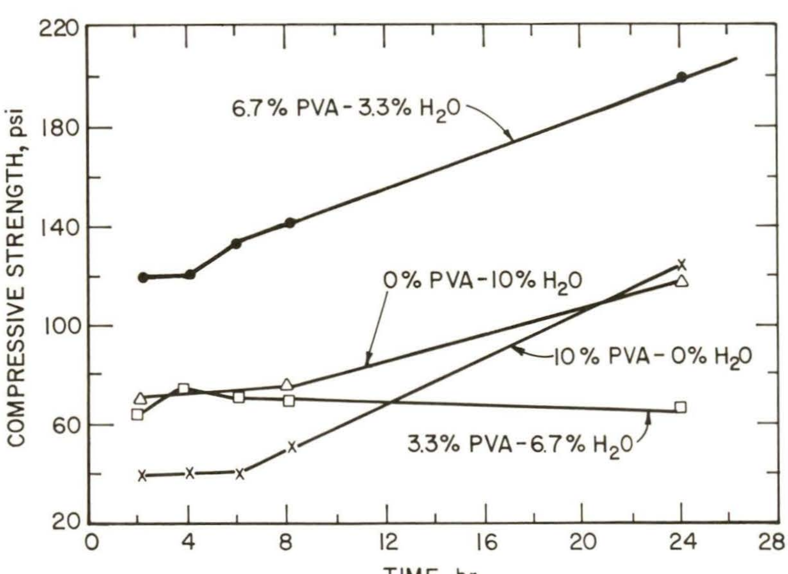


FIGURE 5. - Effect of time on compressive strength with varying amounts of PVA.

Figure 6 indicates that the tensile strength of the mixture containing 6.7 percent PVA and 3.3 percent H_2O increased steadily over a 24-hour period. The 3.3 percent PVA-6.7 percent H_2O mixture had the highest tensile strength at 2 and 4 hours, but its strength decreased after 6 hours.

The PVA is effective in increasing compressive and tensile strengths; however, 1 percent polyphosphate was about as effective as 6.7 percent PVA latex and is considerably cheaper.

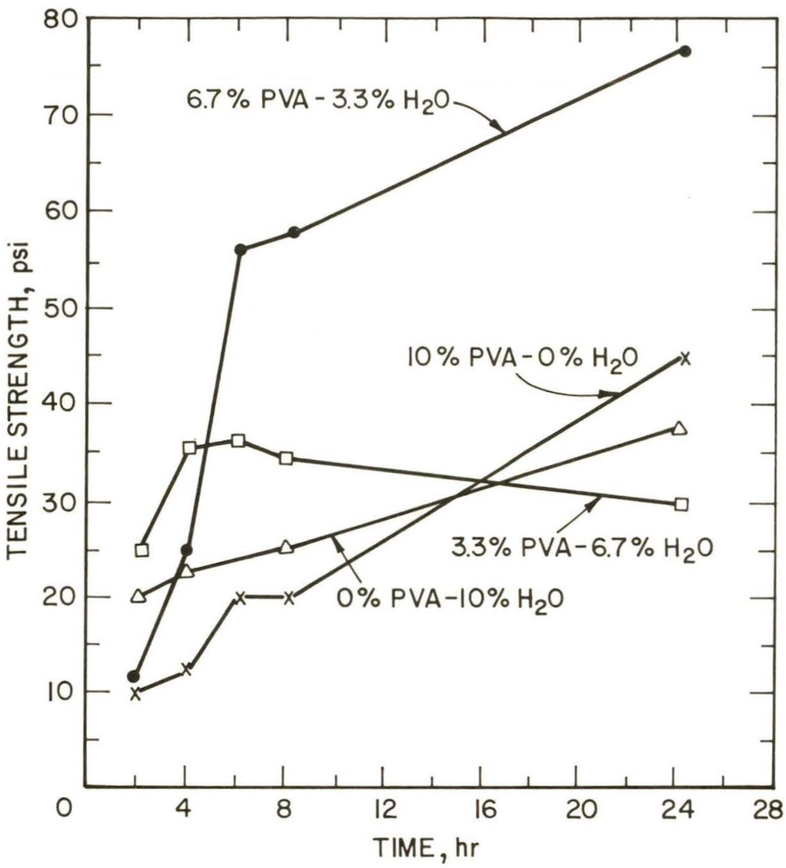


FIGURE 6. - Effect of time on tensile strength for varying amounts of PVA.

CASTING EXPERIMENTS

Gray cast iron and steel castings were produced using cement-bonded molds. The basic molding mix consisted of 90 parts sand (AFS average grain fineness of 57), 12 parts cement, and 5 to 7 percent water. Gray cast iron was also cast in resin-bonded sand for comparison.

The sand and cement were dry-mixed for 1-1/2 to 2 minutes in the paddle mixer. Water was added, and mixing continued for 2 to 3 minutes.

Plate castings 10 by 7 by 1 inch in size were made of both gray cast iron and steel using a match plate pattern. Since the standard Steel Founders Society of America V-notch test block (5) is widely used to determine the surface finish and degree of metal penetration produced by different sand mixtures, the V-notch sections of gray cast iron were cast to indicate the severity of metal penetration into a given sand mixture.

The molding sand was hand-rammed and tucked around the patterns. The patterns were pulled within 1 hour after making the molds. Molds were cured for 2, 12, and 24 hours before pouring the molten iron or steel. In addition, some castings were made to determine the effect of mold washes and a wetting agent on the surface finish of the gray iron castings.

Iron Castings

Molds were prepared using 7 percent water and cured for 24 hours in the mixing room before pouring. When coated, molds were torched dry prior to closing. Gray iron was melted in a 300-pound induction furnace lined with magnesia and was poured at about 2,650° F.

Several of the plate castings are shown in figure 7. When both molds were coated, the surface finishes of the castings from the cement-bonded molds were comparable to those from the resin-bonded molds. However, the castings

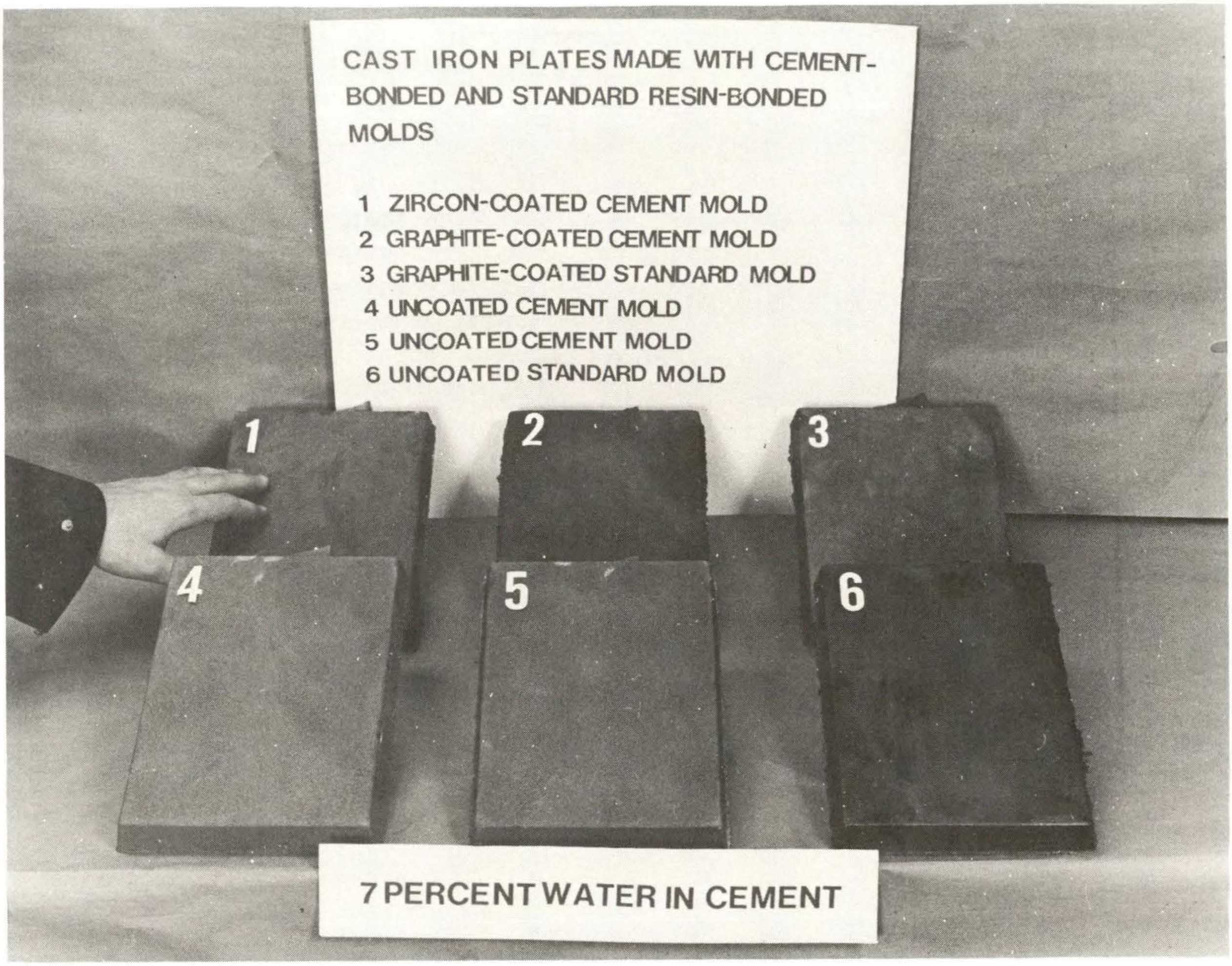


FIGURE 7. - Cast iron plates made with cement-bonded and standard resin-bonded molds.

produced in uncoated resin-bonded molds had a smoother surface than those in the uncoated cement-bonded molds.

Another group of plate castings and SFSA V-notch test blocks were poured in cement-bonded molds using 5 percent water. Although less steam was evolved during pouring, the surface features of the castings were identical. The castings are shown in figure 8. A wetting agent, 0.1 percent Ultra-wet,[5] was used in making the mold for casting 3, but no apparent differences were evident.

Excellent peel was observed on the cast iron for the cement-bonded molds on the surface of the casting and in the V-notch. Some penetration was noted in the V-notch and cutaway corner of both castings.

[5]Reference to specific brand or trade names is made for identification only and endorsement by the Bureau of Mines is not implied.

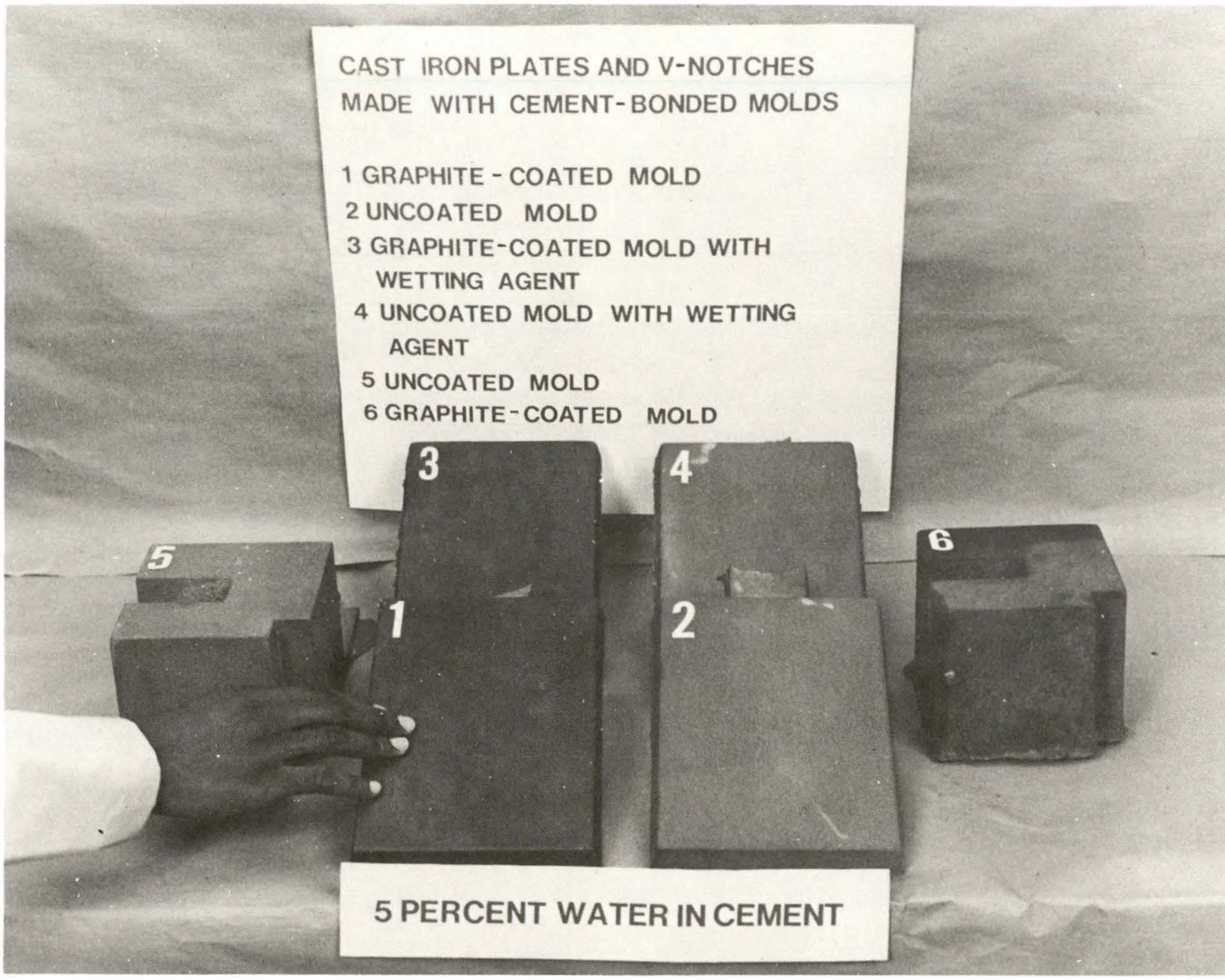


FIGURE 8. - Cast iron plates and V-notches made with cement-bonded molds.

Plate casting molds using 7 percent H_2O were stored for 2 and 24 hours before pouring to make surface-finish comparisons. These castings, shown in figure 9, had no significant differences in surface finish.

Steel Castings

Plate castings of steel were poured using cement-bonded molds containing 5 percent H_2O, which had been stored for about 12 hours prior to pouring. A fair surface finish (fig. 10) was exhibited on the drag half of the castings, but slag inclusions were found in the cope half. Areas of burn-on were noted on some castings. The use of a zircon mold wash, applied to the surface of the mold, produced a poor surface finish owing to a mold-metal reaction.

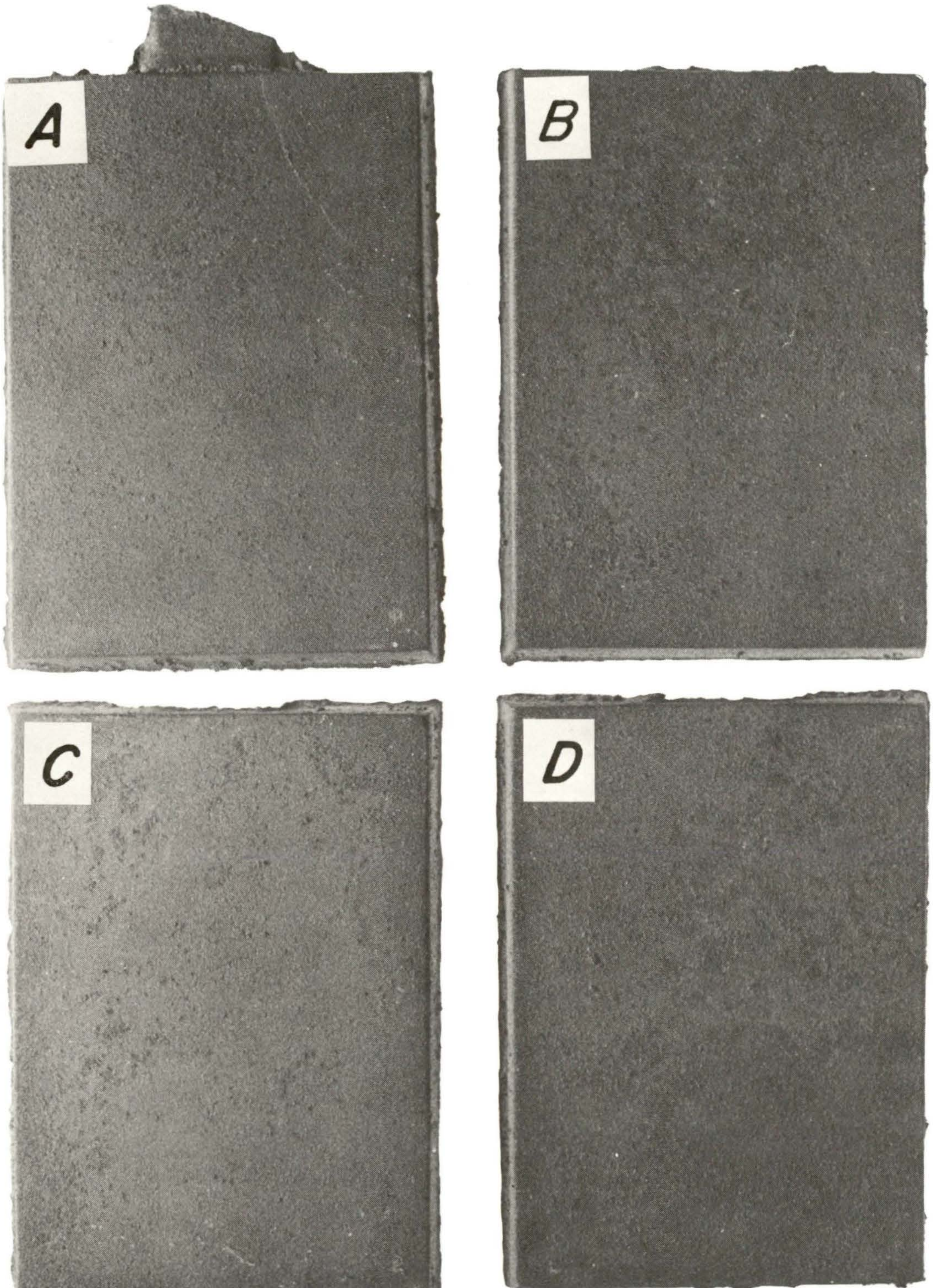


FIGURE 9. - Cast iron plates made in uncoated cement-bonded molds. Plates A and C were made from molds cured 24 hours, and plates B and D are from molds cured 2 hours.

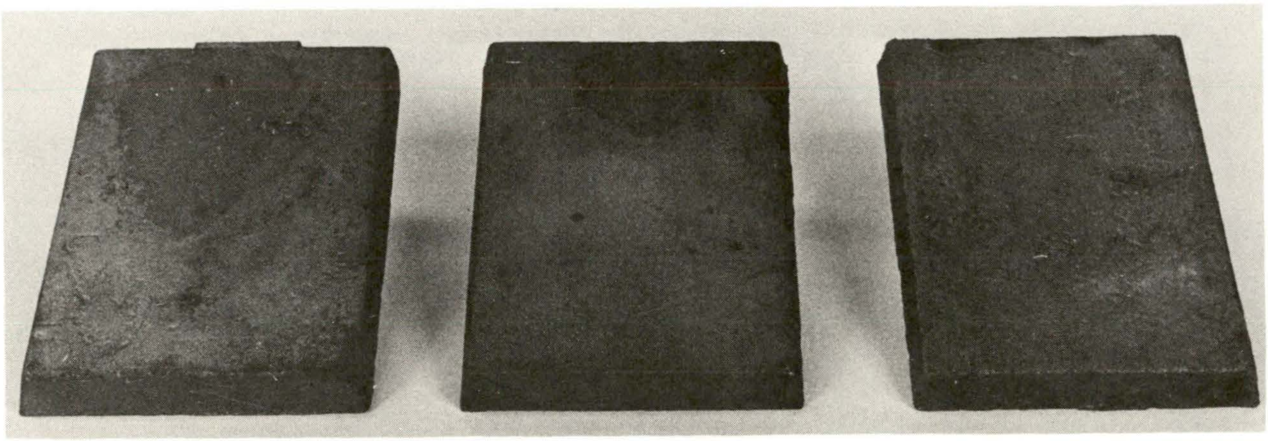
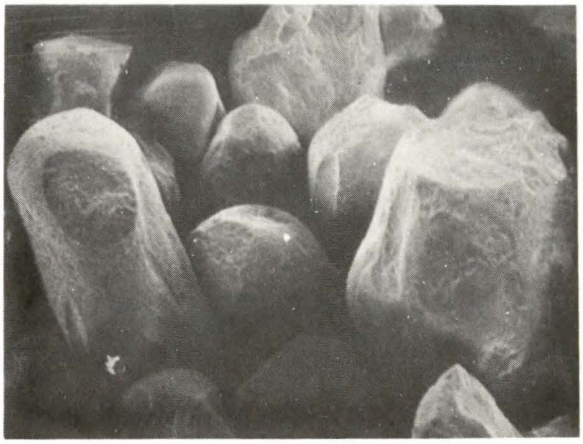


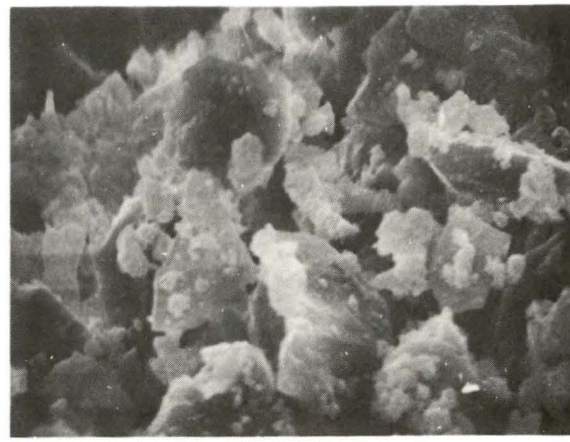
FIGURE 10. - Drag surface of steel castings poured in cement-bonded molds.

Scanning Electron Photographs

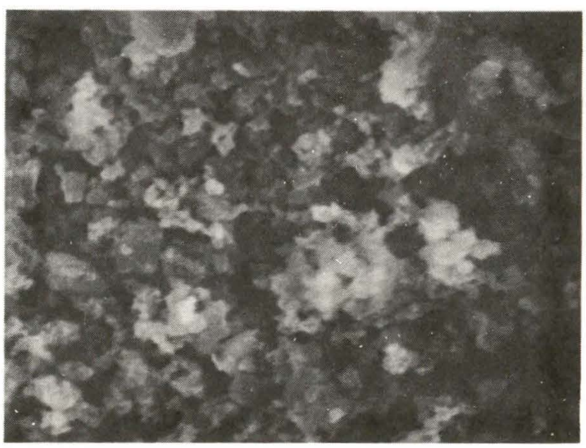
Scanning electron microscope (SEM) photomicrographs were made of the components in the cement binder system and of a mold after an iron casting had been made. The SEM photographs (fig. 11) show that the calcium aluminate has a much smaller particle size than the white portland cement. The cement mixture gives a fairly uniform coating of the sand grains. The bonds between sand grains are broken during casting, but the sand grains are still coated with the binder. This is typical of other "air set" binders and indicates that the sand should be amenable to recycling.



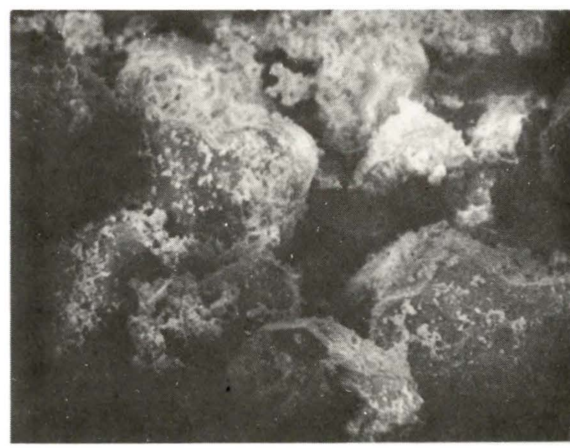
A. 100X



B. 5,000X



C. 10,000X



D. 200X

E. 200X

F. 200X

FIGURE 11. - SEM photographs showing (A) sand grains, (B) white portland cement, (C) calcium aluminate, (D) dry cement-coated sand, (E) bonded sand and cement, and (F) molding sand after casting has been made.

CONCLUSIONS

Mixtures of calcium aluminate and white portland cement were used successfully to bond molding sand for ferrous castings. In some cases these inorganic binders could substitute for petroleum-based binders, thus utilizing a more readily available resource and eliminating organic vapors which constitute an occupational and environmental hazard.

Sound castings were produced using gray cast iron. Excellent peels were noted, with only slight penetration of the metal into the V-notch and cutaway corners.

Fair surface finishes were produced in steel castings. Slag inclusions were found on the cope half of the castings, and areas of burn-on were also noted.

It is concluded that mixtures of calcium aluminate and white portland cement could be used as a molding sand binder, considering the following factors:

1. Set times of 30 minutes or less occur with WPC-CA ratios in the range from 60:40 to 40:60.

2. The compressive and tensile strengths of mixtures containing 90 parts sand, 10 to 12 parts cement (60:40 WPC-CA), and 5 to 10 percent water are more than adequate after 1 hour.

3. The compressive strength after 1 hour increased as the water content increased from 3 to 12 percent. The tensile strengths are almost independent of the water content.

4. Storage at higher humidity and temperature increased the strength in the sand-cement-water mixtures.

5. Additions of 1 percent polyphosphate to the mixtures increased the compressive strength about 100 percent and the tensile strength about 50 percent for curing times longer than 4 hours. The polyphosphate, however, increased the set times from about 30 minutes to 1 to 1-1/2 hours.

6. Additions of polyoxyethylene up to 0.3 percent did not improve the flowability of the sand mixtures.

7. Significant increases in compressive and tensile strengths were found when 6.7 percent PVA latex and 3.3 percent H_2O were used instead of 10 percent H_2O.

8. Cement molds produced rougher casting surfaces than resin-bonded molds.

9. When graphite washes were used on both molds, the casting surface finishes from the cement and resin-bonded molds were comparable.

10. Steel castings from the cement-bonded molds had areas of burn-on.

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