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Effect of Latex and Superplasticiser on Portland Cement Mortar in the Hardened State

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Abstract

The report deals with the individual and combined effect of latex and superplasticiser on Portland cement mortar in the hardened state. The selected two superplasticisers (out of five) and four latexes were studied for 7-day and 28-day compressive strength, deformation, ultrasonic pulse transit time, water absorption (three cycles), and some microstructures by SEM of hardened mortar. It has been observed that addition of superplasticisers improved compressive strength, deformation, toughness and water resistance of hardened latex-modified mortar. Also the addition did not alter the tendency for smooth progressive failure of only latex-modified mortar as was evident from ultrasonic pulse transit time.

Keywords: Cement, mortar, latex, superplasticiser, combined effect, compressive strength, deformation, water absorption, ultrasonic pulse time.

INTRODUCTION

This paper is in continuation of Ref. 1. Two superplasticisers, out of five initially selected for compatibility study, and four latexes were used for the preparation and testing of hardened mortars.

MATERIALS

Cement, aggregate and latexes used in this study were the same as in Ref. 1. Two superplasticisers, S_1 and S_5, were selected out of the initial five (in Ref. 1) on the basis of their compatibility with the latexes. Before mixing with the mortar, a silicone-emulsion type defoamer was added to the latex in a weight ratio of 0·7% of silicone solids in the defoamer to the total solids in the latex.

TESTING PROCEDURE

Hardened mortar tests

Hardened mortar specimen cubes of size 70·7 mm^3 were prepared in accordance with IS 4031 in four groups. The first group (UM) consisted of unmodified specimens (UM) with cement:sand = 1:3 (by weight) and w/c = 0·5. In the second group two types of superplasticisers, S_1 and S_5 (2% by weight of cement) were used to form superplasticised mortar mix (SM). In the third group four latexes (A, B, C, D) were used (with 5%, 10%, 15% and 20% solid polymer content by weight of cement) to make latex-modified mortar (LM). In the last group combinations of superplasticisers (S_1 and S_5 type) and latexes (A, B, C, D) were used (SLM). In all the SM, LM and SLM specimens variable water-cement ratios (Table 1)

Table 1. Hardened properties of unmodified and modified mortar specimens (flow = 155 ± 5 mm for all cases)

Serial no.	*Reference*[a]	*Water: cement ratio*	*Ultimate load (Pu) (kN)*		*Deformation at Pu (mm)*		*Toughness at Pu (kN mm/mm³ × 10⁻⁵)*	*Initial tangent modulus (kN/mm²)*	*Pulse transit time (μs)*	*Density (kN/m³)*
			7-day	*28-day*	*7-day*	*28-day*				
1	UM	0·500	78	126	0·35	0·40	8·16	4·22	17·6	21·95
2	SM(S1)	0·390	114	140 (+11·0)	0·38	0·44 (10)	10·48 (28)	4·22	16·4	22·62
3	SM(S5)	0·400	120	142 (+12·7)	0·41	0·48 (20)	11·67 (43)	4·22	16·2	22·00
4	LM(A5)	0·400	96	133 (+5·5)	0·70	0·98 (145)	19·83 (143)	2·17	18·3	21·18
5	LM(A10)	0·357	86	128 (+1·5)	1·41	1·73 (333)	33·85 (315)	1·13	18·7	21·24
6	LM(A15)	0·330	78	122 (−3·0)	1·50	1·81 (353)	33·57 (311)	1·13	18·8	21·10
7	LM(A20)	0·314	68	110 (−12·7)	1·56	1·98 (395)	32·86 (302)	0·85	19·5	21·47
8	LM(B5)	0·410	82	127 (+0·8)	0·95	1·28 (220)	25·77 (216)	1·69	19·0	21·51
9	LM(B10)	0·365	80	130 (+3·0)	1·46	1·82 (355)	35·18 (331)	1·06	18·6	21·30
10	LM(B15)	0·330	68	111 (−12·0)	1·74	2·15 (438)	37·56 (360)	0·85	20·1	21·60
11	LM(B20)	0·308	61	98 (−22·0)	1·98	2·35 (467)	36·77 (351)	0·71	20·5	21·62
12	LM(D5)	0·420	79	132 (+4·7)	0·97	1·31 (227)	27·66 (239)	1·70	19·5	21·24
13	LM(D10)	0·370	83	128 (+1·6)	1·31	1·67 (318)	31·67 (288)	1·06	19·3	21·53
14	LM(D15)	0·350	69	108 (−14·0)	1·68	1·95 (387)	33·37 (309)	0·86	20·1	21·47
15	LM (D20)	0·320	62	95 (−24·6)	2·10	2·36 (490)	35·43 (334)	0·71	21·1	21·42
16	SLM (A5+S1)	0·310	97	138 (+3·7)	0·71	0·98 (0·0)	22·30 (12)	2·13	18·7	21·61
17	SLM (A10+S1)	0·272	107	135 (+5·5)	1·61	1·98 (14)	40·54 (20)	1·21	17·2	22·32
18	SLM (A15+S1)	0·270	85	128 (+5·0)	2·01	2·62 (45)	50·11 (49)	0·77	17·5	21·67
19	SLM (A20+S1)	0·280	77	112 (+2·9)	2·30	3·22 (63)	56·26 (71)	0·57	19·2	21·24
20	SLM (B5+S1)	0·320	91	135 (+6·3)	0·92	1·41 (10)	29·26 (14)	1·42	18·2	21·53
21	SLM (B10+S1)	0·290	84	136 (+4·6)	1·82	2·23 (23)	45·68 (30)	0·85	19·2	21·87
22	SLM (B15+S1)	0·275	76	114 (+2·7)	2·21	2·78 (29)	48·05 (28)	0·61	19·4	21·30
23	SLM (B20+S1)	0·270	70	107 (+9·2)	2·41	2·94 (25)	47·24 (28)	0·53	19·1	21·44
24	SLM (D5+S1)	0·350	96	138 (+4·5)	0·90	1·38 (5·3)	30·12 (9)	1·42	18·6	21·84
25	SLM (D10+S1)	0·320	88	139 (+8·6)	1·65	2·32 (39)	49·95 (58)	0·94	18·6	22·55
26	SLM (D15+S1)	0·310	72	112 (+3·7)	2·18	2·71 (38)	47·49 (42)	0·71	19·3	22·49
27	SLM (D20+S1)	0·280	68	102 (+7·4)	2·38	2·99 (26)	45·92 (30)	0·53	19·7	22·52
28	SLM (A5+S5)	0·300	112	141 (+6·0)	0·91	1·18 (20)	27·12 (37)	1·69	18·1	21·53
29	SLM (A10+S5)	0·273	111	143 (+11·7)	1·74	2·15 (24)	47·78 (41)	0·94	17·0	21·95
30	SLM (A15+S5)	0·280	92	126 (+3·2)	2·10	2·52 (39)	49·28 (47)	0·71	17·1	22·09
31	SLM (A20+S5)	0·280	82	112 (+2·0)	2·40	3·12 (58)	54·68 (66)	0·53	18·8	21·81
32	SLM (B5+S5)	0·320	82	134 (+5·5)	1·10	1·35 (5·4)	28·17 (91)	1·42	17·6	21·81
33	SLM (B10+S5)	0·300	84	136 (+3·8)	1·96	2·40 (32)	49·08 (39)	0·85	18·9	21·64
34	SLM (B15+S5)	0·280	76	118 (+6·3)	2·30	2·76 (61)	52·02 (38)	0·71	19·3	21·41
35	SLM (B20+S5)	0·270	72	104 (+6·1)	2·60	3·20 (36)	51·31 (40)	0·50	18·8	21·50
36	SLM (D5+S5)	0·350	87	134 (+1·5)	1·15	1·51 (15)	31·69 (15)	1·21	18·5	21·81
37	SLM (D10+S5)	0·300	88	135 (+5·5)	1·87	2·50 (50)	52·98 (67)	0·77	18·2	22·30
38	SLM (D15+S5)	0·280	73	112 (+3·7)	2·40	2·67 (37)	46·94 (41)	0·61	19·0	22·26
39	SLM (D20+S5)	0·260	69	106 (+11·6)	2·48	3·10 (31)	50·27 (42)	0·50	19·3	22·52

Table 1. *contd.*

Serial no.	*Reference*[a]	*Water: cement ratio*	*Ultimate load (Pu) (kN)*		*Deformation at Pu (mm)*		*Toughness at Pu (kN mm/mm³ × 10⁻⁵)*	*Initial tangent modulus (kN/mm²)*	*Pulse transit time (μs)*	*Density (kN/m³)*
			7-day	*28-day*	*7-day*	*28-day*				
40	LM(C5)	0·430	74	120 (−4·8)	0·84	1·25 (212)	22·94 (181)	—	19·4	20·96
41	LM(C10)	0·410	—	—	—	—	—	—	29·4	20·12
42	LM(C15)	0·400	—	—	—	—	—	—	34·7	20·19
43	LM(C20)	0·400	—	—	—	—	—	—	31·2	20·40

[a]SM(S1) = Superplasticised mortar with S_1 type superplasticiser; SM(S5) = superplasticised mortar with S_5 type superplasticiser; LM(A5) = latex-modified mortar with 5% of latex A; SLM(A5 + S1) = superplasticised–latex-modified mortar with 5% of latex A and superplasticiser S_1.

Notes:

(1) The dosage of superplasticiser for all cases was 2% by weight of cement.
(2) All specimens with C-type latex except for C5% exhibited extremely poor compressive strength, so are not shown.
(3) Values within parentheses show % increase in load, deformation and toughness of SM and LM over UM, and SLM over corresponding LM.
(4) Transit time was measured across a width of 70·7 ± 1 mm for all the specimens.
(5) Density was recorded as saturated surface dry weight per unit volume for 28-day cured mortar.

were used to adjust a flow range of 155 ± 5 mm (ASTM C430, flow table) as obtained in unmodified mixes. Selection of two superplasticisers S_1 and S_5 out of the initial five[1] was based on the fact that S_2, S_3 and S_4 entrained prohibitive amounts of air, delayed setting time inordinately and could not reduce much water content from the latex–mortar system and hence lacked compatibility with the latexes used. Unmodified (UM) and superplasticised mortar (SM) specimens were subjected to moist curing for 7 days at 32–36°C and subsequent air curing at relative humidity 85–90% whilst latex mortar (LM) and superplasticised–latex mortar (SLM) were subjected to 2-day moist curing at 32–36°C and subsequent air curing at relative humidity 85–90%. All the specimens were hand mixed for a batch of three cubes. Time of mixing was restricted to 3–4 min measured from the instant of mixing gauge water. Moulded specimens were vibrated in a mortar vibrator. Table 1 shows reference of each type of specimen.

7-day and 28-day compressive strength and deformation test

A set of 51 types of modified and unmodified specimens were tested at ages of 7 days and 28 days. For each type the average of three specimens was considered. Specimens were loaded uniaxially in a compression testing machine (EPP 300, Mohr and Federhaff, Germany) at 600 kN measuring range. Deformations were recorded using a dial gauge of 0·002 mm least count at an interval of 10 kN load. After attaining peak load the load deformation records were continued to obtain a part of the descending branch of the load–deformation plot. The fracture UM and LM specimens were retained for scanning electron microscopy (SEM) study. The test results are shown in Table 1.

Ultrasonic pulse transit time

Transit time was measured across the specimen, during different stages of loading till failure, by an ultrasonic equipment (CCT-4, Proceq, Zurich, Switzerland; frequency 10 MHz). The transducers were placed on opposite faces of the specimen transverse to the direction of load. Tests were conducted on 20 selected specimens. Ultrasonic pulse transit times at zero load were also recorded for all mortar specimens at 28-day age. Corresponding densities were also measured in each case for comparison (Table 1).

Water absorption test

A set of 39 types of 28-day specimens, unmodified and modified, were oven dried at 100–105C for 72 h, cooled in a desiccator and weighed. The specimens were then immersed in water at 32°C with a head above specimen equal to 300 mm. The specimens were removed from the water from time to time and weighed under saturated surface dry condition after the lapse of 2, 4, 6, 24, 48, 72, 96 and 120 h. This procedure of oven drying and subsequent immersion in water was repeated three times. The values of water absorption with time were recorded for all three cycles. Next, all the specimens were tested for uniaxial

Table 2. Water absorption (average of 3 cycles) and loss (−) or gain (+) in compressive load after absorption test

Reference	*Average water absorbed (%)*	*% Loss or gain in compressive load*	*Reference*	*Average water absorbed (%)*	*% Loss or gain in compressive load*
UM	6·6	−9·8	SLM(B5+S1)	2·3	−4·3
SM(S1)	4·0	−8·1	SLM(B10+S1)	1·8	−4·2
SM(S5)	3·7	−8·8	SLM(B15+S1)	1·7	−3·3
LM(A5)	4·6	−6·5	SLM(B20+S1)	1·6	+2·3
LM(A10)	4·7	−5·9	SLM(D5+S1)	2·5	−3·6
LM(A15)	4·4	−5·5	SLM(D10+S1)	1·7	−5·4
LM(A20)	3·6	+1·5	SLM(D15+S1)	1·8	−5·2
LM(B5)	5·3	−4·0	SLM(D20+S1)	1·4	−1·2
LM(B10)	2·7	−5·3	SLM(A5+S5)	4·9	−4·8
LM(B15)	2·5	−4·5	SLM(A10+S5)	4·1	−4·0
LM(B20)	2·1	+2·7	SLM(A15+S5)	4·1	−5·3
LM(D5)	2·7	−5·6	SLM(A20+S5)	3·4	+2·1
LM(D10)	2·7	−6·0	SLM(B5+S5)	1·8	−3·8
LM(D15)	2·0	−6·3	SLM(B10+S5)	2·5	−4·3
LM(D20)	2·5	−6·4	SLM(B15+S5)	1·9	−4·3
SLM(A5+S1)	4·5	−4·9	SLM(B20+S5)	1·5	+1·8
SLM(A10+S1)	3·6	−4·3	SLM(D5+S5)	2·4	−4·3
SLM(A15+S1)	3·6	−5·3	SLM(D10+S5)	1·3	−3·5
SLM(A20+S1)	2·6	+2·2	SLM(D15+S5)	1·4	−4·7
			SLM(D20+S5)	1·9	−0·8

compressive strength to note the effect of an alternate wetting and drying cycle on the specimens. For each type an average of two samples was taken (Table 2).

TEST RESULTS AND DISCUSSION

7-day and 28-day strength and deformations

From Table 1 and Fig. 1, it is evident that latex content beyond 10–11% in LM mixes reduced the compressive strength. This was true for all three latexes, A, B and D. The C-type latex beyond 5% showed extremely poor strength for both 7-day and 28-day ages. This fact was also confirmed by SEM and ultrasonic pulse time. SEM of a fractured specimen of LM mixes with latex C showed non-uniform hydrated products with large size voids (Fig. 2) and malformed hydration products with medium to large size pores (Fig. 3). Transit time was extremely high compared to the unmodified mix (Table 1). This is another indication for the presence of many voids which have drastically reduced the strength. Therefore results of compressive strength for C-type latex beyond 5% were excluded in Table 1. Addition of superplasticisers S_1 and S_5 enhanced the compressive strength compared to non-superplasticised latex-modified mortar. This was possible primarily due to the use of a much lower water–cement ratio. The increase in strength was between 3 and 10% for all SLM specimens over corresponding LM specimens. Both superplasticisers S_1 and S_5 in SLM specimens with A-latex maintained higher strength (than unmodified mortar) up to 15% of latex addition. For the B and D types this value was 12·5% of latex addition. However, in all cases the SLM (except SLM with A 10% + S_5) had shown relatively inferior strength compared to corresponding SM specimens.

Deformations at both 7-day and 28-day ages increased significantly with the addition of latex only and latex plus superplasticisers combined. Figure 4 shows a distinct increase in deformation with the increase of latex content. This increase is further enhanced by the addition of superplasticisers S_1 and S_5 in the latex–mortar system. Figures 5, 6, and 7 show a progressively flat load–deformation curve with the increase of latex content of A, B and D latex. This fact of increased deformability is common for latex mortar or the latex–concrete system.[2] SEM of the fractured surface shows a more dense, compact hydrated product with a polymer film and strand formation across the voids (Figs 8 and 9) whilst the unmodified sample shows unfilled large voids (Figs 10 and 11), which justifies the higher deformability in latex mortar. Ultrasonic pulse transit time (UPTT) with stress (% of ultimate stress) of the unmodified sample shows the fluctuating UPTT

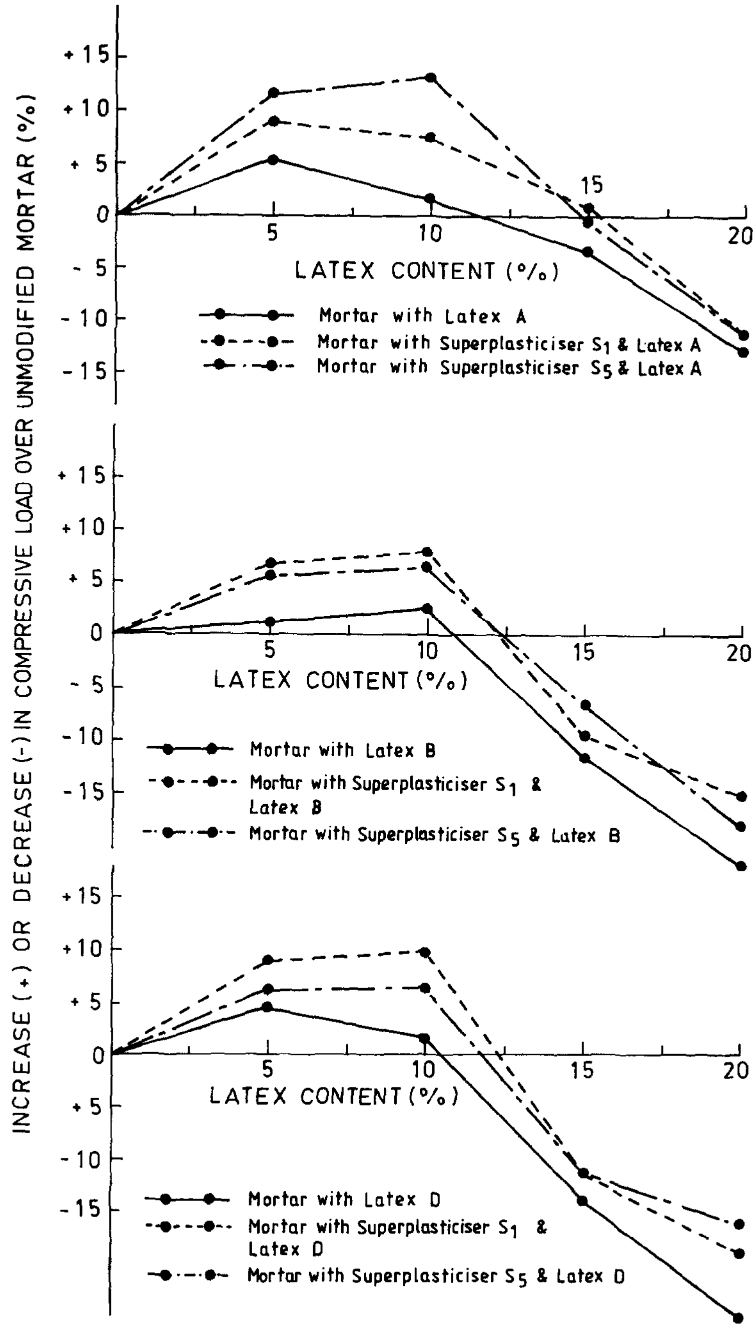

Fig. 1. Increase or decrease in compressive load (%) versus latex content (%).

versus stress curve (Fig. 12) with a sudden change in transit time near 75–80% of ultimate stress, which is common for unmodified mortar,[3] whilst the latex-modified mortar (with or without superplasticiser) shows a smoother transition of the UPTT versus stress relation up to failure (Fig. 12). This confirms a more ductile and smooth progressive failure in the case of latex-modified mortar with or without superplasticisers.

In the case of SLM specimens, Figs 13–15 show a similar load–deformation relation. This indicates that increase in deformation being due to increase in latex content was a valid supposition even for superplasticised–latex–mortar system. This was true for both superplasticisers, S_1 and S_5. Moreover, the UPTT versus stress curve for SLM is similar to that of the corresponding LM (Fig. 16); this means that the addition of superplasticiser did not alter the tendency for smooth progressive failure as occurred in the case of LM mortar. Moreover, lowering of UPTT range at all stress levels for SLM specimens (Fig. 16) ensures a denser matrix due to superplasticiser addition. Figure 17 shows that in the case of SLM,

Fig. 2. SEM of fracture surface of LM (C latex 10%). Non-uniform hydration is revealed. Large size voids are prominent.

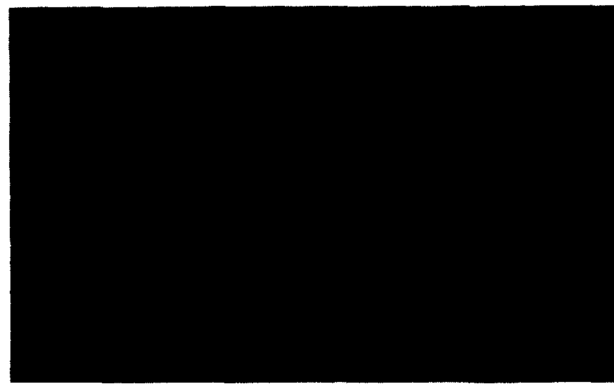

Fig. 3. SEM of fractured surface of LM (C latex 20%). Malformed hydration products with medium–large size pores.

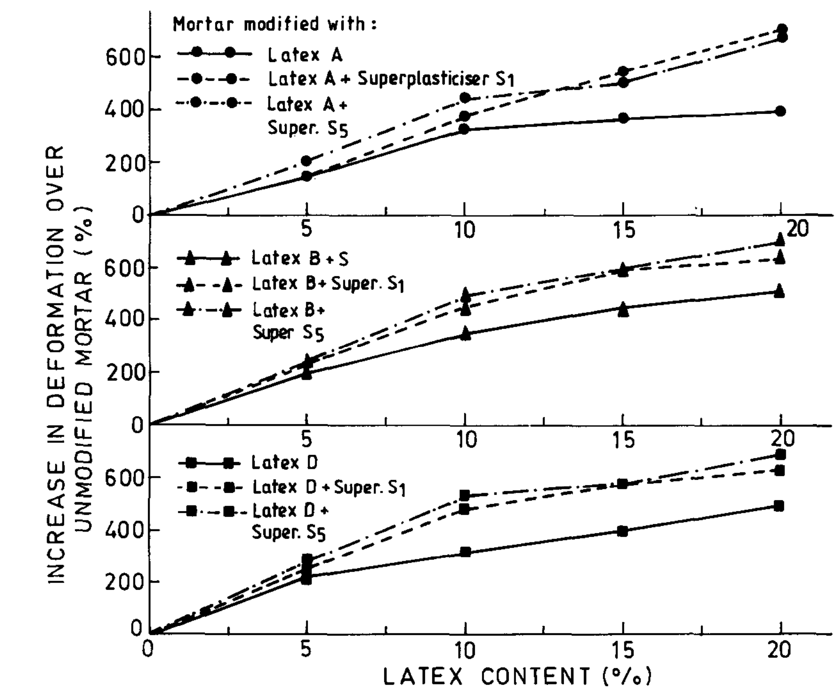

Fig. 4. Increase in deformation (%) versus latex content (%).

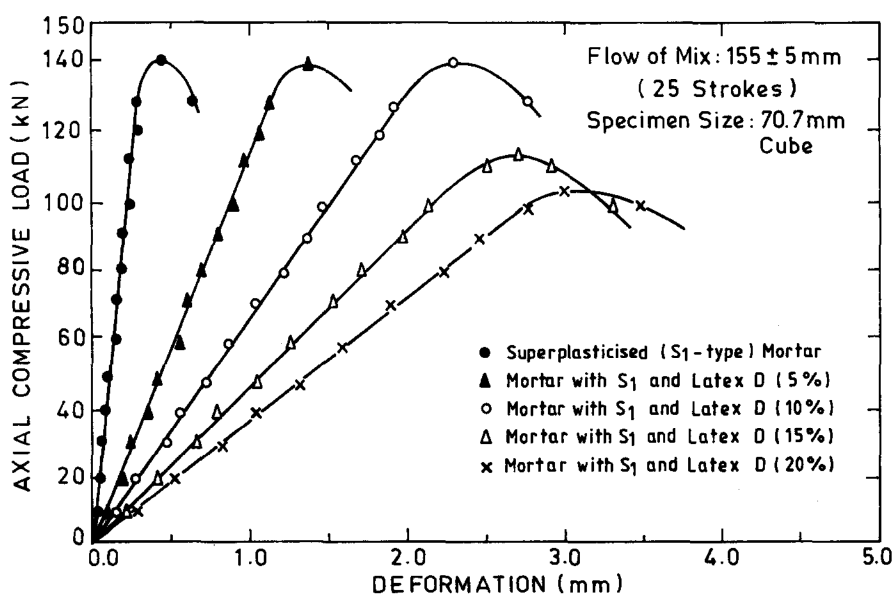

Fig. 5. Typical load–deformation plot of 28-day unmodified and latex-modified (A-type) mortar cube specimen.

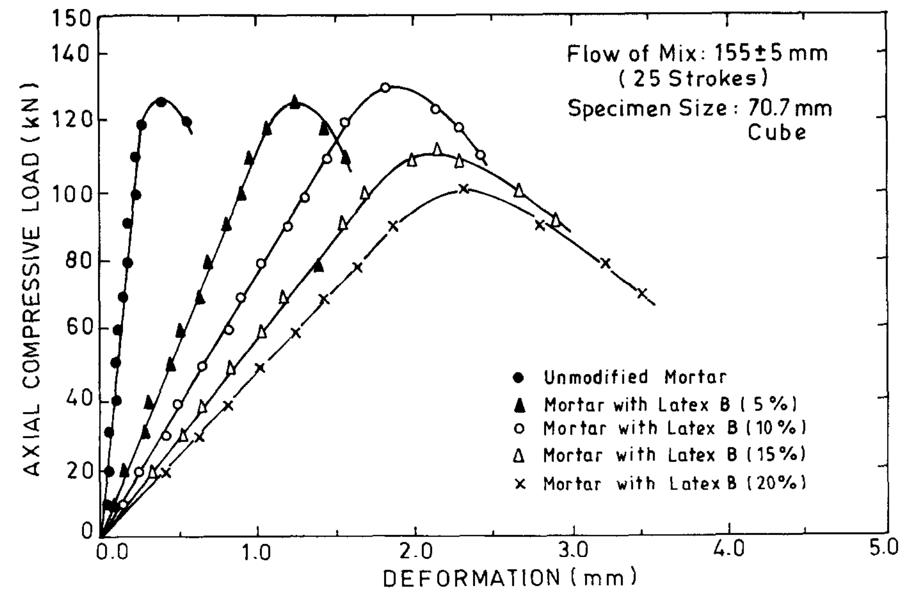

Fig. 6. Typical load–deformation plot of 28-day unmodified and latex-modified (B-type) mortar cube specimen.

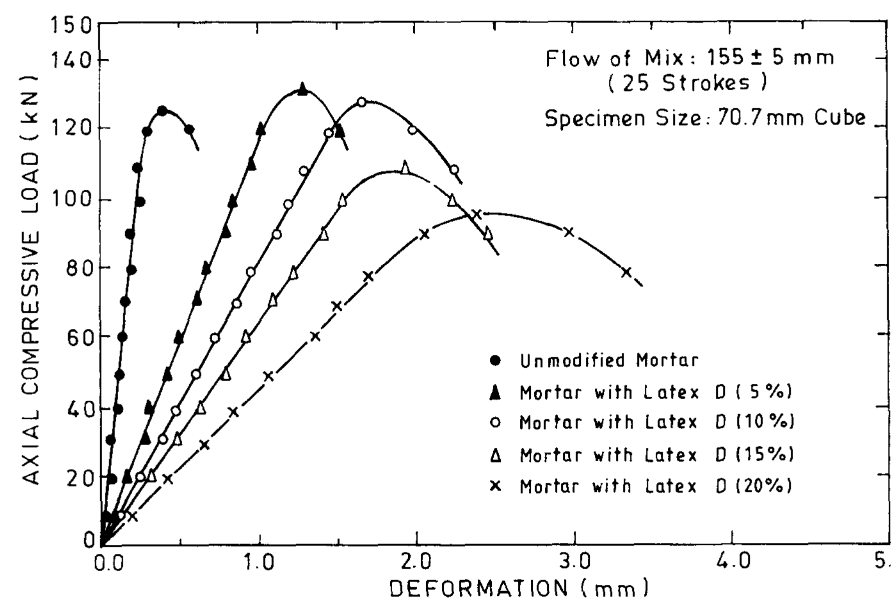

Fig. 7. Typical load–deformation plot of 28-day unmodified and latex-modified (D-type) mortar cube specimen.

Fig. 8. SEM of fractured surfaced of LM (A latex 20%). Voids are much smaller than in Figs 10 and 11.

Fig. 9. SEM of fractured surface of LM (B latex 20%). Hydrated surface similar to LM (A latex 20%) in Fig. 8.

Fig. 10. SEM of fractured surface of unmodified mortar. Well-developed hydrated products with large size pores.

Fig. 11. SEM of fractured surface of unmodified mortar. Heterogenity is prominent.

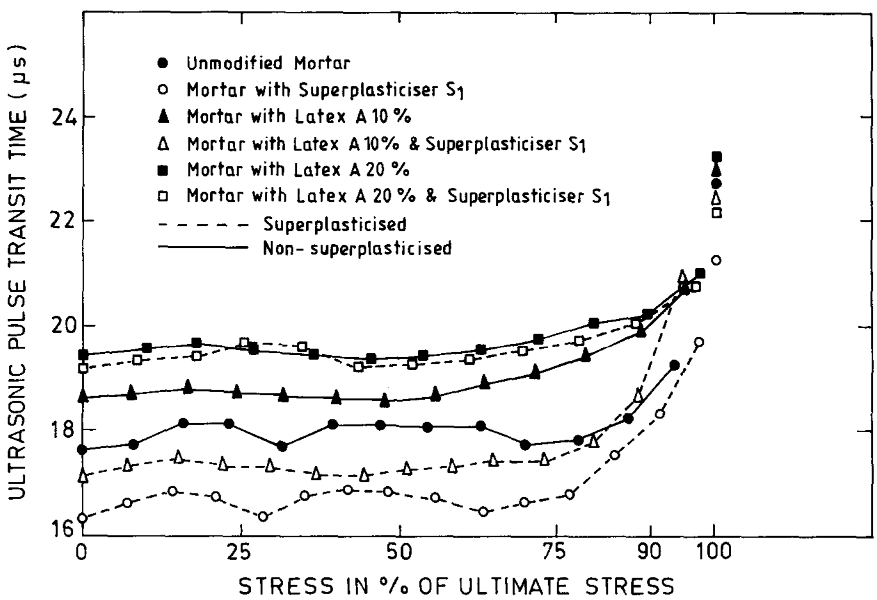

Fig. 12. Ultrasonic pulse transit time versus stress in % of ultimate stress plot of unmodified and modified 28-day mortar specimen (70·7 mm^3 cube).

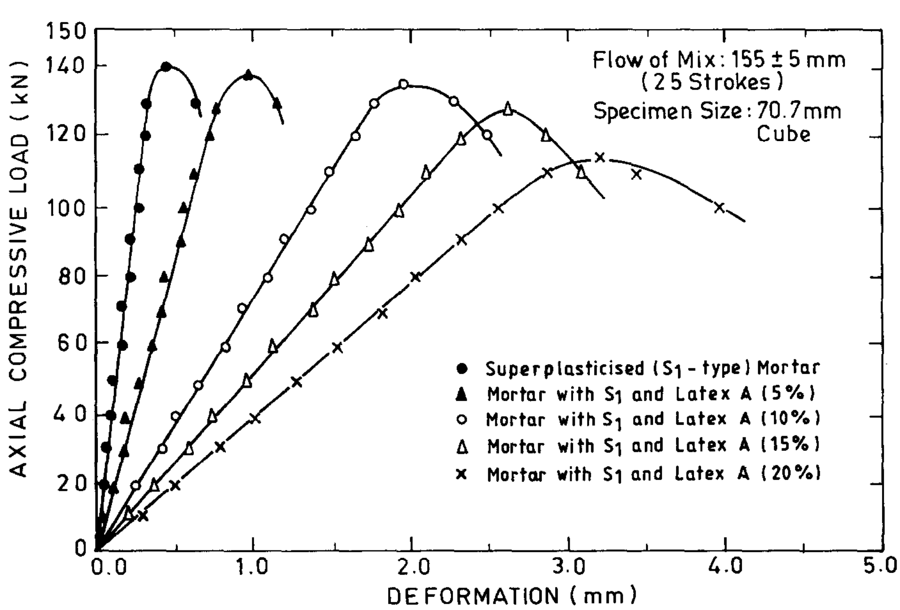

Fig. 13. Typical load–deformation plot of 28-day superplasticised (S_1-type) and superplasticised (S_1)–latex (A)-modified mortar cube specimen.

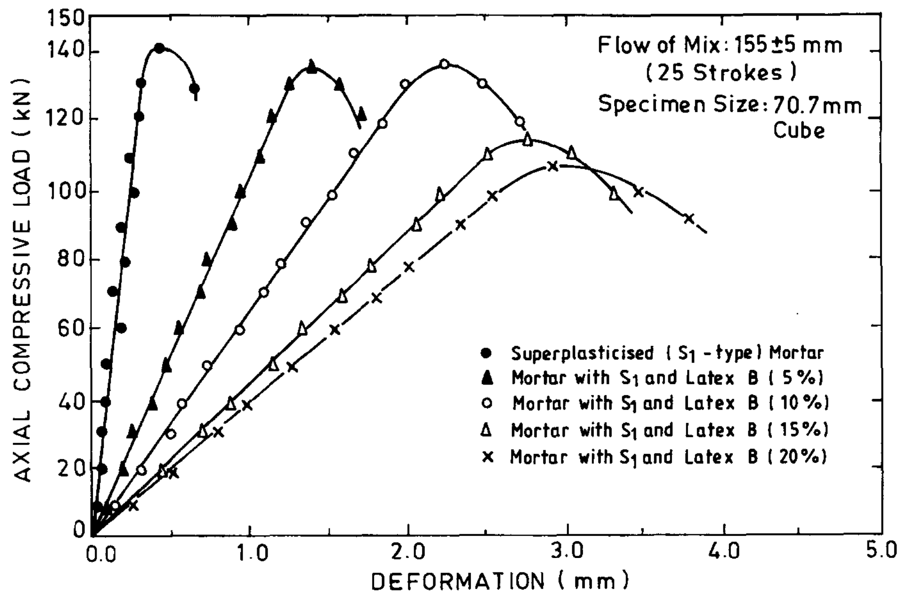

Fig. 14. Typical load-deformation plot of 28-day superplasticised (S_1-type) and superplasticised (S_1)-latex (B)-modified mortar cube specimen.

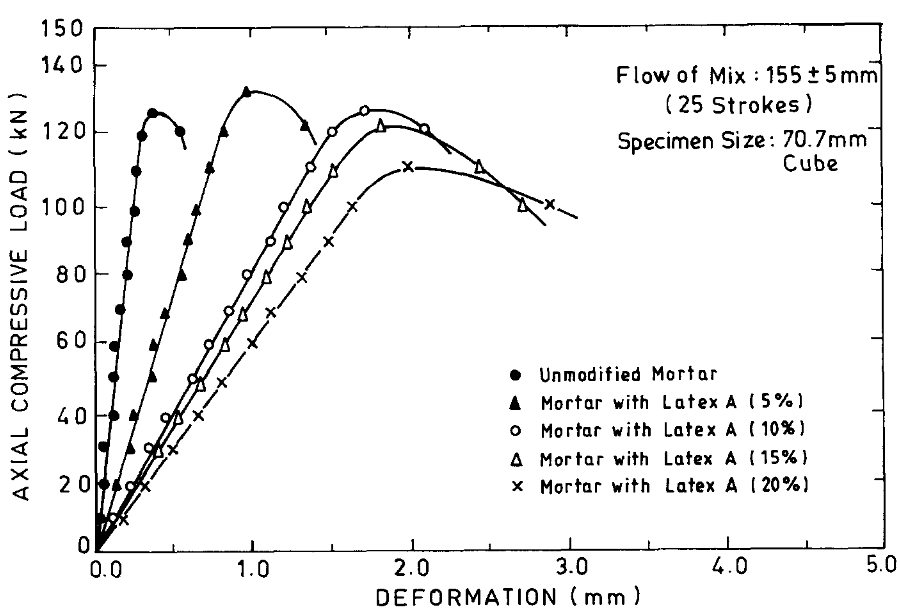

Fig. 15. Typical load-deformation plot of 28-day superplasticised (S_1-type) and superplasticised (S_1)-latex (D)-modified mortar cube specimen.

the superplasticiser S_5 gave slightly more deformation than did S_1 for latex up to 10% (type A). The situation, however, got reversed beyond 10%, where S_1 had an edge over S_5 with respect to deformation. Figure 18 suggests that addition of superplasticiser not only increased the compressive strength but improved the deformation to some extent. This may be due to the fact that superplasticiser utilised part of the latex water to form a denser gel than its non-superplasticised counterpart, and perhaps the polymer film, which is the main contributor to deformability, now being more restrained could sustain larger intergranular movement without disintegration.

The load-deformation relation was influenced insignificantly by type of latex as is evident in Fig. 19.

Initial tangent modulus (ITM) and measure of toughness

Table 1 shows that in all cases of LM the initial tangent modulus decreased over UM and this decreasing tendency was maintained with the inclusion of more and more latex. This was true

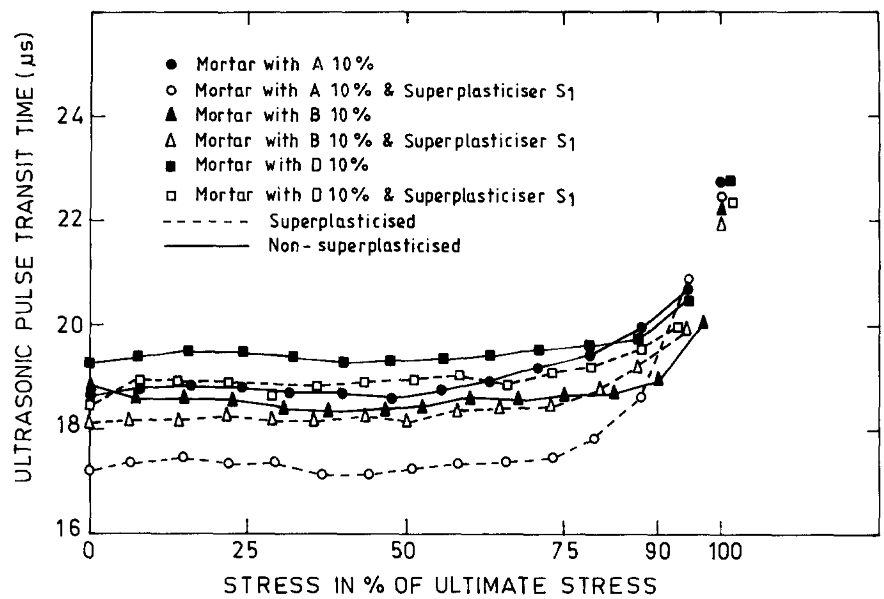

Fig. 16. Ultrasonic pulse transit time versus stress in % of ultimate stress plot of unmodified and modified 28-day mortar specimen (70·7 mm^3 cube).

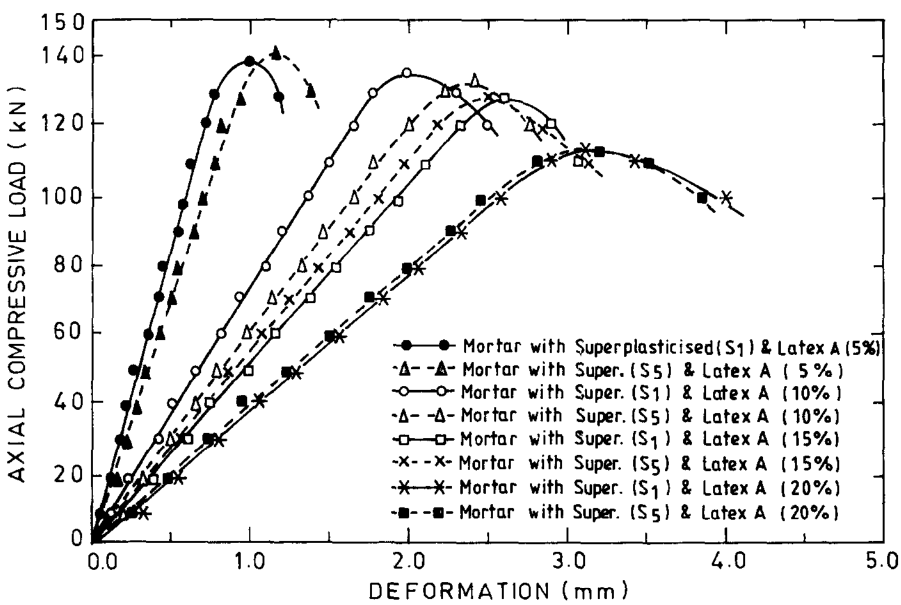

Fig. 17. Load–deformation plot of 28-day superplasticised (types S_1 and S_5)–latex A (5%, 10%, 15%, 20%)-modified mortar cube specimen.

for all three latexes, A, B and D. SLM specimens behaved similarly, with lower ITM values compared to corresponding LM specimens. This is in agreement with the increased deformability of LM over UM, and of SLM over SM, LM and UM.

For composites, the estimation of toughness by area bounded by load–deformation for a unit volume of strained material was preferred to other methods.[4] The results in Table 1 show significant increase of toughness of LM over UM by 330% (latex A 20%), 350% (latex B 20%) and 340% (latex D 20%). Further increase of toughness was noticed with superplasticiser inclusion. An increase of toughness of 4–65% over corresponding LM specimens occurred for different latexes and both types of superplasticisers.

Water absorption test (three cycles)

From Figs 20 and 21 it is evident that unmodified samples absorbed much more water than all

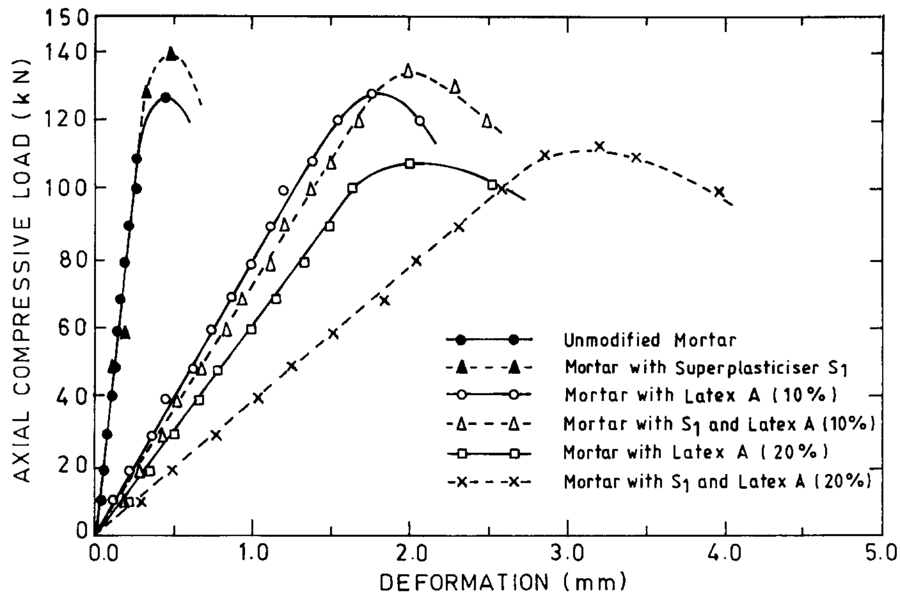

Fig. 18. Load-deformation plot of 28-day unmodified, superplasticised, superplasticised-latex (A-type) mortar cube specimen.

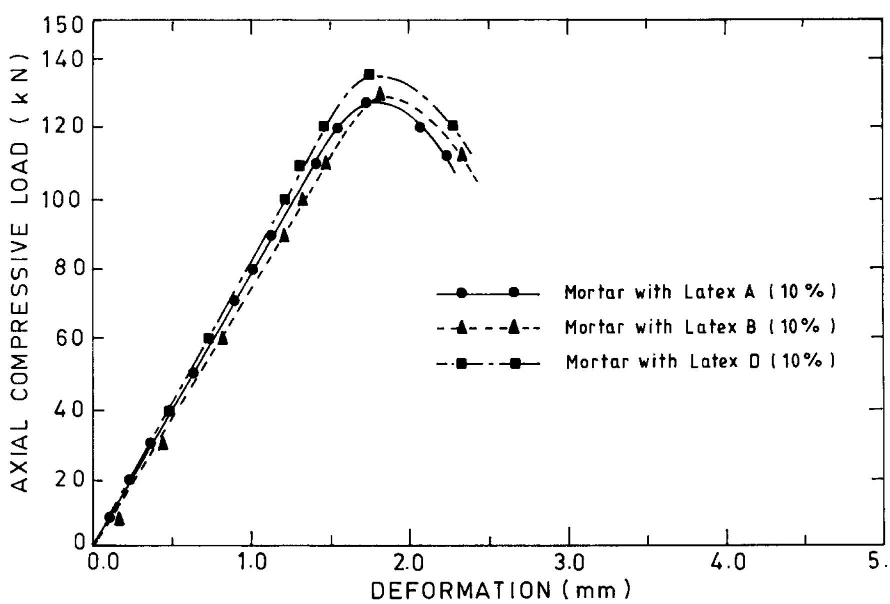

Fig. 19. Load-deformation plot of 28-day latex-modified (types A, B and D) mortar cube specimen.

modified cases. Latex addition therefore improved the pore distribution.[5] This was confirmed by SEM of samples, in which pores were seen to be more discretised and therefore became discontinuous (Figs 8 and 9). Latex also filled some void spaces by polymerisation.

Addition of superplasticisers S_1 and S_5 decreased the absorption value by 1–2% (Table 2) over the corresponding non-superplasticised latex-modified mortar. Moreover, superplasticised latex-modified mortars showed a saturation in water absorption after 96 h which did not occur in the non-superplasticised latex-modified mortar. Three cycles of water absorption with time showed little variation. Among the various latexes types B and D absorbed less water than type A (about 42% less). This observation was valid even when superplasticisers were added (Fig. 21).

It has been found that decrease in compressive loads (with respect to an undisturbed set of specimens of identical mix and age) after three cycles of wetting and drying (absorption test) for all superplasticised latex-modified mortar specimens was much less than in corresponding non-superplasti-

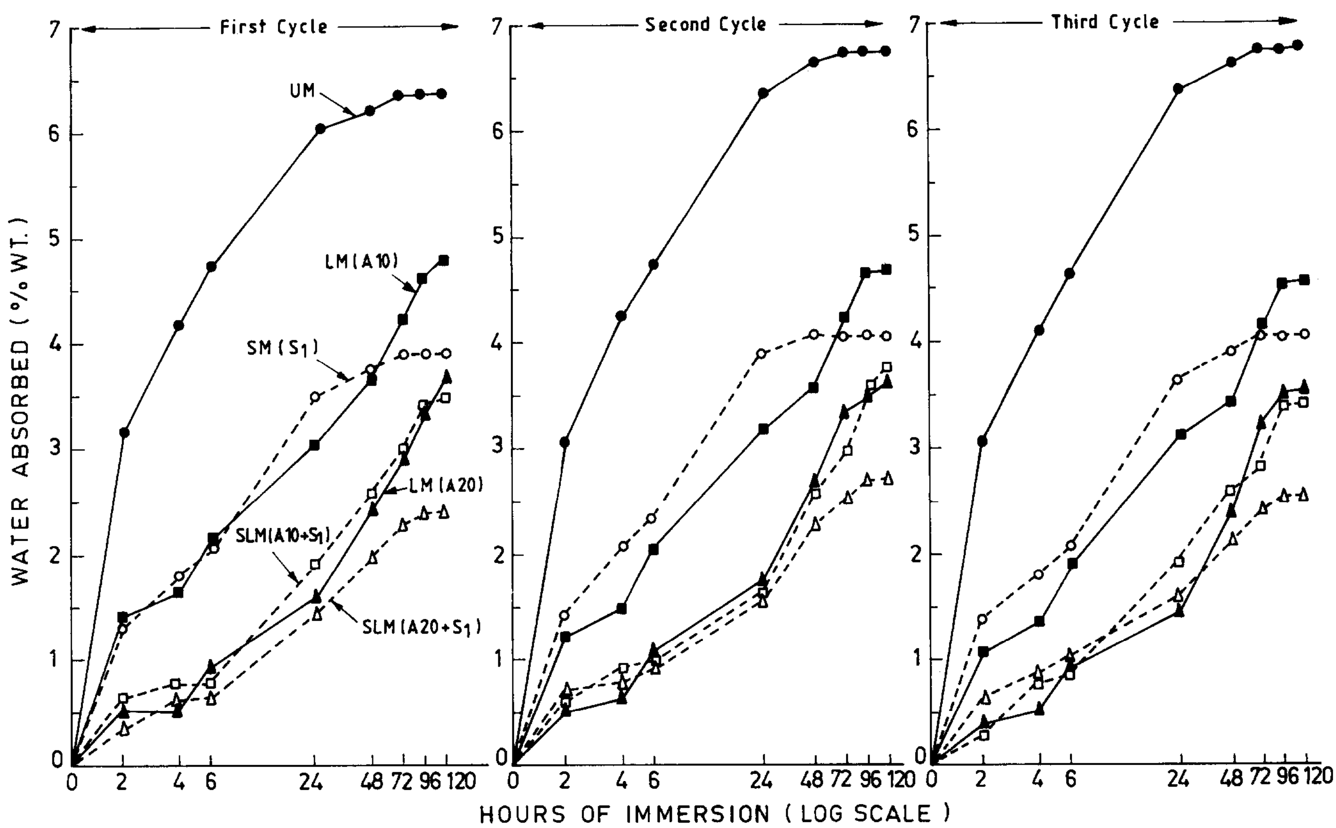

Fig. 20. Three cycles of water absorption versus hours plot. Unmodified (●); with superplasticiser S_1 (○); latex A 10% (■); latex A 10% + superplasticiser S_1 (□); latex A 20% (▲); latex A 20% + superplasticiser S_1 (△); non-superplasticised (———); superplasticised (- - - -).

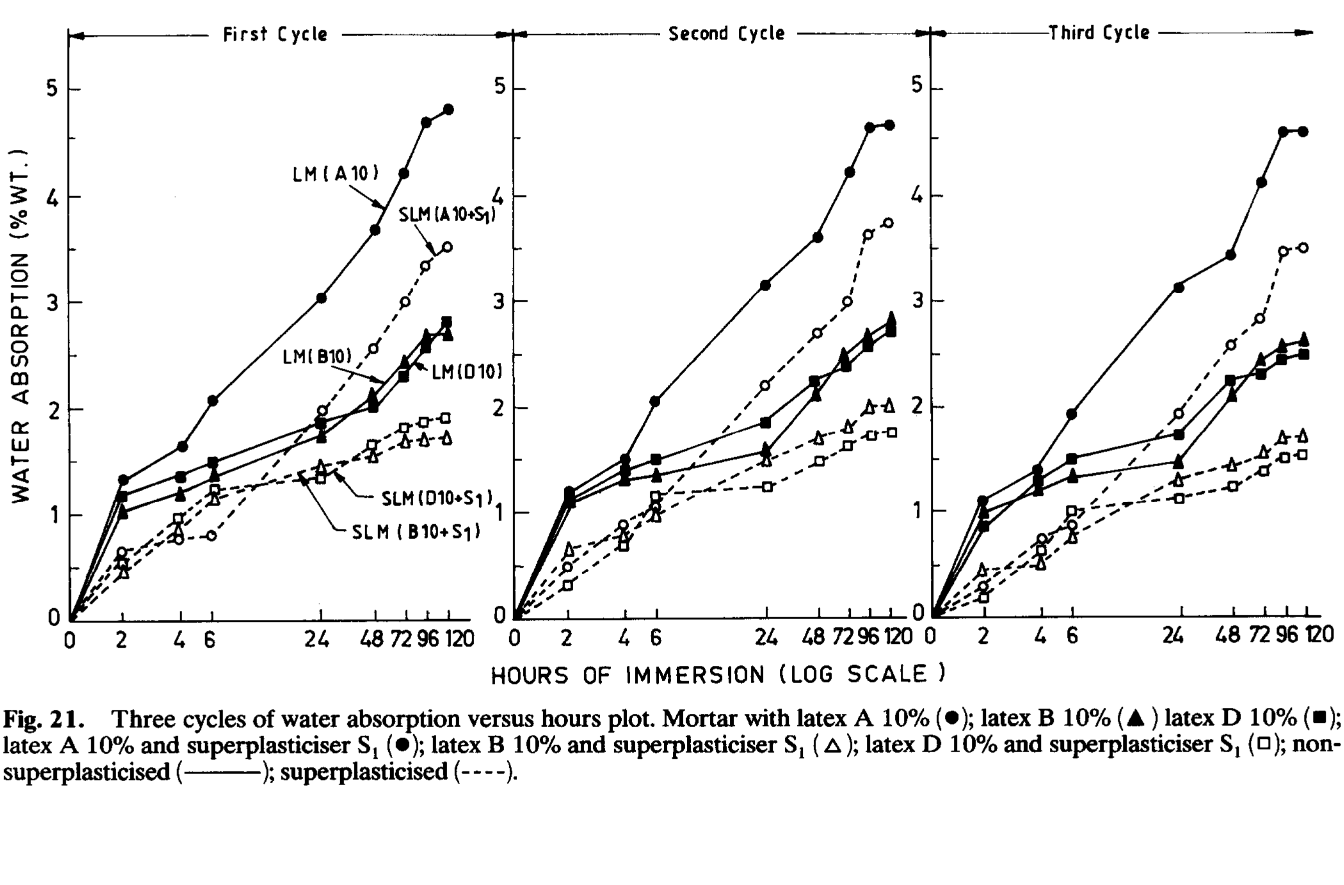

Fig. 21. Three cycles of water absorption versus hours plot. Mortar with latex A 10% (●); latex B 10% (▲) latex D 10% (■); latex A 10% and superplasticiser S_1 (●); latex B 10% and superplasticiser S_1 (△); latex D 10% and superplasticiser S_1 (□); non-superplasticised (———); superplasticised (- - - -).

cised mortar (Table 2). This observation indicates increased durability of the superplasticised latex-modified system compared to its non-superplasticised counterpart.

CONCLUSIONS

(1) Latex-mortar improves compressive strength (compared to UM) for up to 10–11% of latex addition; when superplasticised, it may improve for up to 12–15% of addition. SLM shows higher deformation compared to corresponding LM; this may be due to the restraint of polymer films within the denser gel in the case of SLM.

(2) All LM specimens show a significant increase in toughness over UM. Superplasticiser (both S_1 and S_5) inclusion improves the values further.

(3) Ultrasonic pulse transit time and SEM confirm the presence of voids and the poor hydrated structures of C-type latex–mortar, beyond 5% addition. Also the UPTT–stress pattern indicates a smooth progressive failure of LM and SLM specimens.

(4) Water absorption for all latex–mortar is less than for unmodified mortar. Addition of superplasticiser further reduces the water absorption. Loss in compressive strength after three cycles of wetting and drying of SLM specimens was less than for corresponding LM specimens.

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