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The lack of quality control measures during the mixing of masonry mortars on construction sites is evident to observers of field practice. Sand and cementitious materials are often measured with a shovel, water by the bucket or with a hose, and only on rare occasions is the mixing time checked.

Observations indicate that the length of mixing time usually reflects the demand for mortar at the working site rather than concern for its quality. Fox example, first thing in the morning or just after lunch, when the masons are starting work and all demanding mortar at the same time, the mixing machine is dumped almost as soon as the last materials are added. At the other extreme, in mid-morning or mid-afternoon, when all the mortar boards are full but the supply in the mixer box needs replenishing, the machine may be allowed to run 20 to 30 minutes before being dumped.

These observations raise questions about the effect of various mixing times on mortar properties, and a study was undertaken to provide some answers. Water requirement, flow, retentivity, air content and compressive strength were included in the investigation. The latter is one of the major concerns of the masonry contractor and this paper reports the effect of mixing times on it.

THE PROGRAM

The study included three mortar types, M, S and N, listed in the CSA[1] and ASTM[2] Mortar Specifications. Five material combinations were used for each mortar type. For Types M and S, one Portland cement was combined with two hydrated limes and three masonry cements, while the Type N mortars included two Portland cement-hydrated lime combinations and three masonry cements. Mixing time varied from 1 to 30 minutes. Compressive strength tests were conducted on 2-in. cubes after 28-day curing periods.

MATERIALS

All cementitious materials were available locally and were known to conform to their respective CSA Standards.

Masonry cements Nos. 1 and 2 are known to be the interground cement clinker-limestone varieties, while No. 3 is a blended Portland cement-hydrated lime. All contain air-entraining agents and all had mixing instructions on the bag - Nos. 1 and 2 recommended 1 part masonry cement and 3 parts sharp, clean sand; No. 3 required 1 bag to 18 No. 2 shovelsful of sand and machine mixing for a maximum of 5 minutes. The instructions on all three bags were designed to produce Type N mortars.

The aggregate used was 50 per cent Standard and 50 per cent Graded Ottawa sand.

MIXING

The materials were proportioned by weight, transposed from a volume basis using the following unit weights: Portland cement, 87 1/2 lb; masonry cements Nos. 1 and 2, 70 lb; masonry cement No. 3, 55 lb; and hydrated lime, 50 lb. The amount of water added was that required to produce a flow value of 120 ± 2 per cent. The different mortar mixes, the weights of materials and quantities of water per batch are listed in Table 1.

The mortars were mixed in a Hobart mixer, using the procedures outlined in CSA Standard A8[3], except that the "wait period" before the final mixing was increased from 1 1/2 to 3 minutes. For the purpose of this study mixing time is defined as the length of time the mortar was mixed after the final "wait period".

During the study it was found that the "control" flow value decreased with increasing mixing time until the mortar was no longer workable. At that point sufficient water was added to restore the initial flow value. Following addition of the extra water the mortar was mixed for 1 minute at medium speed.

The practice of adding water was considered to be similar to retempering on the construction site where the mixer tender, or the mason, adds water until the mortar regains satisfactory workability.

CURING AND TESTING

All the mortar cubes were moulded, cured and tested for compressive strength by procedures described in CSA Standard A179. Air content determinations, using the density method, were carried out on separate batches of mortar. Results are shown graphically in Figures 1, 2 and 3.

DISCUSSION

Type M Mortars (Table 2)

Portland Cement-Lime. Compressive strength values were highest after 3 to 5 minutes mixing and then dropped steadily. The decrease is attributed to the extra water that was required to retemper the mortar.

At 30 minutes the "extra" water was 40 per cent of the original water content. Meanwhile the air content decreased.

Portland Cement - Masonry Cement. The mortar containing masonry cement No. 1 had the least drop in compressive strength after 30 minutes' mixing time of any of the five Type M mortars. Its air content dropped 3 per cent after 30 minutes' mixing while the water quantity was 22 per cent above the original value. Compressive strength for mortar containing masonry cement No. 2 exceeded the required 2500 psi at 1 minute, but dropped steadily with increasing mixing time until at 30 minutes it was only 42 per cent of the original value. Compressive strength for the mortar containing masonry cement No. 3, initially below the 2500 psi requirement, dropped steadily with increasing mixing time and at 30 minutes was 53 per cent of the control value. At 30 minutes 11 to 15 per cent "extra" water had been added to these last two mortars and air contents were 40 to 45 per cent above the level for the control mortars.

Type S Mortars (Table 3)

Portland Cement-Lime. Compressive strengths were maximum after 3 minutes' mixing and then decreased until values were 20 to 23 per cent below control values after 30 minutes' mixing, at which time 30 to 40 per cent extra water had been added and air contents dropped to 25 to 45 per cent of the control values.

Portland Cement-Masonry Cement. The mortar containing masonry cement No. 1 had a higher compressive strength after 30 minutes' mixing than it did initially. Twenty-one per cent more water had been added while the air content was 10 per cent below the initial value. Compressive strengths for the mortars containing masonry cements Nos. 2 and 3 dropped below the 1800 psi requirement after 2 minutes' mixing and at 30 minutes strengths were only 52 and 27 per cent of control values respectively. The decrease is attributed to an increase of 14 and 24 per cent in water content, and an increase of 40 to 52 per cent in air content.

Type N Mortars (Table 4)

Portland Cement-Lime. Compressive strength values were maximum at 3 and 5 minutes and then dropped steadily until after 30 minutes' mixing they were 61 and 80 per cent of the control values, with water contents 42 and 34 per cent above, and air contents reduced to 30 and 40 per cent of the values for, control mortars.

Masonry Cement. Maximum compressive strength values occurred after 1 and 3 minutes' mixing. As mixing time was increased compressive strength values dropped - at 5 minutes values for mortars containing masonry cements Nos. 2 and 3 were below the 750 psi requirement and at 15 minutes mortar containing masonry cement No. 1 was also below. Strength values levelled off after 15 minutes, but at 30 minutes they were only 49, 29 and 25 per cent of the control values. At 30 minutes increased water requirements were 36, 27 and 7 per cent above the initial amounts and air contents had increased 7, 54 and 82 per cent, respectively, for the three mortars.

GENERAL

There was a consistent pattern of dropping compressive strengths with increasing mixing times for Types M, S and N mortars. Reductions in strength for cement-lime mortars are attributed to the additional water required to maintain satisfactory workability, while in mortars containing masonry cement, reductions are attributed to a combination of increasing water and air contents.

Strength values for the cement-lime mortars after 30 minutes' mixing, despite substantial decreases due to the prolonged mixing period, remain well above the minimum requirements in mortar specifications.

Types M and S mortars containing masonry cement No. 1 are not seriously affected by longer mixing, but strength for Type N mortars falls below the 750 psi requirement after 15 minutes' mixing.

Values for the mortars containing masonry cements Nos. 2 and 3 drop well below the specification requirements after a small increase in mixing time. Prolonged mixing of these mortars is accompanied by an increase in air content, and this combined with the extra water quantities, results in the lower strength values.

Requirements for mixing time in mortar specifications have been inconsistent, probably reflecting a lack of knowledge of its significance. The current ASTM C270 requires a minimum of 3 minutes' mixing and prior to 1975 CSA A179 required a maximum of 10 minutes' mixing. The 1975 revision of the CSA Specification contains both the maximum and the minimum requirements. The results of this study emphasize the importance of the maximum requirement, and, in fact, indicate that some mortars should not be mixed longer than 5 minutes.

RECOMMENDATIONS

Mixing time requirements, based on studies of the effect of mixing time on mortar properties, should be contained in mortar specifications.

Mixing time could be regulated on construction sites by placing an automatic timer on the mixing machine, one that would stop the mixer at the correct time, or a timer with an alarm bell to alert the mixer tender when the desired time has been reached.

ACKNOWLEDGEMENTS

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REFERENCES

1. CSA Standard A179-1975 - Mortar and Grout for Unit Masonry.

2. ASTM C270-73 - Standard Specification for Mortar for Unit Masonry.

3. CSA Standard A8-1970 - Masonry Cement.

TABLE 1

MIXING PROPORTIONS

Mortar Type	Material Proportions (Parts by Volume)	Weight per Batch (gm) P.C.	M.C.	H.L.	Sand	Water Volume (ml)
M	1P.C.:1M.C.#1:6S	262.5	210	--	1440	225
	1P.C.:1M.C.#2:6S	262.5	210	--	1440	220
	1P.C.:1M.C.#3:6S	262.5	165	--	1440	220
	4P.C.:1H.L.#1:15S	420	--	60	1440	245
	4P.C.:1H.L.#2:15S	420	--	60	1440	240
S	1P.C.:2M.C.#1:9S	175	280	--	1440	215
	1P.C.:2M.C.#2:9S	175	280	--	1440	217
	1P.C.:2M.C.#3:9S	175	220	--	1440	210
	2P.C.:1H.L.#1:9S	350	--	100	1440	260
	2P.C.:1H.L.#2:9S	350	--	100	1440	245
N	1M.C.#1:3S	--	420	--	1440	206
	1M.C.#2:3S	--	420	--	1440	225
	1M.C.#3:3S	--	330	--	1440	220
	1P.C.:1H.L.#1:6S	262.5	--	150	1440	275
	1P.C.:1H.L.#2:6S	262.5	--	150	1440	265

M.C. = Masonry Cement

S = Sand

P.C. = Portland Cement

H.L. = Hydrated Lime

TABLE 2

TYPE M MORTARS

Mortar Mix	Mixing Time (min)	Water Volume (ml)	Retempered	Initial Flow (%)	Air Content (%)	Compressive Strength (psi)
1P.C.:1M.C.#1:6S	1	225	No	120.8	15.6	3644
	2	"	"	124.8	16.0	3704
	3	"	"	123.0	16.5	3642
	5	"	"	123.2	16.5	3575
	10	233	Yes	120.3	14.5	3352
	15	243	"	120.9	14.0	3582
	30	275	"	120.7	12.5	3169
1P.C.:1M.C.#2:6S	1	220	No	120.4	20.3	2604
	2	"	"	122.8	23.4	2350
	3	"	"	122.3	24.4	2086
	5	"	"	118.8	24.9	1858
	10	225	Yes	120.1	25.6	1902
	15	240	"	120.4	28.5	1128
	30	255	"	120.4	28.5	1089
1P.C.:1M.C.#3:6S	1	220	No	120.1	21.4	1934
	2	"	"	126.2	25.5	2018
	3	"	"	126.0	27.4	1560
	5	"	"	123.2	27.5	1468
	10	"	"	119.4	29.5	1334
	15	230	Yes	121.0	30.1	914
	30	245	"	120.5	31.0	1038
4P.C.:1H.L.#1:15S	1	245	No	120.9	8.6	4780
	2	"	"	125.5	8.1	4863
	3	"	"	119.6	8.1	5024
	5	255	Yes	119.7	7.5	4917
	10	275	"	120.3	7.0	4483
	15	295	"	119.7	5.7	4230
	30	345	"	120.7	3.1	3663
4P.C.:1H.L.#2:15S	1	240	No	119.7	9.3	4419
	2	"	"	122.1	9.0	4793
	3	250	Yes	120.9	8.7	4728
	5	255	"	119.9	7.6	5107
	10	275	"	119.5	6.0	5030
	15	295	"	119.5	5.9	4852

TABLE 3

TYPE S MORTARS

Mortar Mix	Mixing Time (min)	Water Volume (ml)	Retempered	Initial Flow (%)	Air Content (%)	Compressive Strength (psi)
1P.C.:2M.C.#1:9S	1	215	No	120.5	16.0	2874
	2	"	"	121.1	16.6	2702
	3	"	"	123.0	17.0	2642
	5	225	Yes	121.2	15.8	2725
	10	230	"	120.3	15.7	2732
	15	235	"	120.9	15.5	2709
	30	260	"	120.1	14.4	2936
1P.C.:2M.C.#2:9S	1	217	No	119.8	19.8	1916
	2	"	"	122.4	22.6	1878
	3	"	"	123.0	24.5	1626
	5	"	"	120.0	26.0	1399
	10	222	Yes	121.3	27.3	1461
	15	227	"	119.6	28.7	1066
	30	247	"	119.4	27.6	995
1P.C.:2M.C.#3:9S	1	210	No	120.0	21.9	2009
	2	"	"	122.6	24.8	1761
	3	"	"	119.8	26.3	1723
	5	220	Yes	119.9	30.8	899
	10	230	"	119.9	34.5	701
	15	240	"	120.1	32.6	744
	30	260	"	119.7	33.3	548
2P.C.:1H.L.#1:9S	1	260	No	120.9	7.5	3896
	2	"	"	118.8	7.2	4065
	3	270	Yes	120.3	6.2	3971
	5	280	"	120.8	5.7	3979
	10	300	"	120.7	4.1	3854
	15	322	"	120.8	3.8	3556
	30	365	"	120.2	1.9	3004
2P.C.:1H.L.#2:9S	1	245	No	120.7	8.3	4265
	2	"	"	120.3	8.2	4302
	3	257	Yes	120.3	8.0	4177
	5	263	"	120.4	7.4	3846
	10	275	"	120.9	5.8	3928
	15	285	"	120.4	4.1	3900

TABLE 4

TYPE N MORTARS

Mortar Mix	Mixing Time (min)	Water Volume (ml)	Retempered	Initial Flow (%)	Air Content (%)	Compressive Strength (psi)
1M.C.#1:3S	1	206	No	120.2	19.6	1370
	2	"	"	121.5	21.0	1215
	3	"	"	122.4	21.6	1313
	5	214	Yes	119.7	21.8	1040
	10	231	"	121.0	21.5	1085
	15	236	"	119.9	25.2	697
	30	281	"	120.3	21.0	676
1M.C.#2:3S	1	225	No	119.6	21.1	1036
	2	"	"	119.8	22.2	1044
	3	"	"	118.2	25.2	818
	5	235	Yes	119.9	28.1	549
	10	250	"	119.7	32.4	371
	15	265	"	120.9	33.5	289
	30	285	"	121.2	32.5	296
1M.C.#3:3S	1	220	No	119.0	17.7	1155
	2	"	"	120.6	20.2	1047
	3	"	"	123.8	22.9	1006
	5	"	"	126.0	24.0	719
	10	"	"	124.6	28.3	402
	15	225	Yes	120.6	30.8	373
	30	240	"	119.5	32.2	287
1P.C.:1H.L.#1:6S	1	275	No	120.6	6.6	2563
	2	"	"	119.8	6.6	2797
	3	285	Yes	119.7	6.0	2636
	5	300	"	119.1	4.8	2474
	10	330	"	119.4	3.6	2160
	15	355	"	120.9	2.3	1891
	30	390	"	119.2	1.9	1562
1P.C.:1H.L.#2:6S	1	265	No	121.1	7.1	2504
	2	"	"	120.6	6.9	2618
	3	"	"	118.7	6.6	2616
	5	"	"	118.0	6.5	2736
	10	290	Yes	120.0	5.4	2565
	15	315	"	120.5	3.6	2201

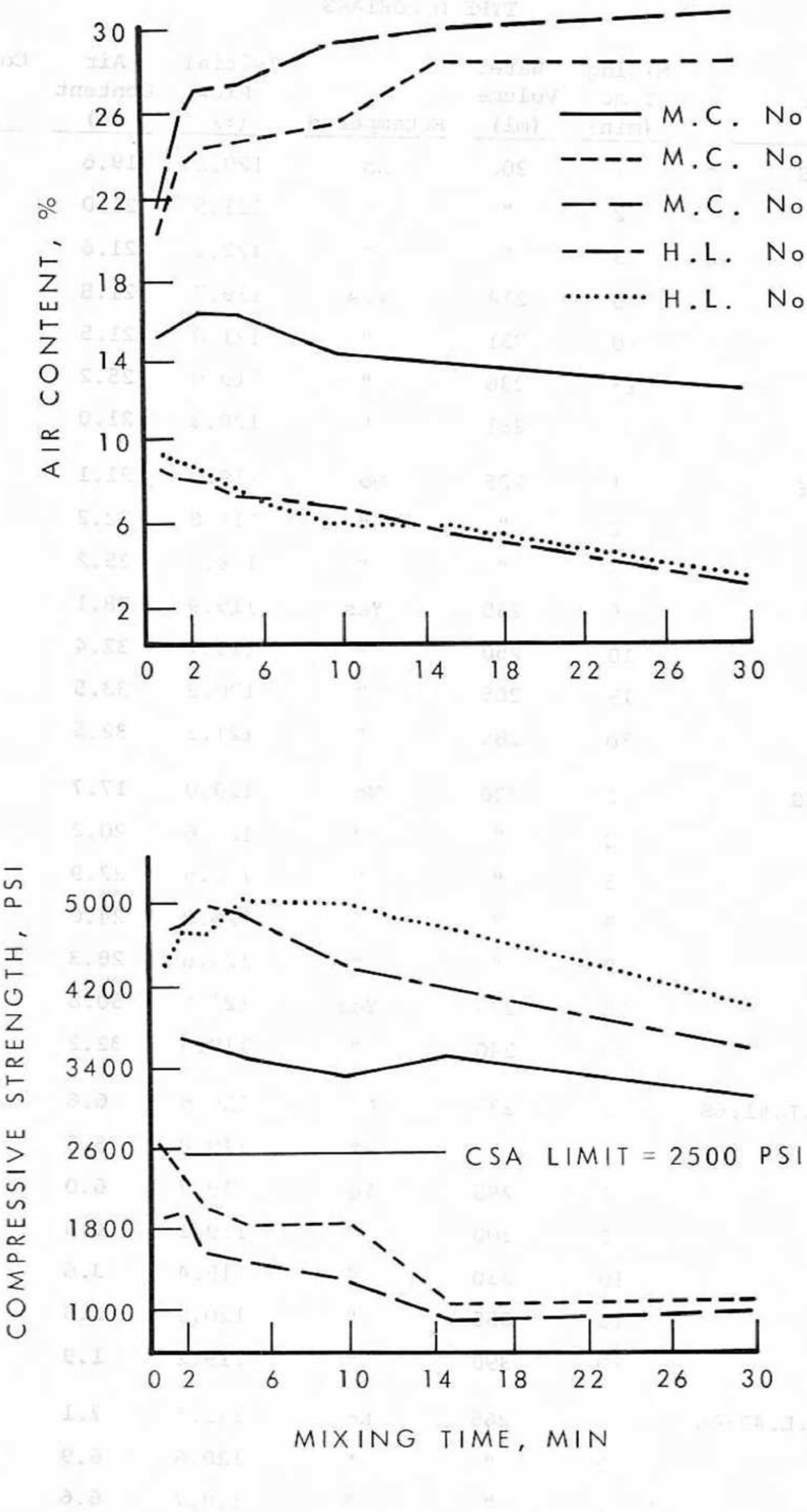

FIGURE 1

TYPE M MORTARS - CONSTANT FLOW

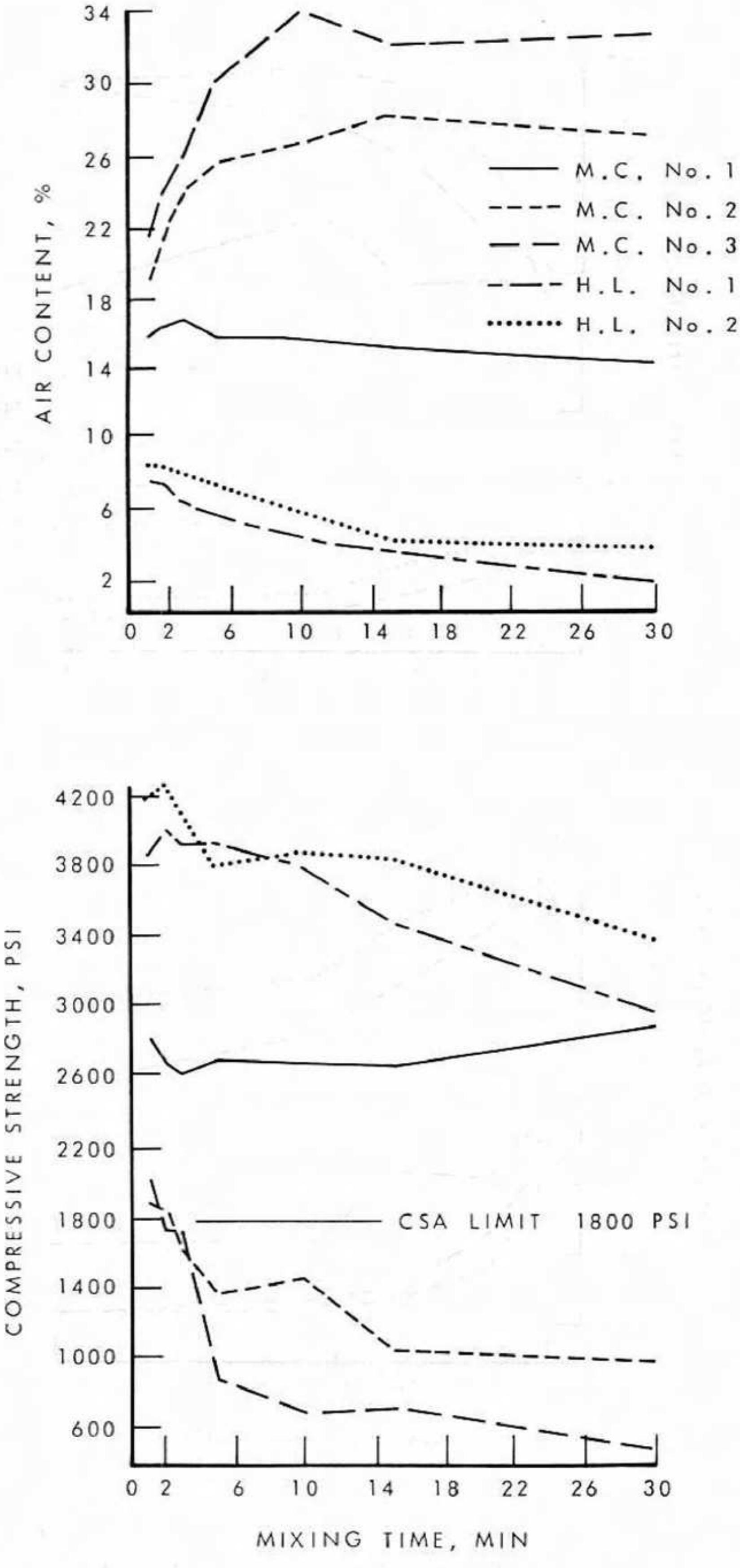

FIGURE 2

TYPE S MORTARS - CONSTANT FLOW

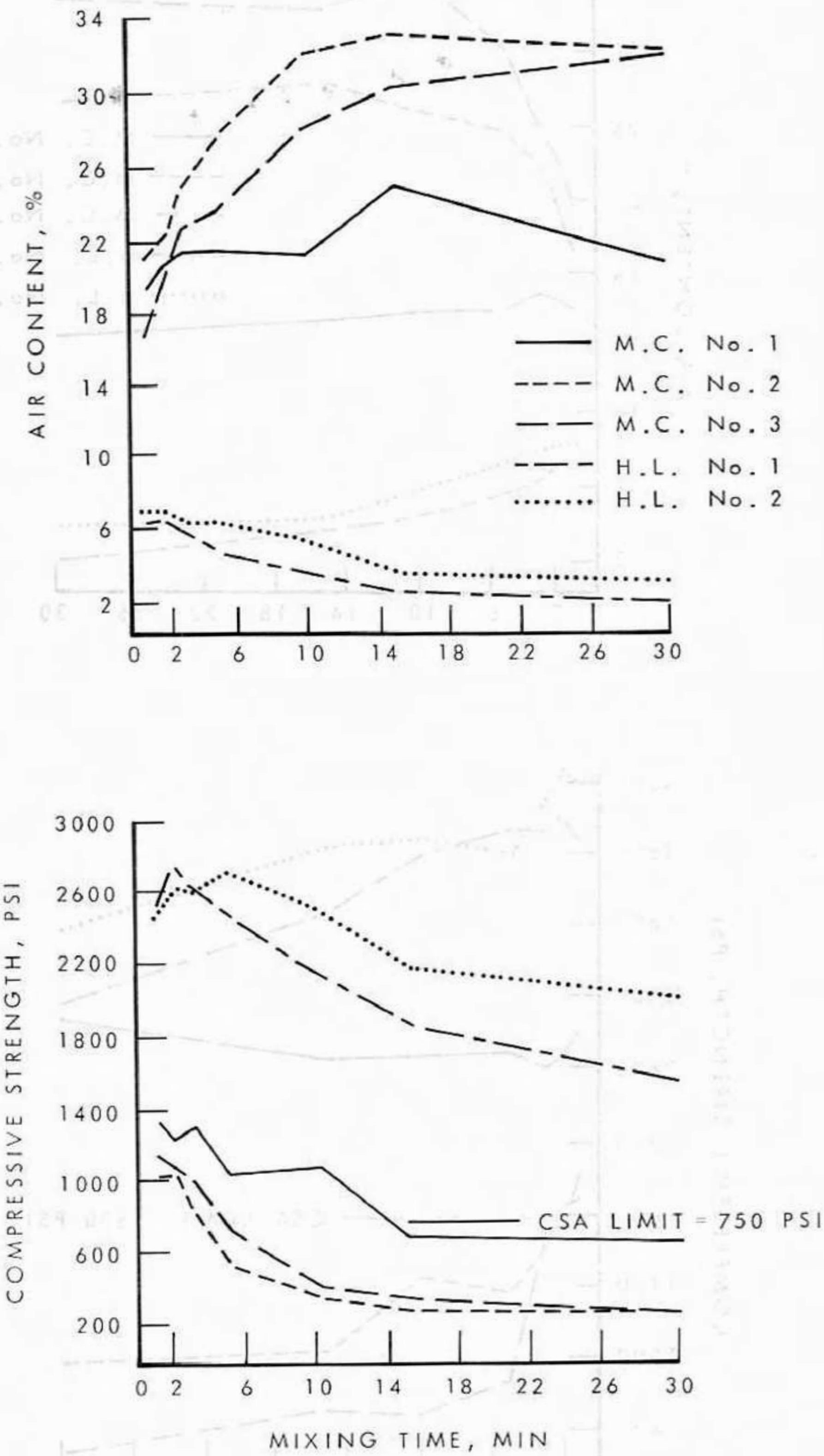

FIGURE 3
TYPE N MORTARS - CONSTANT FLOW