Pergamon

Cement and Concrete Research, Vol. 25, No. 3, pp. 647-657, 1995

0008-8846/95 $9.50+.00

0008-8846(95)00053-4

PROPERTIES OF PASTES, MORTARS AND CONCRETES CONTAINING NATURAL POZZOLAN

M. Jamal Shannag[1], Asim Yeginobali[2]

Dept. of Civil Engineering, University of Michigan, Ann Arbor, MI 48109
Dept. of Civil Engineering, Middle East Technical University, Ankara-Turkey

(Refereed)
(Received May 17; in final form November 9, 1994)

ABSTRACT

Laboratory tests were conducted to investigate the effects of a local natural pozzolan on certain paste, mortar and concrete properties when used as a separate admixture or interground in amounts more than used in the commercial pozzolanic portland cement (i.e. more than 15 % by weight).The pozzolan was ground in two levels of fineness and was used together with some local cements. According to the results the finer pozzolan was more active. It could be added upto 25 % by weight of cement without reducing the 28 day strength. At 35% admixing levels the strength of ordinary portland could be matched at around 90 days. Pozzolanic addition reduced the heat of hydration, somewhat prolonged the setting times and improved the soundness of cements. It caused some increase in mortar shrinkage and slightly reduced the workability of mortars and concretes. Based on the test results the use of the natural pozzolan as a separate concrete admixture and as an addition in the production of a family of blended local cements are recommended.

INTRODUCTION

Pozzolans are materials of natural or artificial origin which are not cementitious by themselves but form a hydraulic cement when mixed with lime hydrate due to their aluminosiliceous composition. Although they have a long history in the production of such simple cements, in recent decades their use has been mostly as additions to portland cements and as admixture to concrete. The reaction of pozzolan with the lime already existing in cement or liberated during the hydration process modifies some properties of the cements and the resulting concrete. Such effects naturally depend on the amount of pozzolan added as well as on the properties of the cement and on the "activity" of the pozzolan added. It can be stated that when the pozzolan is added up to 15 % by weight the resulting "blended" cement is similar to ordinary or modified portland cements with some reductions in density, heat of hydration and early strength. Setting times may be prolonged and sulfate resistance is somewhat improved. Loss in early strength may be compensated by finer grinding. As the pozzolan content increases the blended cement starts resembling the low-heat portland cements. It may also provide increased sulfate resistance but the loss in early strength can be compensated only with time. The strength deficiency of the blended cements becomes serious beyond about 40% replacement levels. Since the pozzolan-lime (or cement) reactions are also not very well understood the properties of the local pozzolan and their potential uses with the local cements can best be judged by laboratory experiments (1,2).

Considering the present limited use of the available natural pozzolan a study was initiated to investigate its effects when added to cement in amounts up to 35 %. The findings of the study could be useful in developing new types of local blended cements and could make separate use of this pozzolan as concrete admixture feasible.

The study was conducted in the laboratories of Jordan University of Science and Technology (JUST) and Jordan Cement Factories Company (JCFC).

MATERIALS USED IN THE STUDY

1. Aggregate

certain cement properties determined according to American Society for Testing and Materials (ASTM) and British Standards (BS) procedures required the use of Ottawa and leighton Buzzard standard sands, for the majority of experiments with mortars a natural sand from Suweileh, Jordan was used. Although it was relatively fine with a fineness modulus of 1.86, the sand was suitable and homogeneous for the laboratory use.

Crushed limestone aggregate, available in the market in three particle size groups were used in the production of the concrete batches. Aggregate properties complied with requirements for use in concrete and the combination of the size groups was formulated to provide a suitable grading.

2. Pozzolan

The natural pozzolan was a blend of certain volcanic tuffs from Tal Rimah region of northeastern Jordan and the same material used in the production of the pozzolanic portland cement from the Fuhais cement plant. It was ground to required levels of fineness at Jordan Cement Factories Company (JCFC) laboratories and delivered to Jordan University in two shipments. Although they were from the same source and had similar compositions, their fineness and activity values were different as shown in Table 1. Therefore, in this study they were referred to as Pozzlan A and Pozzlan B, the latter being ground finer and used in the later stages of the experiments.

3. Cements

All locally produced cements were included in the study. These were:pozzolanic portland, ordinary portland, sulfate-resisting and white portland cements. These cements were blended in the laboratory by adding pozzolan in such amounts that total pozzolan contents of 15, 25, and 35 % were obtained. Additional blended cements were prepared at the factory by intergrinding clinker and gypsum and pozzolanic additions at a fineness around 360 m^2/kg. Clinkers of pozzolanic portland and ordinary portland from Fuhais and Rashadiya cement plants were included. Fineness levels up to 500 m^2/kg were also tried.

Typical Chemical and physical properties of the commercial cements are shown in Tables 2 and 3, respectively. Chemical properties of the interground ordinary portland from Fuhais and Rashadiya are included in Table 2 .

LABORATORY EXPERIMENTS

Cement Pozzolan Dry Mixes

The pozzolan was added to each of the commercial cements in the laboratory by dry mixing the ground pozzolan and the cement thoroughly using an electrical mixer. In addition similar cements were prepared in JCFC laboratories by intergrinding clinker, pozzolan and gypsum at various fineness levels. Some properties of such mixtures such as specific gravity, fineness and oxide compositions could be estimated as weighted averages from the properties of cements and pozzolan and the mixing ratios. Other properties, which also show the effects of pozzolanic addition, were determined with tests on pastes and mortars.

EXPERIMENTS WITH PASTES

The normal consistency water requirement for pastes were determined according to ASTM C187 method*. Pozzolanic additions caused an increase in the required water percentage in proportion with their admixing ratio. Setting times for these pastes were determined according to ASTM C191 using the Vicat instrument. In general pozzolanic additions prolonged the initial setting time. They had similar but less definite effect on final setting. The effects of pozzolans on the setting times of finer interground blended cements were not conclusive. Fig.1 shows some of the results. One of the tests used to determine the soundness of cements was the autoclave test performed according to ASTM C151. The linear strains of prismatic paste specimens were measured after accelerated steam curing. The effect of additions were more conclusive with interground blended cements where increased pozzolan contents actually decreased autoclave expansions. Fig 2 shows the results with such cements. Heat of hydration values at 7 days were determined for the pozzolanic portland cement and its 25 % and 35% blended versions using pozzolan A and B and following the procedure of ASTM C186. As shown in Fig.3 the pozzolanic additions caused almost linear decreases in the heat evolved from the hydration paste.

Table 1
Properties of ground natural pozzolan

Chemical (%)	Type of pozzolan	
	A	B
SiO2	40.1	38.5
Al2O3	13.4	12.8
Fe2O3	12.1	11.9
CaO	9.70	9.60
MgO	10.0	9.70
SO3	-	0.01
Na2O	1.40	1.30
K2O	1.50	1.50
Ignition Loss	9.50	12.5
Insoluble residue	-	11.7
Physical		
Specific gravity	2.62	2.55
Specific surface (m^2/Kg)	420	700
Residue on 38 m sieve (%)	29	13.4
Pozz. activity index	60	83

EXPERIMENTS WITH MORTARS

The standard strength for cements are usually performed on mortar specimens. ASTM C109 specifies a water/cement ratio of 0.485 for the mortar if a portland cement is being tested. For other cements the water content should be determined to bring the standard sand mortar to a similar consistency which corresponds to a "flow" of about 110± 5% as measured by the increase in the base diameter of a molded mortar over a shaking table. Since groups of blended cements and a local natural sand finer than Ottawa sand were used in most of the mortar mixes, flow values

* All the ASTM standard test methods and specifications are from references (4) and (5).

Table 2
Chemical properties of cements.

(%)	Type of Cement					
	Pozzolanic Portland	Ordinary Portland	Sulfate resisting	White cement	Inter. Fuhais	Inter. Rashadiya
CaO	53.0	63.2	64.0	63.8	61.3	62.5
SiO2	23.1	21.2	22.2	24.2	20.2	22.0
Al2O3	6.5	6.1	3.8	4.2	5.3	5.7
Fe2O3	4.1	3.0	4.7	0.5	2.9	2.9
SO3	2.9	2.9	2.5	2.6	3.0	2.9
MgO	5.0	1.4	1.1	0.4	4.0	1.5
Na2O	0.2	_	_	_	_	_
K2O	0.8	0.9	0.7	0.4	0.8	0.7
Ignition Loss	3.6	0.8	0.8	3.2	1.6	1.5
C3S	_	42.8	52.7	39.5	47.7	36.5
C2S	_	28.5	23.9	39.6	21.9	35.5
C3A	_	11.1	2.0	10.3	9.1	10.2
C4AF	_	8.8	14.3	1.5	8.8	8.8

would be different at prescribed water / cement ratio. Since it was time consuming to determine the water content to produce a specified flow, it was more practical to study the change in the flow among various mixes at fixed water/cement ratios such as 0.5 and 0.6. Test results indicated a decrease in the flow of the mortars with increasing pozzolan content. As expected lower values were also obtained when local sand was used instead of the standard sand. Typical results with two cements are shown in Fig.4.

The compressive strength was determined for all cements and blended versions. Except for standard cement tests the local natural sand was used in the mortar. Pozzolan A was used with all commercial cements whereas pozzolan B was used mostly with interground blends. Mainly, two levels of water/cement ratio, 0.5 and 0.6 were tried and kept constant for all mixes to study the effect of pozzolan on mortar strength. Some of the findings are summarized below :

Addition of pozzolan A to pozzolanic portland at 25% level decreased early strengths until 90 day age. At this age the blended cement could match the strength of the commercial pozzolanic portland. The strengths were lower when pozzolan content reached 35% level. However, this cement had also acceptable strengths when compared with blended cements of ASTM C595. When this series was repeated with finer interground mixes, the mix with 25% pozzolan A could match the ASTM C150 limits for portland cements. With 35% addition the mix could reach the 90 day strength of the commercial cement as shown in Fig. 5. The strength of ordinary portland was lowered but still complied with ASTM C150 when 15 % pozzolan A was added. Again with 25%

Table 3
Physical properties of commercial cements

Property		Type of cement: pozzolanic portland	ordinary portland	sulfate resisting	white cement
Specific gravity		3.08	3.15	3.16	3.07
Specific surface (m^2/kg)		410	333	321	335
Normal consistency (%)		26.8	26.6	27.6	25.2
Setting Times (min)	Initial	163	160	190	150
	Final	243	248	280	165
Autoclave soundness (%)		0.07	0.03	0.02	-
Compressive Strength (MPa)	3 day	16.4	19.4	14.8	14.5
	7 day	21.7	22.9	22.6	19.7
	28 day	31.9	30.3	32.3	30.1
Tensile strength (MPa)	7 day	3.6	-	-	2.3
	28 day	4.7	-	-	2.9

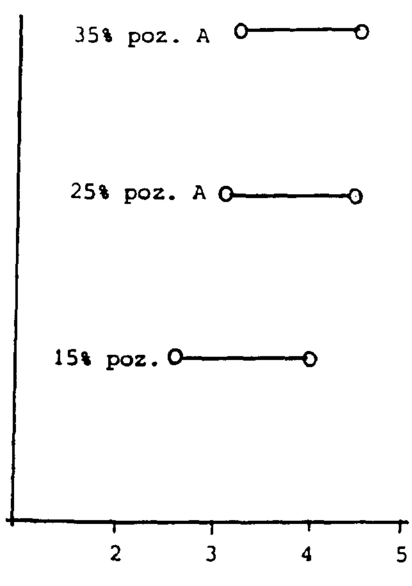

Fig. 1. Setting times for pozzolanic portland.

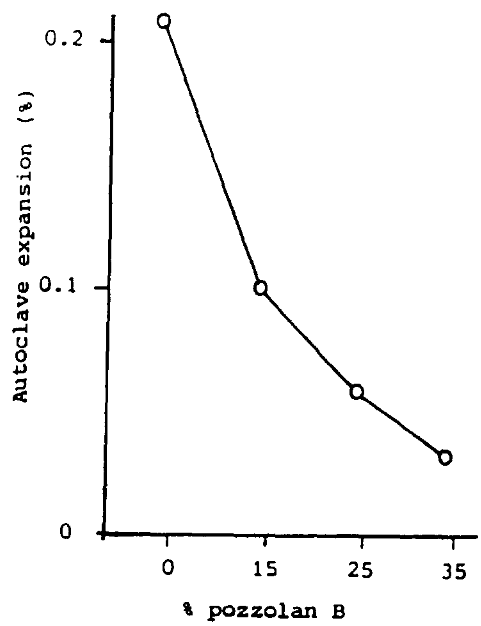

Fig. 2. Soundness of Fuhais ordinary portland.

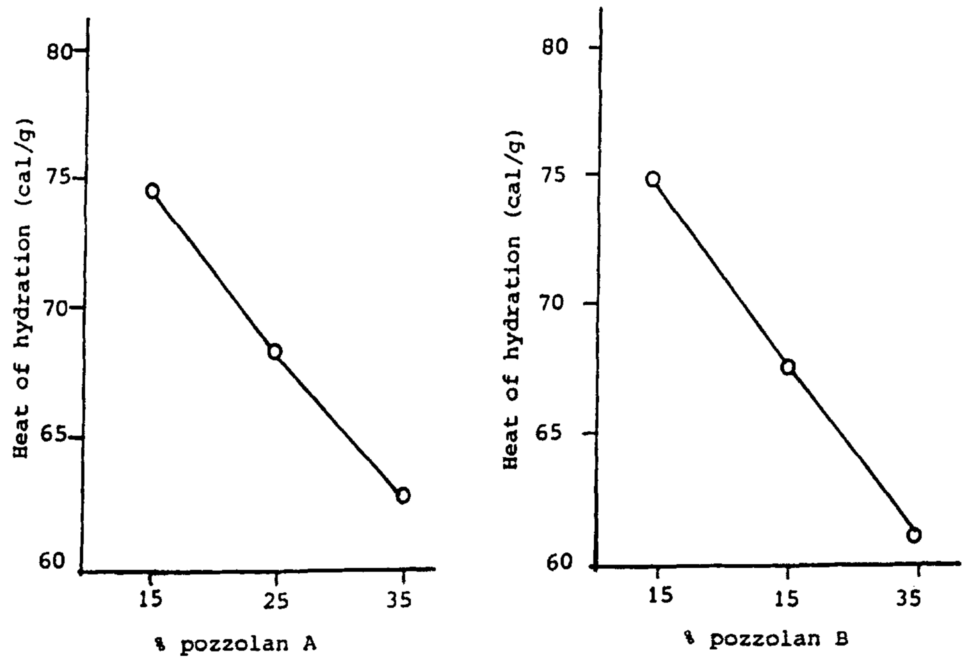

Fig. 3. Effect of pozzolan on heat of hydration of pozzolanic portland cement.

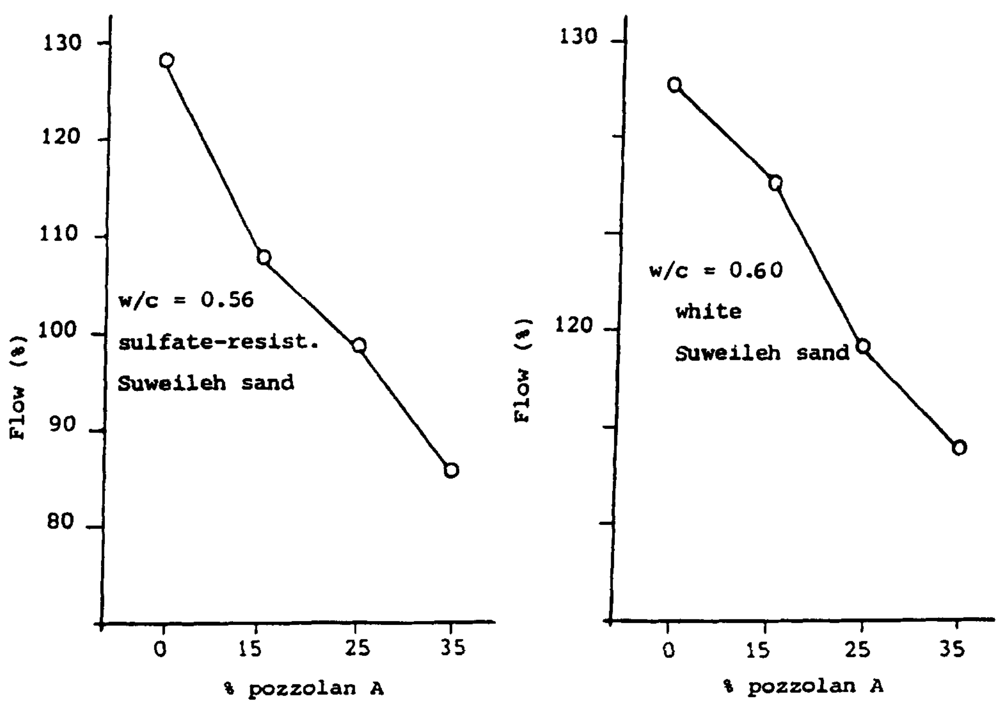

Fig. 4. Effect of pozzolan content on mortar flow.

and 35% pozzolan it could be considered a blended cement according to ASTM C595. The effects of pozzolan A on sulfate resisting and white cements could be described similarly. However, pozzolan A caused more strength reductions with these cements.

Pozzolan B was added to pozzolanic portland and to interground mixes also involving ordinary portland clinkers. Fig. 6 shows its higher activity and effectiveness relative to pozzolan A when used together with pozzolanic portland. The strength results were in conformity with related Jordan standards and 25% addition was quite tolerable. The strengths of interground mixes containing Fuhais clinker and pozzolan B indicated that with a fineness of about 365 m^2/kg, up to 25 % blending was possible and at later ages, even beneficial. Interground mixes with Rashadiya clinker indicated similar effects of pozzolan B on mortar strengths. The results could be arranged to show the optimum pozzolan contents for different ages as presented in Fig.7. The results of another test series showed that by increasing the fineness of the 25% blended mix from 365 m^2/kg to 500 m^2/kg the strengths at all ages could be improved by up to 24 %.

The effect of pozzolan B on shrinkage of mortar was investigated according to ASTM C311 procedure. Although there was an increase in the shrinkage, the total strain was less than the maximum 0.03 % allowed by ASTM C618.

EXPERIMENTS WITH CONCRETES

The experiments were conducted considering a concrete mix which was designed as a typical structural concrete. It contained : 226 kg water , 371 kg cement, 549 kg coarse gravel, 549 kg, 480 kg fine gravel, 429 kg coarse sand and 257 kg fine sand per m3, based on dry aggregate. The cements were pozzolanic portland and pozzolan B blended version. Aggregate was crushed limestone with fine natural sand added. The original 15 % pozzolan content of the cement was increased to 25 % and 35 % levels by additional mixing of pozzolan on weight basis. Water content was slightly increased at 35 % addition level. The concrete batches were repeated in two series to observe the reproducibility of the results. On each batch slump test was performed for workability according to ASTM C143 and strength specimens were cast. The compressive strength was determined on 15 cm cubic specimens at 7, 28 and 90 days ages, (3). Splitting tensile strengths were obtained for some batches following the ASTM C496 procedure. The test results, as the averages of at least three specimens, are shown in Table 4 .

According to Table 4 there was no wide variations in the slump values for the mixes containing increased amounts of pozzolan. Only the mix with 35% pozzolan B was relatively stiff.

Table 4
Properties of the concrete mixes

Pozzolan addition	Batch Series	Slump (cm)	Comp.Strength(MPa) 7 d	28 d	90 d	Split. strength (MPa) 7 d	28 d	90 d
Control	1	7	28.77	40.65	48.34	3.99	4.76	5.58
Mix	2	9	28.99	39.59	47.92	-	-	-
15%	1	8	29.23	40.30	48.56	3.45	4.78	5.29
Pozzolan	2	9	28.88	40.56	48.14	-	-	-
25%	1	10	25.64	36.52	45.34	-	-	-
Pozzolan A	2	9	26.18	36.92	45.32	3.24	-	-
25%	1	7	26.02	39.21	46.76	-	-	-
Pozzolan B	2	7.5	25.99	39.63	46.78	3.39	4.41	5.05
35%	1	9	18.67	31.26	38.34	-	-	-
Pozzolan A	2	11	19.08	30.79	38.32	2.79	-	-
35%	1	6	19.62	32.68	39.12	-	-	-
Pozzolan B	2	7.5	19.26	32.79	40.08	2.77	3.91	4.93

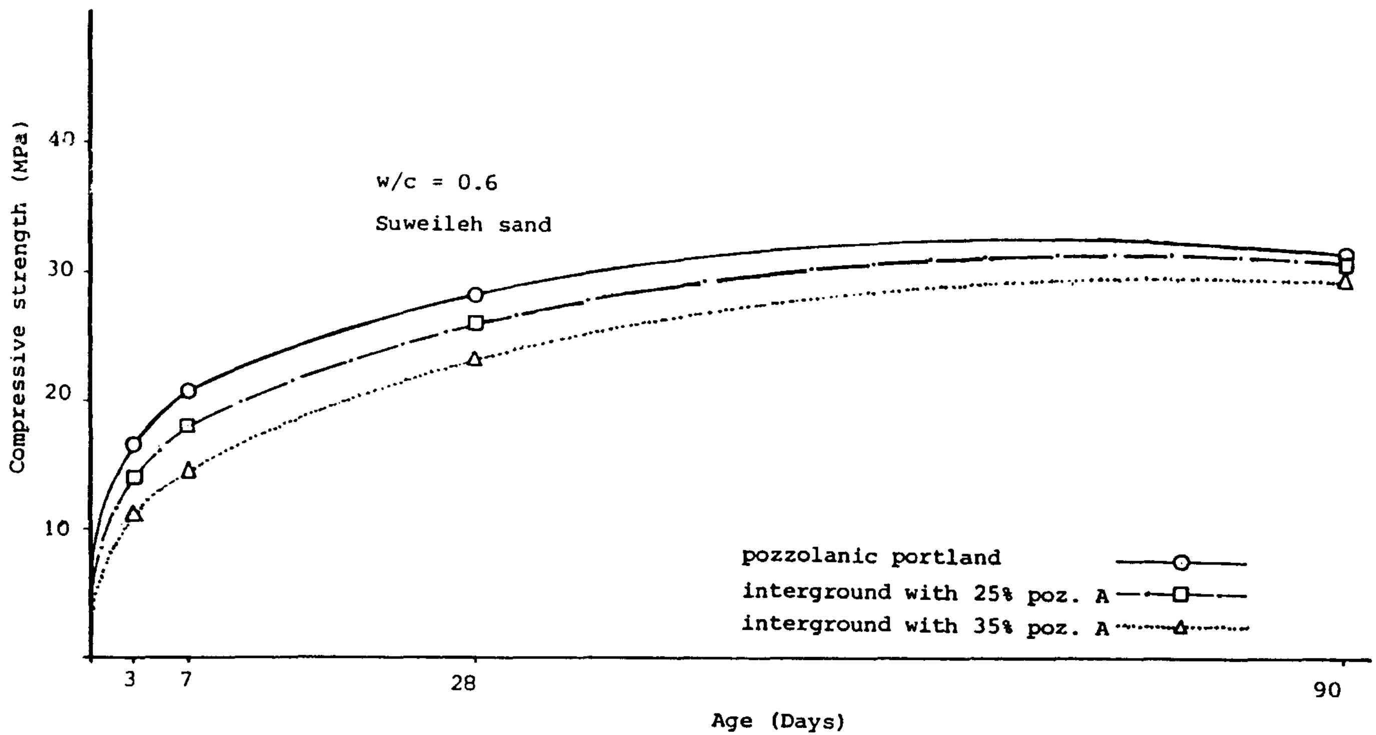

Fig. 5. Compressive strengths of mortars.

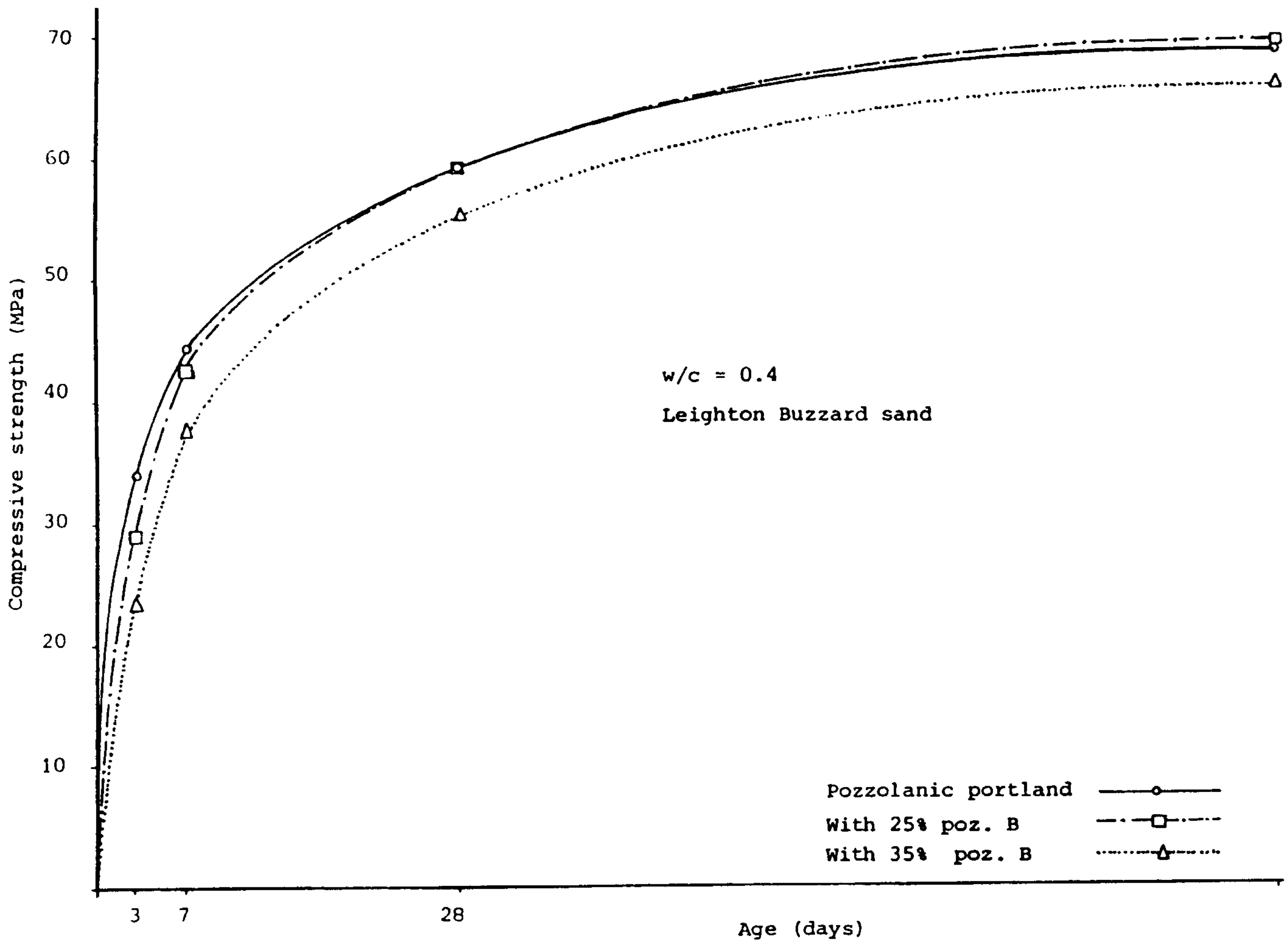

Fig. 6. Compressive strengths of pozzolanic portland and blended versions.

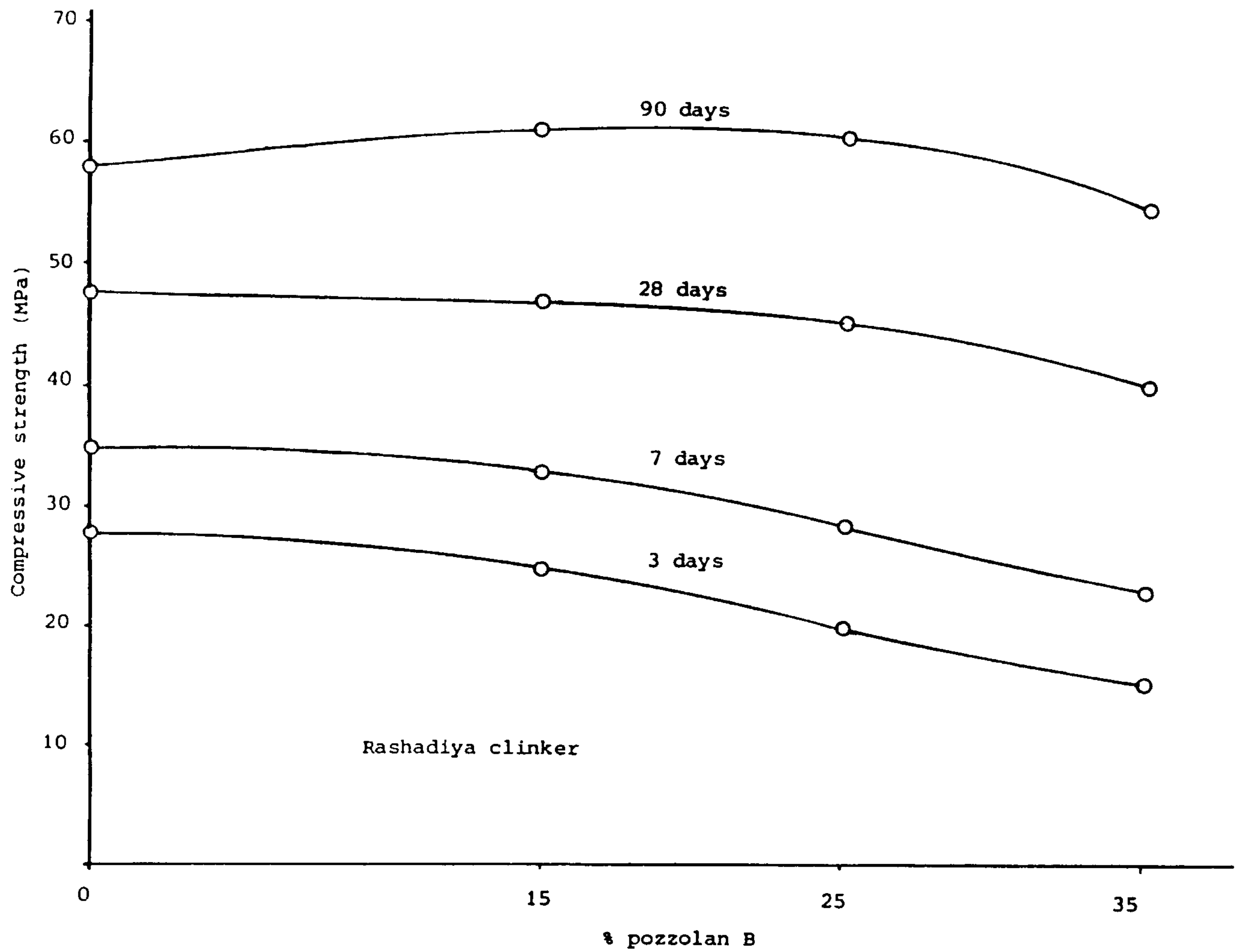

Fig. 7. **Effect of pozzolan content on mortar strength.**

As for the compressive strengths, mixes with 25% pozzolan B developed 28 and 90 day strengths very close to the control strengths obtained with the commercial cement. However, with 35% pozzolan B control strengths could not be matched at any age . Similar mixes containing pozzolan A had slightly lower strengths than the ones containing pozzolan B. The effect of pozzolans on splitting tensile strength of concrete was similar to their effects on compressive strength.

CONCLUSIONS AND RECOMMENDATIONS

Based on the complete experimental data obtained and brief discussions already presented, the following conclusions could be stated:

Pozzolan B had a higher activity index, possibly due to its finer grinding and performed better than pozzolan A. The activity index of pozzolan A did not reach the minimum 75 limit specified by ASTM C618. The activity of pozzolans could change according to the properties of cements they are added to.

When added up to 35% by weight of cement pozzolanic addition caused a reduction in workability of pastes, mortars and concretes, again possibly due to its relatively high fineness.

Pozzolanic addition prolonged the initial setting times. Its effects beyond 25% addition, at finer grinding and on final setting were not clear. In any case all results were confined within usual limits. Pozzolanic addition could improve the soundness of the cement. It reduced the heat of hydration at 7 days by about 9% and 17% for 25% and 35% additions, respectively. Pozzolan seemed to increase the mortar shrinkage but the results were within specified limits.

Pozzolanic addition decreased the early mortar and concrete strengths but resulted in comparable strengths after 28 or 90 days. Considering the interground mixes the one with 25% pozzolan B and 400 m^2/Kg fineness was optimum. It has strengths 3.5% and 10.3% higher than Fuhais ordinary portland at 28 and 90 day, respectively. As a matter of fact, increased fineness and intergrinding improved the strengths of blended cements. Slumps and strengths of concretes containing pozzolan could further be improved by adjustments in the mix design.

Based on the findings of this study, the production of a blended cement with up to 25% pozzolan and with strengths comparable to ordinary portland seems possible and should be tried by JCFC. A family of blended cements using the pozzolan at higher addition levels can be produced and marketed to provide technical and economical advantages in specific local uses. The separate grinding and marketing of the pozzolan as a concrete admixture or for use with other construction materials is also recommended. Field investigations to locate new reserves of natural pozzolans would be useful.

ACKNOWLEDGMENTS

This study was jointly sponsored by the Deanship of Research at Jordan University of Science and Technology and by Jordan Cement Factories Company, (JCFC).

REFERENCES

1. Lea, F.M., Chemistry of cement and concrete, Edward Arnold Ltd., Third Edition, Glasgow, 1970.
2. Yeginobali, A., Some experiences with local pozzolanic materials. In : proceedings of the UN/RILEM/ CIB seminar on low cost housing. Bangkok, Thailand, January , 1987.
3. Neville, A.M., Properties of Concrete, Third Edition, Pitman Publishing, Ltd., London 1981.
4. ASTM, Annual book of ASTM standards. Vol.4.01, cement, lime, gypsum. American Society for Testing and Materials, 1991.
5. ASTM, Annual book of ASTM standards. Vol. 4.02, concrete and mineral aggregates. American Society for Testing and Materials,1991.