the following statement "Where calcium chloride is used as an antifreeze or some other of the basic chlorides, they are very likely to rust steel in spite of the excess of lime that may be in the concrete It is therefore essential to paint them with an alkali or chloride proof paint, and in that case a simple wash with concrete is not sufficient "

SUMMARY

The various investigations reviewed in this report appear to be in substantial accord to the following extent

Calcium chloride and other soluble compounds of calcium chloride base act as accelerators of the hardening of concrete, and when used within limits of approximately 0 to 4 per cent increase the strength to a limited degree The effect of the accelerator being roughly in proportion to the amount of anhydrous calcium chloride in the compound used Since the increase in strength is practically the same for all ages, the relative increase is greatest at early ages Considerable variation in results secured with different brands of cement is also noted

It would therefore appear that there are at least two useful functions for such admixtures

1 To increase the early hardening so that the structure or pavement may be put into earlier service than is possible with normal Portland cement Further special investigations are needed to formulate rules of practice for varying local conditions and different cements
2 To counteract, to some extent, low strength due to curing concrete at low temperatures, provided that the temperature is not below freezing, and the concrete is protected during the setting period Calcium chloride can not be depended upon to protect against freezing during the mixing and setting period

The possible increase in final strength of concrete produced by the use of an accelerator is slight compared with the possible increase due to other recognized methods

The effect of calcium chloride upon steel reinforcement is not definitely determined by the data reviewed

QUICK HARDENING CEMENTS

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INTRODUCTION

The term "quick-hardening cements" is used in this paper to cover all cements giving high early strengths Much investigation has been going on concerning the use of such cement and many varying and contradictory statements have been found. An attempt is here made to distinguish between the types of high early strength cements, and to discuss briefly their composition, manufacture, and uses.

Two general types of quick-hardening cements are to be distinguished, first, high alumina cements, and second, special Portland cements. It should be noted that in each case a term sometimes used, "quick setting," is essentially a misnomer. Such cements are slow setting, about the same as normal Portland cement, but quick hardening, acquiring early high strengths.

HIGH ALUMINA CEMENTS

Definition—Under the head of high alumina cements are grouped those cements with a relatively high percentage of alumina (Al_2O_3, 35–55 per cent), and a relatively low percentage of lime (CaO, 30–40 per cent), and silica (SiO_2, 2–15 per cent), as compared with Portland cements. They seem to depend for their quick hardening properties almost entirely on the properties of the calcium aluminates present

Historical—H S Spackman, in the United States, and Jules Bied, in France, working independently for a number of years with a different objective finally considered they had found their desires realized in alumina cement Mr. Spackman was endeavoring to obtain an early strength, Jules Bied to obtain a cement which would be resistive to the attack of sea water The first high alumina cement was produced in France about 1912, but the early strength was probably not appreciated prior to its use for artillery foundations during the war Lumnite cement, placed on the market in this country in 1924, was the first cement of this character manufactured in the United States; and, up to the present time, we have in this country only this one brand There are, however, at least five such cements made in France and Switzerland.

Raw materials—High alumina cements are produced commercially by fusing a mixture of limestone and bauxite. The raw materials used are not so widely distributed as those used in the making of Portland cement, and it seems that the range of impurities allowable in limestone for the making of high alumina cement is less than that used for Portland cement.

Bauxite is an ore composed of hydrated alumina Three hydrates of alumina are commonly found in nature· $Al_2O_3\ H_2O$ (diaspore); $Al_2O_3\ 2\ H_2O$ (theoretical bauxite), and $Al_2O_3\ 3\ H_2O$ (gibbsite). Bauxite ores may contain varying amounts of each of these hydrates together with iron oxide, silica, water, titanium oxide, and clay. It occurs as an earthy mineral, never crystallized, and may show a great variety of forms and colors Its chief use is in the manufacture of metallic aluminum The requirements for this use ordinarily are above 52 per cent alumina (Al_2O_3), not over 4 5 per cent silica (SiO_2), and not over 6 5 per cent iron oxide (Fe_2O_3)

The amount and extent of bauxite deposits of the required character for making high alumina cement are not definitely known The purity of the bauxite required and its availability are factors in the manufacturing cost of high alumina cement Bauxite deposits in this country seem to be confined to certain southern states The United States is a large producer of bauxite Arkansas furnished about 90 per cent of the domestic production of bauxite Deposits are also being worked in Georgia, Alabama, and Tennessee, and other southern states are known to have deposits

Manufacture —It is not within the scope of this paper to go into much detail regarding the process of manufacture The process of manufacturing high alumina cements consists essentially of fusing a mixture of limestone and bauxite and pulverizing the resulting product Several methods are employed for fusing the raw materials, namely, vertical type of furnace, electric furnace and rotary kiln Descriptions of the processes used in France are found in the technical literature. A vertical type of furnace is used in France, while it is the understanding that the company now producing Lumnite cement uses a rotary kiln E. C. Eckel has recently patented a new type of vertical furnace and predicts the manufacture of high alumina cement at less cost No record has been found of any company which has as yet used the Eckel patent on a commercial scale Lumnite cement is usually very finely ground, not over 10 per cent being retained on a 200-mesh sieve. After grinding, the cement appears as a brown powder.

Composition —It has already been pointed out that high alumina cements differ greatly in chemical composition from Portland cements They have in general a much higher alumina content, a somewhat higher iron oxide content, and a lower content of lime (calcium oxide) and of silica

The essential constituents of these cements are probably dicalcium silicate ($2\,CaO\;SiO_2$) and monocalcium aluminate ($CaO\;Al_2O_3$) Certain other calcium aluminates may also be present in small amounts[1] These are $3\,CaO\;5\,Al_2O_3$ and $5\,CaO\;3\,Al_2O_3$. Each of these aluminates is known to be hydraulic and quick-hardening[2] Tricalcium aluminate ($3\,CaO\;Al_2O_3$), the aluminate found in normal Portland

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[1] (1) Chemical Abstracts, 19, 2117 (1925)
(2) Bates, Technologic Paper No 197, Bureau of Standards, p 27

[2] (1) Chemical Abstracts, 16, 1845 (1922)
(2) Chemical Abstracts, 14, 1422 (1920)
(3) Bates, Technologic Paper No 197, Bureau of Standards, p 4
(4) Bates, Journal of American Chemical Society, 1, 679–96 (1918)

cement, is not present. The quick hardening properties of high alumina cements are due therefore to the setting and hardening of these low-calcium aluminates.

The time of setting corresponds rather closely to that of Portland cement. This allows the handling of concrete in the way usual for Portland cement concrete.

At the present time we have no standard specifications in the United States for either the chemical composition or physical properties of this cement. Such a specification is necessary to safeguard the user.

Properties.—Unless otherwise stated, this paper will be limited to reports of tests on the Lumnite cement manufactured in this country. When comparing tests it should always be borne in mind that the optimum conditions for the development of full strength have probably not been fully established for this cement.

The two outstanding properties claimed by the producers of alumina cements are early strength, and resistance to attack by sea water.

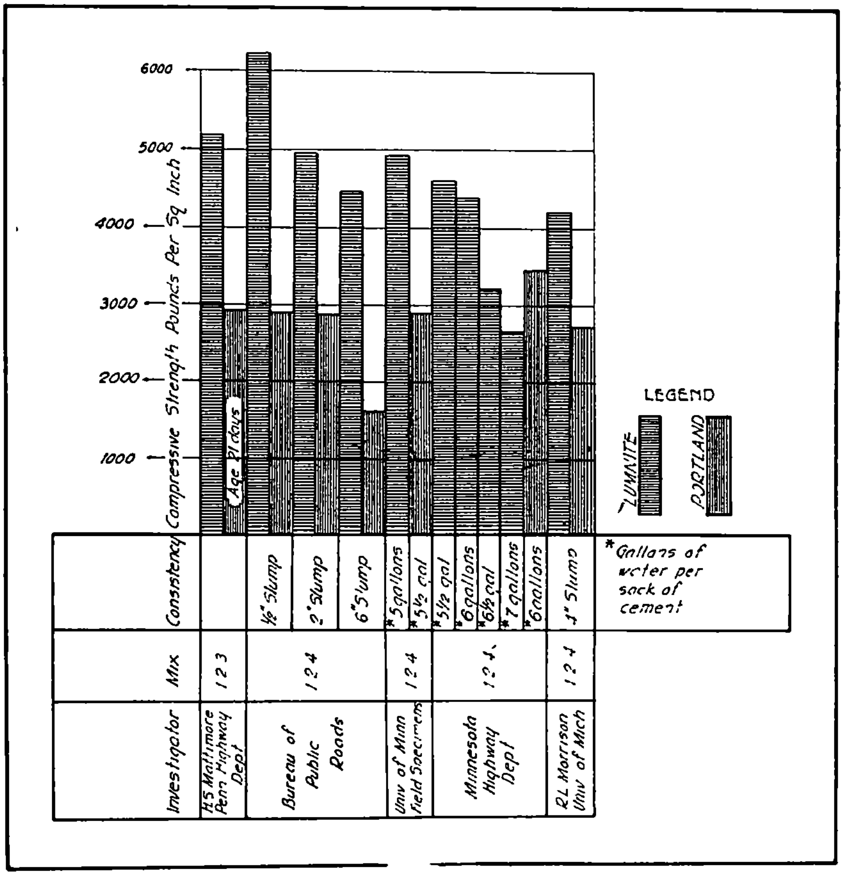


Figure 1—Comparison of Lumnite cement at 24 hours and Portland cement at 28 days

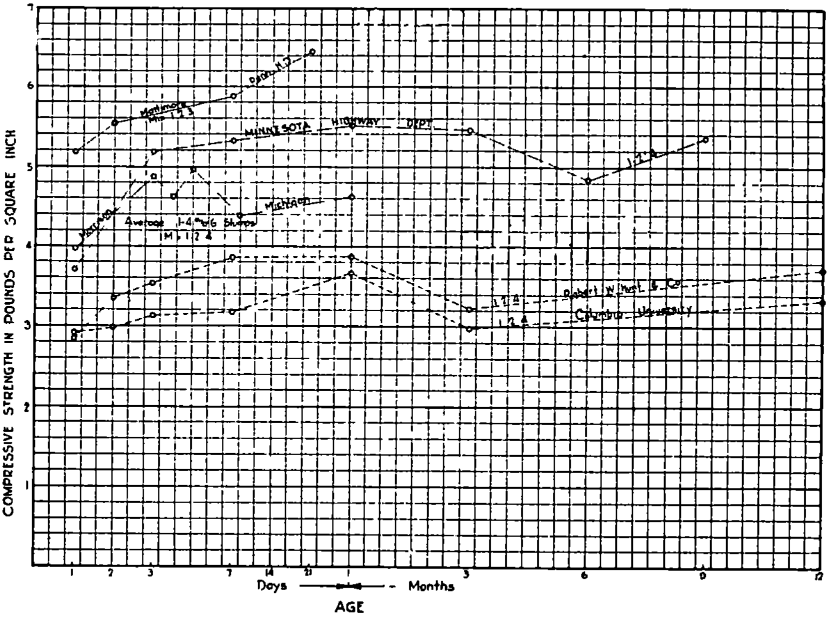


Figure 2—Effect of age on strength of Lumnite cement concrete

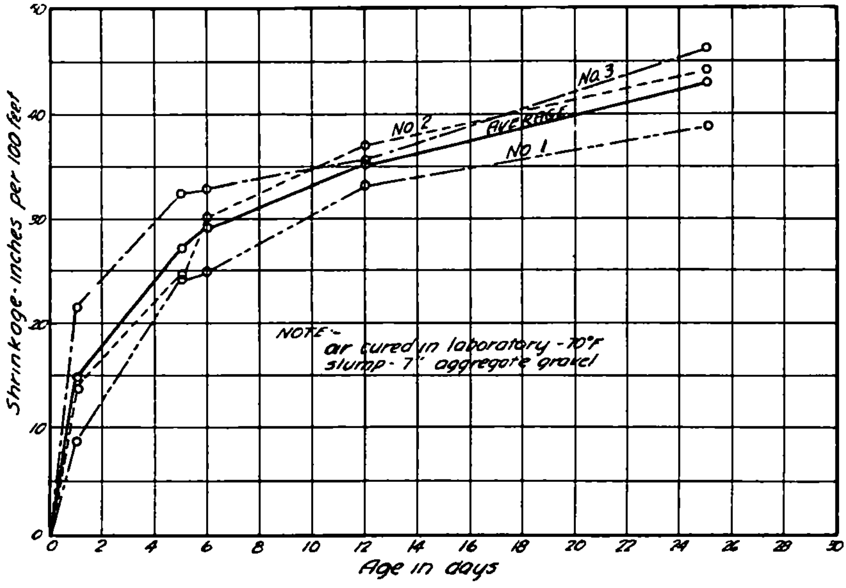


Figure 3—Shrinkage of Lumnite cement concrete beams. Mix 1:2:4

(a) *Early Strength* —Figure 1 shows the relationship between 24-hour strength of Lumnite cement concrete compared with 28-day strength where Portland cement was used under similar conditions The mix is 1 2 4 in all cases except the one on the left where 1 2 3 concrete was used, and it will be noted the age of this Portland cement is 21 days, whereas all the rest are 28 days In all of these tests the 24-hour strength of the Lumnite cement concrete is greater than Portland cement concrete at 28 days—in some cases twice as much The early high strength of this cement has been established

(b) *Effect of Age on Strength* —Figure 2 shows the strength at different ages It will be noted that some investigators have found a slight decrease in strength at different ages while others have shown a steady increase On account of the decrease in most cases being rather slight, it is possible that it may be accounted for by other variables than age

Tests carried out by the Laboratorie National des Ponts et Chaússes (Paris) show a steady increase in the strength of concrete made with Ciment Fondu over a period of five years

(c) *Expansion and Contraction* —Figure 3, by Professor M. B. Lagaard, of the University of Minnesota, is all the committee was able to find on this subject This shows the shrinkage during setting period of Lumnite cement concrete (mix 1 2 4) The beams were placed in the laboratory and were air-cured Further information is needed on shrinkage during setting, as well as expansion and contraction caused by moisture and temperature changes.

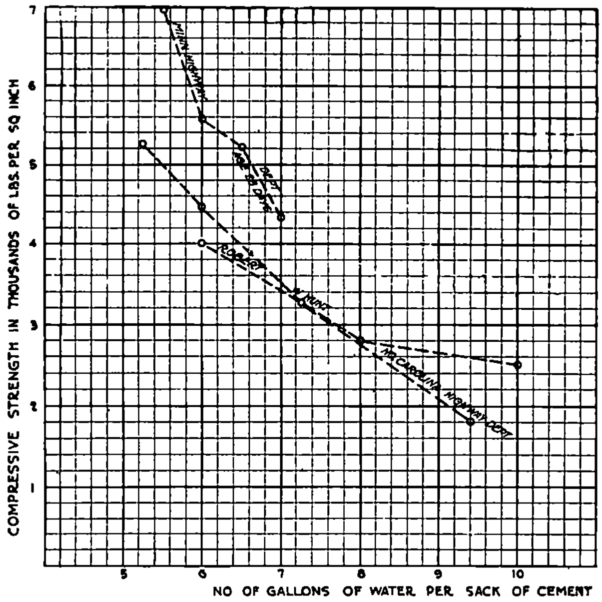


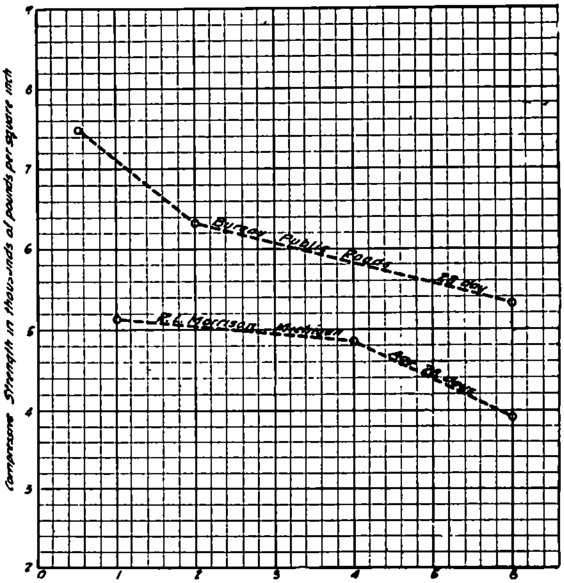
Figure 4—Effect of water on strength of Lumnite cement concrete. Mix 1·2 4

(d) *Bond to Portland Cement Concrete*—Professor R. L Morrison, of the University of Michigan, made tests on the bond between Lumnite cement mortar and Portland cement mortar by replacing six half briquettes of Portland cement mortar in the mould and filling the rest of the space with Lumnite cement mortar The new briquettes formed in this manner were broken at the end of 24 hours and showed bond strength as follows

280, 125, 325, 240, 95, and 190 pounds per square inch

He reports that in one case half the fracture was through the old Portland cement mortar instead of being all at the joint

Mixing, Placing, and Curing—Investigations made to date show that further research is needed on the proper way to proportion, mix, and cure Lumnite cement concrete



Slump in Inches

Figure 5—Effect of water on strength of Lumnite cement concrete

(a) *Quantity of Mixing Water*—Investigations have shown that excess mixing water decreases the strength Figure 4 shows the relationship between strength and number of gallons of mixing water per sack of cement Note the rapid falling off in strength with increasing water content Figure 5 shows the same thing only the amount of mixing water is shown by the consistency or slump.

(b) *Curing and Setting Temperature*—Early instructions from the manufacturing company stated that for several hours after setting,

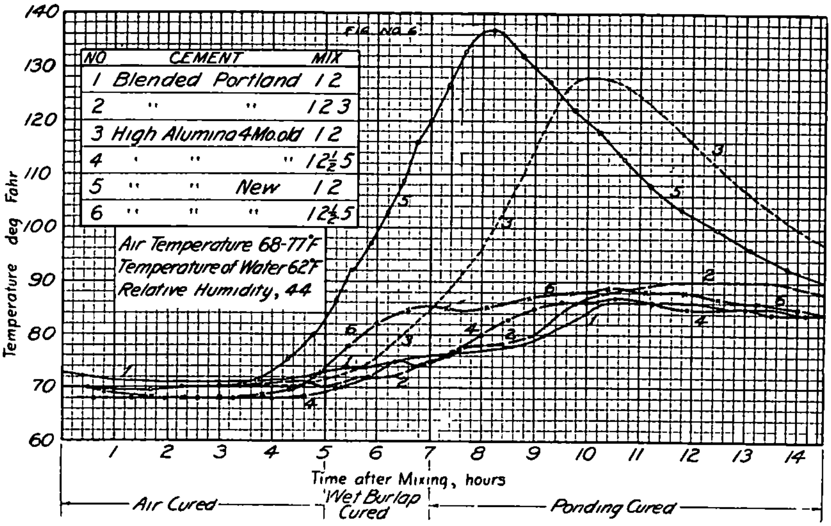


Figure 6—Hydration point of Portland and high alumina cements (H S Mattimore, Pennsylvania Highway Department)

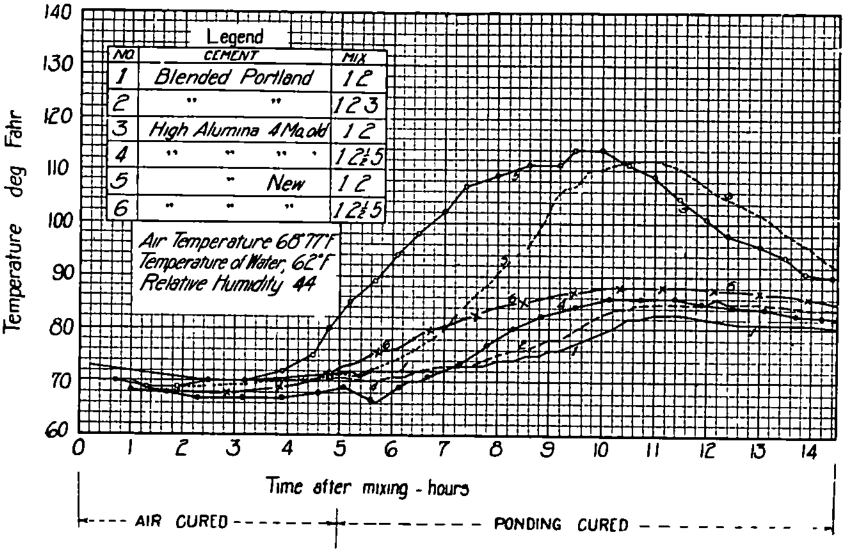


Figure 7—Hydration point of Portland and high alumina cements. Wet burlap not used (H. S. Mattimore, Pennsylvania Highway Department)

exposed surface of the concrete should be kept damp to prevent incomplete hydration indicated by dried out spots. Early investigators cured the Lumnite cement concrete as they had Portland cement concrete, that is, by keeping the surface moist as soon as it is moulded and keeping it sprinkled in moist curing room up to the time of testing. Some investigators noticed defective surfaces, varying from the so-called dusty surface to the distinct scale ⅛ inch or greater in depth.

Figures 6 and 7 are taken from H. S. Mattimore's paper before the American Society for Testing Materials, June, 1925. It will be noted in Figure 6 that the increase in temperature begins about the fifth hour and the heat generated varies directly according to richness of mix. The blended Portland 1:2:3 mix starting from 70° F. increased to a maximum of 90° F. in about 12 hours, while a 1:2½:5 Lumnite reached a maximum of about 88° F. in about 9 hours. The Portland cement in a 1:2 mix reached a maximum of 86° F. in 10¼ hours, and the Lumnite reached a maximum of 137° F. in about 8 hours.

Figure 7 shows the same conditions as the previous one except that the ponding was started at 5 hours, whereas in the previous citation there were 2 intervening hours during which it was covered with wet burlap. The temperatures were kept lower in the second method. Mr. Mattimore draws the following conclusions as the result of his investigation:

1. High-alumina cement has compressive and transverse strengths at 24 hours greater than those of Portland cement concrete at 28 days.
2. Wet burlap curing, effective for Portland cement concrete, increases the temperature during hydration and produces a defective surface when used with high-alumina cement concrete.
3. Application of moisture at too early stages either by sprinkling, ponding, or covering with wet burlap produces a dusty or scaled surface.
4. Water curing should be started when hydration is well under way as indicated by a rise in temperature. This can be detected by a stiffening of the surface and a drying out appearance. Under laboratory humidity and temperature conditions, the safe period was found to be 7 hours after mixing.
5. Storage or air curing in bags reduces the high temperature during hydration and also delays the hydration. After 4 months storage in bags the hydration was delayed about 2 hours.

The manufacturing company now advocates such a method of curing. Further investigations are needed as to cause of dustiness and scaling and how to avoid it. It is impracticable to do extensive outside work and at all times protect freshly placed concrete from rain, which, according to Mr Mattimore's conclusion No 3, causes a defective surface

Figure 8 shows results of tests conducted by Professor M B Lagaard, of the University of Minnesota. The temperature readings were taken during setting period of an insulated cylinder and of another cylinder exposed to air in laboratory maintained at about 72° F

Early hardening and the capacity to generate heat during setting are advantageous properties of cements for cold weather construction. In the case of Lumnite cement your Committee on Character and Use of Road Materials is in doubt as to just what is best curing practice for such conditions. The concrete must be protected from frost up to the time that heat is generated, and, if too cold, after that time There is danger in heating with salamanders or covering, in that there may be excessive heat causing defective surface and perhaps defective concrete Too high and too low temperatures are both detrimental The ponding may be advisable on pavement slab or floors at summer temperatures, but this practice is questionable at zero temperatures especially on structures Whereas considerable more care will probably be required for curing of Lumnite cement concrete it will be for a much shorter period than for normal Portland cement concrete

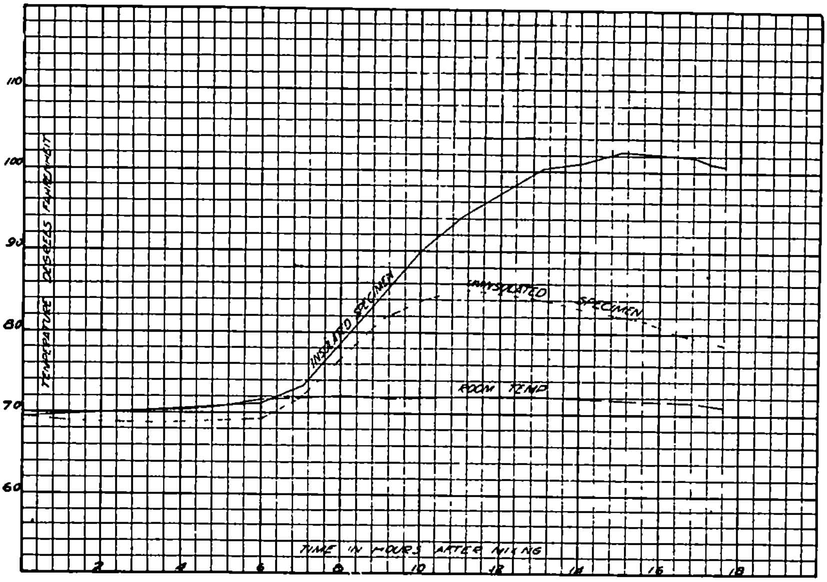


Figure 8—Rise in temperature during setting period of Lumnite cement concrete. Mix 1 2 4 (M B Lagaard, University of Minnesota)

Use of Admixtures—The company manufacturing Lumnite cement states that admixtures such as other cements, limes, and soluble compounds should be avoided.

Dr Haegermann, of Germany, in his paper presented at the 1924 annual meeting of the Portland Cement Association in Chicago, said, "It is a decided disadvantage of alcement, however, that it must not be mixed or augmented with other hydraulic cements, the setting being thereby considerably accelerated and the strengths greatly reduced"

Professor Morrison, of the University of Michigan, has shown the effect of additions of Portland cement on setting time

Resistance to Chemical Action—Concrete made in France with high-alumina cement is said to have been very resistant to the action of sea water Test specimens are reported which have been immersed in sea water, saturated calcium sulphate, and 5 to 12 per cent solutions of magnesium sulphate since 1908 without serious deterioration D G Miller, Drainage Engineer for the Department of Agriculture at University Farm, St Paul, reports no action on cylinders made with French Electro-Ciment after two years' immersion in sodium and magnesium sulphate solutions Cylinders made with Lumnite cement have been immersed in Medicine Lake, South Dakota (a typical "alkali" lake) for one year without deterioration

Uses—Some high alumina cements are said to have been successfully used where resistance to sea waters or early strengths were desired

The Paris Lyons Mediterranee railroad is said to have used more than 7,000 tons of Ciment Fondu for tunnels, etc, along its line near Nice where sulphate-bearing soils are encountered

Although the quantity of Lumnite cement used has been limited it has been widely distributed in this country especially where the rapidity of completion of the work was a more weighty factor than the cost The first cost of the cement is, of course, a factor limiting its general use

Certain experimental work carried on in this country will be later reviewed in the Addenda

SPECIAL PORTLAND CEMENTS

Special cements, closely related in composition to normal Portland cement, have been used to give quick hardening concrete These are here all grouped under special Portland cements, even though some of them may not exactly meet Portland cement requirements

These cements depend, in general, for the development of their quick-hardening properties upon the purity of the raw materials, especial care in burning, and very fine grinding of the resultant clinker The responsible constituent seems to be the tricalcium silicate Certain of these cements are characterized by an increase in calcium content, the percentage of lime (CaO) being increased to 65 to 75 per cent

Dr Haegermann, of Germany, in his paper previously referred to states

"For economic reasons the manufacture of these cements could not be undertaken in Germany before 1924 In the first quarter of this year only two factories began manufacturing Later on 15 other works followed

"The value of such cements has not been fully realized, owing to the fluctuations in Germany's economic conditions In the summer of this year overproduction occurred in consequence of the severe restrictions in the building market for want of capital Things have somewhat improved since September and it is interesting to see that the demand for high early strengths cements has increased as against ordinary Portland cement Consumers appeared to be highly satisfied with these cements, and in my humble opinion they will become very popular and be largely used, and it is just in America where great quantities of Portland cement are used in street making that these cements are sure to find a future High-grade Portland cement with high-grade aggregates will produce concrete satisfying the highest demands The latter, viz, high-grade aggregates, have been duly investigated by Professor Duff A Abrams and others in your country

"Strength Tests in Reinforced Concrete Beams and Floorings Professor Ruth has made tests with high-grade cement with beams made of soft and viscous concrete mixed in the proportion of 1 to 5 and 1 to 6 These tests proved that according to the conditions of mixing and the amount of water applied, in 3 to 5 days the safety point in loading demanded for these beams was more than reached "

No record has been found of such cements being manufactured on a commercial scale in the United States

The effect of admixtures in producing early hardening concrete is covered in another portion of this committee report.

SUMMARY

1 Quick-hardening cements are of two general classes, high alumina cements and special Portland cements

2 Some high alumina cements appear to be resistant to the action of sulphate and "alkali" water

3 The early high strengths of high alumina cements have been established

4. High alumina cements have been used for construction where high early strength is important

5 The present high cost of high alumina cement (2 to 3 times that of Portland), limits its use It may be possible, however, that this cost difference will become less as more high alumina cement is produced and the process of manufacturing is improved.

6 Many practical trials of such cements are in progress The results of these tests should be of great interest and of vital importance to all

7 The method of manufacturing high alumina cement in this country is kept secret, but, is admittedly different from that used abroad Lumnite cement was not placed on the general market until 1924 Investigations to date with this cement are favorable although some objections such as scaling and dusting have been noticed under certain conditions Further information is needed as to uniformity of product, best methods of incorporating and curing, durability, expansion, contraction, and adhesion It must not be assumed that the recognized standard methods of using Portland cement are in all respects applicable to high alumina cements

8 At the present time we have no definite specification for purchasing or testing this cement

ADDENDA

I —French specifications for aluminous cements

Rev mat constr trav pub 185, 42(1925) —Aluminous cement shall be produced by heating a mixt of Al_2O_3, SiO_2, Fe_2O_3, and $CaCO_3$, and grinding the product It shall meet the following requirements not less than 30% Al_2O_3, not more than 2% MgO nor more than 1% S, $(SiO_2 + Al_2O_3)/(CaO + MgO)$ less than 1%, not over 20% retained on a screen of 4,900 mesh per square cm , an apparent density of at least 900 G per liter, an initial set in not less than 45 min , a final set in not more than 7 hrs , tensile strength (specimen immersed in sea water 24 hrs), 2 days, not less than 27 kg 7 days, 28 kg , 28 days, 29 kg When specimens are stored in a moist atm for 24 hrs then immersed in sea water, and finally kept at 100° for 3 hrs , they shall not increase in length more than 1 mm between 2 needle points placed at standard distance

II —Tests made by Professor R L Morrison at the University of Michigan These exhaustive tests are reported in the April, 1925, issue of Concrete Certain parts of his article are here quoted verbatim

Tension tests were made using standard sand under varying curing conditions which would most nearly represent construction conditions, also a standard test using natural sand Table I shows the results of these tests

TABLE I
TENSION TESTS, 1 3 MORTAR
Pounds per Square Inch

Age	Standard Ottawa		Natural				Sand	
	1 day moist air, rest dry		2 days moist air, rest dry		3 days moist air, rest dry		1 day moist air, rest water	
Days	*Lumnite*	*Portland*	*Lumnite*	*Portland*	*Lumnite*	*Portland*	*Lumnite*	*Portland*
1	360	113	?				492	165
2	320	127	415	183				
3			333	187			673	292
4	388	172	353	182	363	178		
7							635	352
28		270	382	332	507	413	690	540
83	417	369	395					

The mortar compression tests were made upon 2 inch by 4 inch cylinders and 2 inch by 2 inch cylinders, the composition and curing conditions being the same as in the case of the tension tests The last set of briquettes and cylinders was broken at 83 days, because if they ran longer the results would not be available at this time Results are given in Table II and Portland check tests results in Table III.

TABLE II
COMPRESSION TESTS, 1 3 MORTAR
Aluminate Cement
Pounds per square inch

Age	Standard Ottawa sand				Natural sand			
	1 day moist air, rest dry		2 days moist air, rest dry		3 days moist air, rest dry		1 day moist air, rest water	
Days	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*
1	6,125	6,340					6,072	7,144
2		6,414	5,624	5,668				
3			5,730	6,656			6,252	8,211
4	6,220	6,741	5,605	5,621	5,297	6,581		
7							4,698	7,167
28		7,195		7,131		7,112	6,082	9,145
83		7,094		7,097				

TABLE III

COMPRESSION TESTS, 1 3 MORTAR

Portland Cement (for Comparison)
Pounds per square inch

Age	Standard Ottawa sand				Natural sand			
	1 Day moist air, rest dry		2 Days moist air, rest dry		3 Days moist air, rest dry		1 Day moist air, rest water	
Days	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*	*2x4 Cyl*	*2x2 Cyl*
1	647	677					843	1,037
2	1,047	1,167	1,143	1,183				
3			1,340	1,483			2,190	2,342
4	1,630	1,650	1,550	1,863	1,247	1,747		
7							3,117	2,610
28	2,060	2,163	2,330	2,457	2,597	3,120		3,950
83			2,667	2,853			4,257	3,690

In making the concrete compression tests, a bank-run gravel was screened into separate sizes and then remixed in predetermined proportions so that the aggregate in the various cylinders would be as nearly uniform as possible

Table IV shows the properties of the aggregate after it was remixed ready for use

TABLE IV

PROPERTIES OF AGGREGATES USED IN CONCRETE CYLINDERS

MATERIAL—Bank-run gravel, screened and remixed
WEIGHT PER CUBIC FOOT—122 pounds
VOIDS—22 6 per cent

ABRASION TEST	
Plain cylinders, Test No 1, per cent of wear	5 6
Test No 2, per cent of wear	6 7
Average	6 2
Slotted cylinders, Test No 1, per cent of wear	10 7
Test No 2, per cent of wear	11 8
Average	11 2

Objectionable particles—1 6 per cent

MECHANICAL ANALYSIS

Screen	Per cent passing	Screen	Per cent coarser
1½ inches	100 0	100 mesh	97 0
1 inch	82 0	48 mesh	92 0
¾ inch	71 0	28 mesh	79 0
½ inch	54 0	14 mesh	72 0
¼ inch	37 0	8 mesh	67 0
8 mesh	33 0	4 mesh	63 0
10 mesh	32 0	⅜ in mesh	50 0
20 mesh	26 0	¾ in mesh	26 0
30 mesh	18 0	1½ in mesh	
40 mesh	14 0		
50 mesh	7 0	Fineness modulus	5 46
80 mesh	4 0		
100 mesh	3 0		
200 mesh	0 5		
Clay and silt	1 5		

Table V shows strengths obtained using various mixes and slumps, all cylinders being cured in moist air.

Table VI shows strengths at 4, 5, 8, and 29 days under various curing conditions

Tables VII and VIII give the results of check tests using Portland cement All cylinders were 6 inches by 12 inches in size.

TABLE V

COMPRESSION TESTS OF CONCRETE ALUMINATE CEMENT CYLINDERS, CURED IN MOIST AIR STRENGTH IN POUNDS PER SQUARE INCH

Mix	Per cent cement	Slump	1 Day	3 Days	4 Days	5 Days	8 Days	29 Days
1 4 8	7 7	1 in	843					
1 4 8	7 7	4 in	456	1,589	1,324	1,242	1,218	1,111
1 4 8	7 7	6 in	450					
1 3 6	10 0	1 in	2,160					
1 3 6	10 0	4 in	1,157	3,137	2,375	2,344	2,073	2,325
1 3 6	10 0	6 in	690					
1 2 4	14 3	1 in	4,537	5,035	5,040	5,091	4,789	5,109
1 2 4	14 3	4 in	4,187	4,973	4,747	5,349	4,615	4,856
1 2 4	14 3	6 in	3,222	4,626	4,079	4,495	3,742	3,943
1 2 3½	15 4	1 in	5,203					
1 2 3½	15 4	4 in	4,728					
1 2 3½	15 4	6 in	4,133					
1 1½ 3	18 2	1 in	5,731					
1 1½ 3	18 2	4 in	5,052					
1 1½ 3	18 2	6 in	4,523					
1 1 2	25 0	1 in	6,449					
1 1 2	25 0	3 in	5,491					
1 1 2	25 0	6 in	5,846					

TABLE VI

ALUMINATE CEMENT CYLINDERS—COMPARISON OF CURING METHODS

Mix Slump	1 2 4 1 in	1 2 4 3 in	1 2 4 6 in	1 3 6 3 in	1 4 8 3 in
Age—4 days					
1 Day moist air, 3 days dry air	5,406	5,092	4,530	2,589	1,429
2 Days moist air, 2 days dry air	5,105	5,160	4,496	2,549	1,410
4 Days moist air	5,040	4,747	4,079	2,375	1,324
Age—5 Days					
1 Day moist, 4 days dry air	5,289	5,096	4,967	2,533	1,447
2 Days moist air, 3 days dry air	5,846	5,025	4,520	2,752	1,459
5 Days moist air	5,091	5,349	4,495	2,344	1,242
Age—8 Days					
1 Day moist air, 7 days dry air	5,007	5,498	3,884	2,431	1,647
2 Days moist air, 6 days dry air	5,482	4,855	3,651	2,479	1,526
8 Days moist air	4,789	4,615	3,742	2,073	1,218
Age—29 Days					
1 Day moist air, 28 days dry air	4,679	4,946	4,139	2,517	1,583
2 days moist air, 27 days dry air	5,338	4,969	4,011	2,397	1,552
29 Days moist air	5,109	4,856	3,943	2,325	1,111

RELATIVE STRENGTH ALL MIXES

Curing	4 Days	5 Days	8 Days	29 Days	Average
1 Day moist air, rest dry	108	104	112	103	107
2 Days moist air, rest dry	107	106	109	105	107
Total time moist	100	100	100	100	100

TABLE VII

PORTLAND CEMENT CYLINDERS, CURED IN MOIST AIR

Strength in Pounds Per Square Inch

(All 4 inch Slump)

Mix	Per cent cement	1 Day	3 Days	4 Days	5 Days	8 Days	29 Days
1 4 8	7 7			209	260	282	589*
1 3 6	10 0	±95	561*		544	662	1,205
1 2 4	14 3	235	755	958	1,144	1,567	2,705

± Broke before load was applied

* Age 35 days

TABLE VIII

CHECK TESTS ON PORTLAND CEMENT—COMPARISON OF CURING METHODS

(All 4 inch Slump)

Mix	124	136	148
Age, 4 days			
1 Day moist air, 3 days dry air	901	512	232
2 Days moist air, 2 days dry air	1,067	524	249
4 Days moist air	958		209
Age, 5 days			
1 Day moist air, 4 days dry air	906	565	269
2 Days moist air, 3 days dry air	1,147	523	247
5 Days moist air	1,144	544	260
Age, 8 days			
1 Day moist air, 7 days dry air	1,302	732	331
2 Days moist air, 6 days dry air	1,395	620	302
8 Days moist air	1,567	662	282
Age, 29 days			
1 Day moist air, 28 days dry air	1,453	807	368
2 Days moist air, 27 days dry air	2,218	953	326*
29 Days moist air	2,705	1,205	589

* Age 35 days

RELATIVE STRENGTH ALL MIXES

Curing	4 Days	5 Days	8 Days	29 Days	Average
1 Day moist, rest dry	94	89	94	58	84
2 Days moist, rest dry	105	98	92	78	93
Total time moist	100	100	100	100	100

TABLE IX
EFFECT ON SETTING TIME OF ADDITION OF PORTLAND CEMENT

Per cent of Lumnite	Per cent of Portland	Per cent of water	Setting time					
			Initial			Final		
			1	2	Ave	1	2	Ave
100	0	21 4	6 00	6 45	6 23	7 50	7 00	7 25
90	10	23 0	4 09	3 55	4 02	4 54	4 45	4 49
85	15	23 4	3 00	2 45	2 53	3 50	3 20	3 35
80	20	24 4	2 40	2 50	2 45	3 40	3 45	3 43
75	25	25 0	3 23					
67	33	26 0	2 23					
60	40			Flash			Flash	
55	45			Flash			Flash	
50	50			Flash			Flash	
45	55			Flash			Flash	
40	60			Flash			Flash	
33	67	23 0				03	05	04
25	75	23 0	02	07	05	08	09	09
20	80	22 8	05	04	05	09	07	08
15	85	22 4	19	17	18	27	26	27
10	90	22 4	2 30	1 50	2 10	4 05	3 30	3 48
0	100	22 8	4 10	4 45	4 27	6 10	6 15	6 13

"The most interesting property demonstrated by these tests is the very high strength attained by aluminate cement at 24 hours, the strength being greater than that of Portland cement at 28 days Maximum strength seems to be reached at from 3 to 5 days The strength of the best 1 2 4 aluminate cement concrete at 5 days was almost exactly twice as great as the strength of the best 1 2 4 Portland cement concrete at 29 days

"It is frequently stated that aluminate cement requires more water than Portland cement, but the results of these tests are not in accord with that statement The strength of the aluminate concrete was, in practically all cases, inversely proportional to the amount of water used. When the strengths were plotted, the curves representing the various slumps are approximately parallel lines, the greatest strength occurring with the use of the smallest amount of water It took practically the same amount of water to produce a given slump with aluminate cement as with Portland cement

"When the strengths of the various mixes are plotted so as to show the relation between the strength and the per cent of cement in the mix, the resulting curves are practically straight lines except for a break at the 1 2 3½ mix This refers to the 24-hour strength only as the investigation has not included sufficient tests, as yet, for the determination of these relationships at later periods At 29 days a 1 4 8 aluminate cement concrete has about the same strength as a 1 3 6 Portland cement concrete, while 1 3 6 aluminate is about as strong as 1 2 4 Portland

"Absence of moisture during the curing periods seems to have much less effect on aluminate cement than upon Portland cement. In fact, in almost every case the cylinders cured in dry air were stronger than those cured in moist air, the average difference in strength being 7 per cent.

"In nearly all cases where the unit crushing strength was more than 4,000 pounds, the aggregate was fractured

"An important question when aluminate cement concrete is used in connection with Portland cement concrete is the strength of the bond between the two materials Six half briquettes of Portland cement mortar were replaced in the moulds and the rest of the space filled with aluminate cement mortar The new briquettes formed in this manner were broken at the end of 24 hours and showed bond strength of 260, 125, 325, 240, 95, and 190 pounds per square inch, or an average of 209 pounds per square inch In one case, about half the fracture was through the old Portland mortar instead of being all the bond

"Many discussions of aluminate cement state that it cannot be mixed with Portland cement without causing a flash set Results of setting time tests made upon such mixtures are given in Table IX and indicate that flash set does not occur unless the proportion of Portland cement falls between 33 per cent and 90 per cent of the mixture

"The tentative conclusion to be drawn from this investigation is that the American aluminate cement, like the European product, is well adapted for use in highway work. While its cost (about three times that of Portland cement) tends to limit its use as a general constructive material, it seems to be well adapted for repair work, and for use in situations where it is urgent that traffic delay be reduced to a minimum It should be possible to open patches to traffic the day after they are placed, thus eliminating the inconvenience and great danger of barricades and difficulty of keeping the patch moist during curing Apparently there would be no difficulty in obtaining a secure bond between the patch and the old pavement. Several state highway departments have constructed experimental sections of aluminate cement concrete pavement and opened them to heavy traffic the following day without serious injury

"Before the final conclusions can be drawn it will be necessary to make long time strength tests, abrasion tests, modulus of rupture tests, etc , and in the meantime the opportunities for observing the behavior of this material under actual service conditions are constantly increasing"

III—Tests by H S Mattimore, Engineer of Materials, Pennsylvania Department of Highways A few excerpts are given from a paper presented at the 1925 meeting of the A S T M

"During the construction by the maintenance forces of the Pennsylvania Department of Highways, of a short section of an experimental road surfaced with high-alumina-cement concrete, a series of test specimens was cast from concrete being placed from a 4-bag capacity concrete mixer These specimens were in the form of beams 6 inches wide, 8 inches deep, and 40 inches in length, for modulus of rupture tests, and 6 by 12 inch cylinders for compression tests In order to secure comparative data, similar specimens of Portland cement concrete were cast from several batches made in the same mixer

"A comparison of the concrete tests made with these cements demonstrates that high-alumina cement produces concrete having considerable higher transverse and compressive strength at 24 hours than Portland cement concrete at 28 days

"It was observed in the examination of the test beams, prior to and after testing, that the surface developed a soft or scaled top, varying from the so-called dusting surface to a distinct scale ⅛ inch or greater in depth This condition was characteristic of all specimens but was more readily observable in the beams than in the cylinders, due to their larger surface area, in fact there was much doubt that it would be detected in a 6 by 12 inch cylinder without critical examination This condition apparently had little or no effect on either the transverse or compressive strengths at the periods recorded in Table II, but such a surface condition is dertimental in floors and concrete road slabs and may affect the durability of any structure" Mr Mattimore's conclusions are quoted on page 153

IV —Test by Columbia University

COMPRESSION TEST RESULTS OBTAINED BY COLUMBIA UNIVERSITY ON LUMNITE CEMENT CONCRETE BLOCK

Series	No 1	No 2	No 3	No 4	No 5
Mix	1 Portland 3 Sand 3 Slag	1 Lumnite 3 Sand 3 Slag	1 Lumnite 3 Sand 3 Slag	1 Lumnite 4½ Sand 4½ Slag	1 Lumnite 6 Sand 6 Slag
Block Per Bbl Cement	60	60	60	90	120
Method of curing	Steam room over night then out of doors until tested	Ditto Series No 1	Out of doors as soon as made and until tested	Ditto Series No 3	Ditto Series No 3
1 day	230 195 210	925 1,000 990	1,600 1,640 1,550	1,230 810 810	445 435 485
Average	212	972	1,597	950	455
2 days	300 315 345	575 690 1,040	1,790 1,850 1,850	1,390 1,400 1,090	670 595 585
Average	320	768	1,830	1,293	617
7 days	615 630 665	950 1,070 1,520	1,930 1,750 1,900	1,020 1,420 1,300	865 800 725
Average	637	1,180	1,860	1,250	797
28 days	900 875 900	1,010 1,240 1,200	2,100 2,110 2,210	1,410 1,560 1,716	635 885 905
Average	892	1,150	2,140	1,577	808

V —Minnesota Highway Department Tests to Show the Effect of Age on Lumnite Cement Concrete, November, 1925

TESTS ON LUMNITE CEMENT USED IN CYLINDERS AND BRIQUETTES

Soundness	O K

Set	Gillmore	Vicat
Initial Set	7 hrs 10 min	6 hrs 20 min
Final Set	8 hrs 20 min	7 hrs 45 min

Retained on 200 mesh sieve	6 89 per cent

TENSION TEST

24 Hours	7 Days	28 Days
385	435	415
420	530	475
385	420	440
425	Av 462	Av 443
365		
340		
Av 387		

TESTS ON FINE AGGREGATE USED IN CYLINDERS

Source—John Wunder Sand & Gravel Co

Passing ¼-inch screen	98 1 per cent

Analysis of part passing ¼-inch screen

Passing No 10	74 2 per cent
Passing No 20	51 0 per cent
Passing No 50	9 5 per cent
Passing No 100	1 7 per cent
Color Plate No 1	
Loss by elutriation	0 75 per cent

TENSILE STRENGTH 1 3 MORTAR
PORTLAND CEMENT

7 Day		28 Day	
Sample	Ottawa	Sample	Ottawa
375	295	540	350
350	275	465	385
390	250	485	400
Av 372	Av 273	Av 497	Av 378
Ratio—1 36		Ratio—1 32	

COARSE AGGREGATE USED IN CYLINDERS

Source—Gravel from John Wunder Sand & Gravel Co

Grading of gravel

Passing 1½-inch screen	100 per cent
Passing ¾-inch screen	60 per cent
Passing ¼-inch screen	5 per cent
Passing ⅛-inch screen	0 0 per cent

TENSILE STRENGTH OF LUMNITE CEMENT BRIQUETTES

Mix 1 part of Lumnite cement
3 parts of standard Ottawa sand by weight
All briquettes stored in moist air for 24 hours and then in water until tested

Age when tested	Cement Water Ratio							
	0 51	0 54	0 57	0 60	0 63	0 66	0 69	0 72
	Tensile strength							
24 hours	388	423	394	371	385	397	378	370
3 days	551	546	495	464	487	472	455	462
7 days	490	491	465	527	515	469	478	470
28 days	455	452	435	447	461	423	414	398
3 months	478	466	436	428	448	413	386	369
6 months	548	505	523	487	479	448	445	450
9 months	582	496	496	487	449	500	479	498

Each figure average of six tests

COMPRESSION TESTS ON 6" x 12" LUMNITE CEMENT CONCRETE CYLINDERS

Mix 1 2 4 by volume
Cured in moist air up until time of testing

Age when tested	Water used gal /sack cement				Portland cement concrete 6 gal water per sack
	5½	6	6½	7	
24 hours	4,475	4,615	3,095	2,815	142
24 hours	4,700	4,490	3,305	2,485	164
24 hours		4,030			189
Average	4,588	4,378	3,200	2,650	165
3 days	5,730	5,510	5,330	4,070	792
3 days	6,740	5,240	4,250	4,580	673
3 days		5,450			715
Average	6,235	5,400	4,790	4,325	727
7 days	5,380	5,500	5,330	4,430	1,520
7 days	6,620	5,500	4,660	5,300	1,460
7 days		5,280			1,610
Average	6,000	5,427	4,995	4,865	1,530
28 days	7,060	5,390	5,260	4,280	3,240
28 days	6,850	5,355	5,160	4,330	3,500
28 days		6,000			3,640
Average	6,955	5,582	5,210	4,305	3,460
3 months	7,470	6,410	4,410	4,765	4,425
3 months	6,480	6,600	4,580	4,000	4,325
3 months		5,275			3,860
Average	6,975	6,095	4,490	4,382	4,203
6 months	6,170	4,240	4,620	4,130	3,660
6 months	5,680	5,250	4,370	3,740	4,200
6 months		5,730			3,880
Average	5,925	5,073	4,495	3,935	3,913
9 months	6,300	5,950	4,965	4,420	3,473
9 months	6,380	5,320	5,264	4,530	4,770
9 months		5,130			4,823
Average	6,340	5,467	5,114	4,475	4,355

Slump test on Lumnite cement concrete using 6 gallons of water per sack of cement was 6½ inches For Portland cement concrete with the same aggregate and same amount of water, the slump was 4½ inches

LUMNITE CYLINDERS FROM UNIVERSITY EXPERIMENTAL PAVING

Age	Breaking load lbs /sq in	Average of three
24 hours	5,050	
	4,800	
	4,900	4,917
48 hours	4,110	
	5,590	
	4,160	4,620
72 hours	5,650	
	5,050	
	4,630	5,110
7 days	6,040	
	5,210	
	5,380	5,543
1 month	4,975	
	5,330	
	5,830	5,378

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