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Influence of Naphthalene-Sulfonated Polymer Based Superplasticizers on the Strength of Ordinary and Lightweight Concretes

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Synopsis: Two superplasticizers, both based on naphthalene-sulphonated formaldehyde condensed resin, were used to prepare concretes with three types of portland cement, two cement contents, two types of aggregates, cured at room temperature and steam cured.

One of the admixtures was found to be particularly suitable for precast concrete and the other one was considered to be more convenient for long transportation of concrete where a low workability loss is required.

Data on workability loss, flexural and compressive strength, and steel-concrete bond were obtained. The increase in the compressive strength caused by the admixtures was notably higher than the increase in the flexural strength. The increase in the strength was higher for ordinary than for lightweight aggregates. Moreover, the increase in strength also was found to depend on, a) the type of cement, b) the age, and c) the temperature of curing. The steel-concrete bond, determined with both smooth and twisted bars, was considerably increased by using superplasticizer both in ordinary and lightweight concrete.

Concretes, with and without admixtures, were placed with different vibration time and the influence of workability on compressive strength distribution was examined. Flowable concretes containing the admixture were higher in compressive strength and at the same time showed a much lower standard deviation.

Keywords: admixtures; bond (concrete to reinforcement); compressive strength; concretes; flexural strength; lightweight aggregate concretes; napthalene compounds; plasticizers; plastics, polymers and resins; precast concrete; segregation; workability.

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INTRODUCTION

It is well known that a reduction in the w/c ratio improves all properties of concrete, and in particular increases its strength (1). Unfortunately, the w/c ratio cannot be reduced below a certain value since the workability of concrete becomes so low that, for a given method of compaction, the concrete cannot be completely compacted. If one excludes some particular and sophisticated methods of compaction, the stiffest concrete that can be satisfactorily placed is the "no-slump" concrete, that is a concrete with a slump less than 25 mm (2). However a no-slump concrete is very difficult to place especially if it is to be placed in highly reinforced, precast elements. If vibration of fresh concrete is not fully and carefully performed macroscopic voids and in some cases honeycombing can result in the concrete elements. This causes differences between the strength of actual well compacted concrete specimens and the strength of the actual concrete placed in the elements, the difference being higher for stiffer concretes. It shall be assumed that when this difference is low the concrete is "reliable". In Figure 1, for example, three groups of concretes are shown with different reliability. The higher the workability, the lower the difference between unvibrated and fully vibrated specimens, and the greater the reliability of concrete.

Reliability depends on (a) efficiency, care and degree of compaction, (b) density of reinforcement and geometry of elements, and (c) workability of fresh concrete. Only the last parameter concerns intrinsically the quality of concrete and will be examined in this paper.

The workability can be improved by increasing w/c ratio, by using richer mixes and by adding water-reducing admixtures. However, if high strength and reliable concretes are to be obtained, w/c ratio must be decreased, and only very effective water-reducing agents (superplasticizing admixtures) added to relatively rich mixes should be considered.

Superplasticizing additives are substantially based on sulphonated naphthalene-formaldehyde polymers, or sulphonated melamine-formaldehyde polymers (3), and they can be used either for reducing the w/c ratio in order to increase its strength or for raising the workability. In this paper superplasticizing additives, based on sulphonated naphthalene-formaldehyde polymers, have been used both to reduce w/c ratio and to raise workability so that high-strength and reliable concretes could be obtained.

EXPERIMENTAL: MATERIALS AND PROCEDURES

Materials

a) Cement

Three different types of portland cements have been used. Table I shows the chemical analysis, fineness and setting time of these cements which can be roughly classified as Type I, Type III, and Type V according to the ASTM specification.

b) Aggregates

Natural aggregates (sand and gravel) and expanded clay have been used to prepare ordinary and lightweight concretes respectively. The particle size distributions of individual and combined aggregates are shown in Figures 2 and 3 for ordinary(specific gravity = 2500 Kg/m^3) and lightweight concretes (specific gravity = I600 to I800 Kg/m^3) respectively.

c) Admixtures

Two chloride-free superplasticizing admixtures (Rheomac 7I6 and Rheomac 877) both based on sulphonated naphthalene-formaldehyde polymer have been used. The normal dosage rate is I,5 liters per I00 Kg of cement for Rheomac 7I6 (admixture No. I)and 3.0 liters per I00 Kg of cement for Rheomac 877 (admixture No.2). With these dosage rates the dry polymer is approximately 0.48 by weight of cement for both admixtures.

The former is particularly suitable for long transportation of concrete such as ready mix concrete where a low workability loss is highly desirable. The latter is more convenient for precast concrete where a rapid stiffening during the preliminary curing at room temperature and before the steam treatment is necessary. In Figure 4 workability as a function of time is schematically shown for concretes containing admixture No.I or No.2. The values of slump and time concerning Figure 4 depend on the initial slump, temperature, type of cement, and type of aggregates, etc.

Procedure

Thirty eight different concretes were made and they were cured both at room temperature (20°C) and by steam curing, giving a total of 76 concretes.

The steam curing cycle was as follows: 4 hours at 20°C, from 20°C to 70°C in 3 hours, and 6 hours of steam curing at 70°C, then cooling at room temperature for two hours.

Concretes with a nominal cement content of 400 and 500 Kg/m^3 have been tested for each cement. The actual cement content, calculated from the specific gravity and the air content is shown in Tables 2-7.

Concretes without admixtures have been mixed at plastic consistency (slump about I00 mm). Although concretes containing admixtures were prepared at very flowable consistency (slump 200 mm)the w/c ratio was considerably lower than the w/c ratio of the corresponding concretes without admixtures.

In spite of the very high workability, concretes with admixtures were very cohesive, practically unsegregable and bleeding was negligible, so that "rheoplastic" concretes (4-6) were obtained.

Structural lightweight concretes (specific gravity = I600-I800 Kg/m^3 were also prepared using natural sand, expanded clay (Figure 3) and type I and III portland cements.The compositions of the lightweight concretes are reported in Tables 5-7.

Experimental

Measurements of entrapped air, bleeding, workability and specific gravity were made on the fresh concretes. Entrapped air was between I and 2 per cent, while bleeding water was never higher than 2 cm^3 per liter of concrete with the use of admixtures. The I00xI00xI00 mm specimens, all well compacted up to constant weight, have been tested in compression at the age of I,7, 28 and 90 days for ordinary weight concretes and I,7 and 28 days for lightweight concretes. The data are shown in Tables 2-7 and each value is the average of three specimens.

The I50xI50x530 mm specimens have been tested in flexure at ages of 7 and 28 days, and in many cases also at 90 days. These tests showed much less reproducibility than compressive strength tests, and in some cases a decrease in the value of flexural strength with time has been observed.

On some specimens steel-concrete bond strength was measured at 7 and 28 days by determining the loading necessary to pull out either smooth or twisted bars (diameter 20 mm) cast in cylindrical concrete specimens.

Fifty I00xI00xI00 mm cm specimens of six different concretes were prepared in order to evaluate concrete reliability; they were vibrated for different times and all were cured for 7 days at room temperature. Comparison of compressive strength as a function of vibration time gives the possibility of evaluating the reliability of concrete as a function of accuracy of placing.

DISCUSSION OF RESULTS

Compressive strength

The compressive strengths of steam cured concretes at I day are remarkably higher than those cured at room temperature. However the increase depends on the type of cement: strength increase of concretes without admixtures at I days is about 100% with Type I and Type III cement (Tables 3-4), while it is over 200% with Type V (Table 2), which is a low C_3A portland cement. Also, at later ages, the compressive strength of steam cured concretes prepared with this cement remains higher than that of the same concretes cured at room temperature. On the contrary, concretes containing Type I or Type III cement, with both ordinary and lightweight aggregates, and cured at room temperature generally, show 7 day compressive strength higher than the same concretes steam cured. This behaviour is considered to be usual (7), while the behaviour obtained with Type V cement should be regarded as unusual. Figure 5 shows the effect of steam curing on compressive strength of concretes both without admixtures prepared with a low C_3A portland cement (Type V) and with a normal portland cement (Type I).

The addition of admixtures, besides causing a remarkable increase in workability (slump from 100 to over 200 mm), strongly increases the strength. However this effect depends on the type of admixture and cement.

In concretes containing Type V cement, addition of admixture No.2 causes a higher increase in the compressive strength at early and later ages, than that caused by addition of admixture No.I. For example, with admixture No.2 it is possible to obtain strengths higher than 600 Kg/cm^2 at I day and higher than 1000 Kg/cm^2 at 90 days for steam cured concretes, an increase in compressive strength of over 70% at I day and about 30% at 90 days in comparison with the concretes without admixtures. The strength increase is particularly remarkable taking into account that concretes without admixtures were much less workable.

For concretes prepared with Type I cement, the strength increase at early ages using admixture No. 2 is higher than that reached by using admixture No.I while compressive strengths at 7 and 90 days are comparable. The 90-day compressive strengths in the presence of admixtures are about 1000 Kg/cm^2 with a cement content of 400 Kg/m^3, and about 1100 Kg/cm^2 with a cement content of 500 Kg/m^3.

For concretes containing Type III cement the strength increases at I day caused by both admixtures are comparable. However, the later age strength is higher with admixture No.I, particularly for concretes cured at room temperature. For example, at 90 days the compressive strength of concrete cured at room temperature and containing the admixture No.I is higher than 1200 Kg/cm^2 with a cement content of 400 Kg/m^3 and higher than 1300 Kg/cm^2 with 500 Kg/m^3 cement content.

The above mentioned results demonstrate that the selection of an admixture should take into account the type of cement and the curing cycle. Moreover, other technological aspects such as the time of transportation must also be considered: for example, admixture No. I, which causes a lower increase in the compressive strength than admixture No. 2 when used with a low C_3A cement (Table 2), may be preferred if one

considers the advantage of the low workability loss (Figure 4).

It is important to note that with some cements it is possible to eliminate steam curing and to obtain the same compressive strength by the use of a superplasticizer: this is true, for example, for Type I cement and particularly for Type III cement in the presence of admixture No.2 (Tables 3-4).

On the contrary, the addition of admixtures to Type V cement, which is particularly affected by steam curing, allows one to shorten the steam curing cycle but it is not possible to completely eliminate it.

The effect of admixtures on lightweight concretes prepared with expanded clay aggregate (Tables 5-7) is less than that observed with ordinary concretes. As it will be shown later, the most remarkable advantage for using these admixtures for lightweight concretes is a higher steel-concrete bond strength and the possibility of reducing the vibration time to place them.

The strength increase caused by the use of admixture No.2 in lightweight concrete (specific gravity $\simeq$ 1800 Kg/m^3) made with Type I cement, is about 10-20% at I day and about 3-10% at 28 days (Table 5). The highest compressive strength achievable is about 450 Kg/cm^2 at I day and more than 600 Kg/cm^2 at 28 days.

The effect of admixtures on lightweight concretes (specific gravity $\simeq$1800 Kg/m^3), made with Type III cement is more pronounced than that observed on concretes containing Type I cement: strength increase goes from a minimun value of 15% to a maximum of 50% at I day, and from a minimum of 10% to a maximum of 20% at 28 DAYS (Table 6). Admixture No.I is as effective as No.2 both at room temperature and in the steam curing, both at early and later ages: the highest compressive strength obtained is more than 500 Kg/cm^2 at I day and more than 750 Kg/cm^2 at 28 days. If specific gravity is reduced from 1800 Kg/m^3 to 1600 Kg/m^3 (Table 7), by using a lighter expanded clay (400 Kg/m^3 in bulk), the highest compressive strength achievable is more than 300 Kg/cm^2 at I day and more than 400 Kg/cm^2 at 28 days.

Flexural Strength

It is well known that flexural strength measurments are less reproducible than measurements of compressive strength.

For this reason, in some cases, lower flexural strengths were obtained at later ages than at earlier age.

On the other hand, it is not possible to increase flexural strength considerably, contrary to what happens with compressive strength, either by increasing the cement content from 400 to 500 Kg/m^3, or reducing the w/c ratio by using admixtures and prolonging the curing from 7 to 90 days (Tables 2-4).

Flexural strengths range from a minimum of 45 to a maximum of 65 Kg/cm^2 for ordinary concretes without admixtures and from a minimum of 50 to a maximum of 80 Kg/cm^2 for concretes with admixtures (Tables

2-4).

Flexural strength for lightweight concretes ranges from a minimum of I2 Kg/cm^2 to a maximum of 30 Kg/cm^2 without admixtures and from a minimum of 24 to a maximum of 43 Kg/cm^2 for concretes with admixtures (Table 5-7).

Reliability of Concrete

The data discussed in the previous section concern concretes fully compacted to a constant weight independently of their workability. In the present section the results of ordinary and lightweight concretes having a different workability and compacted differently are discussed. Table 7 shows the composition of stiff,plastic and fluid concretes without admixtures, and rheoplastic (4-6) concrete with admixture No.2. The w/c ratio of stiff and rheoplastic concretes is approximately the same, and both these mixes have a w/c ratio lower than that of plastic and fluid concretes. Fluid concrete without admixtures was particularly segregable and showed high bleeding; values up to 60 cm^3 of water per liter of concrete were obtained.

These mixes were placed with a vibration time of 0,5,I0,20 and 30 seconds, in order to obtain concretes with a different degree of compaction. Ten specimens for each vibration time were prepared for a total of fifty specimens.

The histogram of Figure 6 shows the frequency, that is the percentage of specimens whose compressive strength fall into a range of 50 Kg/cm^2. For example, in Figure 6d, 75% of specimens gave compressive strength values in the range of 675 to 725 Kg/cm^2, while only 5% of specimens gave compressive strength of 575 to 675 Kg/cm^2. Because of the same w/c ratio ($\simeq$0,34), the highest compressive strength for both stiff concrete without admixture and rheoplastic concrete with admixture is 700$\pm$25 Kg/cm^2 and this value corresponds to the most fully compacted concretes. Only I5% of stiff concrete specimens (Figure 6a) had strengths of 700$\pm$25 Kg/cm^2 as only a part of the specimens vibrated for the longest time (30 seconds) were fully compacted. On the contrary, in the case of rheoplastic concrete, (Figure 6d) due to its high flowability, not only the specimens vibrated for the longest time, but also many of those vibrated for shorter time were fully compacted and reached strengths of 700$\pm$25 Kg/cm^2.

The compressive strength of the fully compacted plastic concrete without admixture (Figure 6b) is at best 500$\pm$25 Kg/cm^2 and 40% of specimens attain this value. The highest compressive strength of fully compacted fluid concrete without admixture (Figure 6c) is 350$\pm$25 Kg/cm^2 and 70% of specimens reached this value.

The highest strength of plastic and fluid concretes is obviously lower than the highest strength of stiff and rheoplasti concretes

because of the higer w/c ratio.

Moreover the lowest strength corresponding to concretes, unvibrated or vibrated for shorter times, is 500$\pm$25 Kg/cm^2 for rheoplastic concrete, 200$\pm$25 Kg/cm^2 for fluid concrete, I50$\pm$25 Kg/cm^2 for plastic concrete and only I00$\pm$25 Kg/cm^2 for stiff concrete.

Finally, the average compressive strengths are 679, 327, 403 and 405 Kg/cm^2 for rheoplastic, flüid, plastic and stiff concrete respectively, while the standard deviations are 44,40,98 and 200 Kg/cm^2 for rheoplastic, fluid, plastic and stiff concrete respectively.

Similar conclusions can be drawn for lightweight concretes (Figure 7).

All these results demonstrate that rheoplastic concretes are very reliable implying that strengths obtained in well compacted laboratory specimens can also be achieved easily in structural elements. In other words, for very flowable concretes containing the above type of admixture, and therefore having a relatively low w/c ratio, the quality, and in particular the strength,is much less dependent on the density of reinforcement and the geometry of element, and on efficiency, care and time of compaction realized on a job-site.

Influence of the Admixture on Steel-Concrete Bond Strength

Table 9 shows steel-concrete bond strength at 7 and 28 days for smooth and twisted bars. The addition of admixture No.2 improves the adhesion between steel and concrete for both ordinary and lightweight mixes. For example, in ordinary weight concrete the addition of the admixture raises the steel-concrete bond strength at 7 days from I2 Kg/cm^2 to 35 Kg/cm^2 for smooth bars and from I50 Kg/cm^2 to 275 Kg/cm^2 for twisted bars. Similar improvements are observed for lightweight concrete; in the presence of the admixture, the steel-concrete bond strength of a lightweight concrete becomes substantially the same as that of an ordinary weight plastic concrete without admixture, althoug the lightweight concrete is much more flowable.

CONCLUSIONS

The test results reported show that, by using admixtures described in this paper based on sulphonated naphthalene-formaldehyde polymer, reliable, high strength concretes can be obtained. The compressive strength of these concretes is substantially the same of a well compacted no-slump concrete with the same low w/c ratio. On the other hand, in the fresh state the concrete is very flowable, cohesive and practically unsegregable.

Because of its high workability and low segregation the strength of this concrete locally placed into formwork is not very dependent on the efficiency, care and time of compaction, or on the density of reinforcement and geometry of elements. It has been proposed to define such a concrete as reliable. Reliability is also due to the remarkable increase of the steel-concrete bond strength caused by the presence of the admixture.

The choice of a superplasticizer admixture requires one to take into account the type of cement and the curing cycle for the steam treatment. Moreover other techonological aspects such as for example the time of transportation must be considered. In the present paper two admixtures with different performances for the workability loss have been examined.

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TABLE I

Characteristics of Cements Used

	Type I	Type III	Type V
CaO	63,60%	62,92%	63,08%
SiO_2	20,80%	2I,43%	22,25%
Al_2O_3	5,5I%	5,3I%	3,7I%
Fe_2O_3	2,99%	2,68%	4,58%
MgO	0,85%	I,63%	2,46%
SO_3	2,95%	3,37%	2,I0%
Na_2O	0,I9%	0,I2%	0,08%
K_2O	0,38%	0,I4%	0,I4%
Insoluble residue	0,I5%	0,22%	0,I0%
Loss on ignition	2,00%	2,22%	I,50%
C_3S	56,9%	44,2%	50,2%
C_2S	I9,3%	28,I%	25,9%
C_3A	9,8%	9,5%	2,I%
C_4AF	9,8%	8,I%	I3,9%
Initial set (h)	3^h 08'	I^h 45'	2^h 20'
Final set (h)	4^h 23'	2^h 40'	4^h 36'
Blaine cm^2/g	3855	5I60	3763

TABLE 2

Ordinary Concretes Prepared with Type V Cement

Nominal cement content (Kg/m³)	Actual cement content (Kg/m³)	Temperature °C	Adm. (N°)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm²) I d Compr.	7 d Flex	7 d Compr	28 d Flex	28 d Compr.	90 d Flex	90 d Compr.	Specific Gravity (Kg/m³)
400	418	20	-	0,43	100	115	52	442	60	637	64	783	2500
	418	70	-	0,43	100	369	53	603	54	700	58	790	2500
	423	20	1	0,33	220	191	56	620	58	840	59	900	2562
	423	70	1	0,33	220	242	52	564	56	729	57	833	2562
	423	20	2	0,29	225	305	62	702	62	827	64	985	2550
	423	70	2	0,29	225	660	62	745	63	940	62	1045	2550
500	485	20	-	0,39	100	115	51	514	49	680	50	823	2512
	485	70	-	0,39	100	406	51	628	51	772	53	915	2512
	503	20	1	0,31	230	197▲	54	597	67	828	69	926	2562
	503	70	1	0,31	230	294	56	555	64	805	65	847	2562
	502	20	2	0,27	220	261	70	715	74	917	79	1071	2537
	502	70	2	0,27	220	680	77	809	77	966	73	1151	2537

(•)= w/c ratio does not incluede the water of admixture.
▲ = at 2 days

TABLE 3

Ordinary concretes Prepared with Type I Cement

Nominal cement content (Kg/m³)	Actual cement content (Kg/m³)	Temperature °C	Adm. (N°)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm²) I d Compr.	7 d Flex	7 d Compr.	28 d Flex	28 d Compr.	90 d Flex	90 d Compr.	Specific Gravity (Kg/m³)
400	411	20	-	0,46	110	175	53	520	55	728	62	827	2462
	411	70	-	0,46	110	375	54	471	52	642	50	745	2462
	415	20	1	0,35	205	51	66	751	67	895	72	1113	2525
	415	70	1	0,35	205	475	63	616	64	806	67	935	2525
	417	20	2	0,32	210	356	68	711	68	875	72	999	2525
	417	70	2	0,32	210	586	59	704	68	835	74	944	2525
500	477	20	-	0,42	105	248	45	581	64	732	60	879	2487
	477	70	-	0,42	105	450	48	549	66	716	61	856	2487
	498	20	1	0,31	210	91	63	783	69	960	71	1180	2537
	498	70	1	0,31	210	570	58	761	72	900	82	1087	2537
	498	20	2	0,31	210	432	64	791	68	973	79	1071	2537
	498	70	2	0,31	210	717	74	813	82	927	79	1083	2537

(•) = w/c ratio does not include the water of admixture.

TABLE 4

Ordinary Concretes Prepared with Type III Cement

Nominal cement content (Kg/m^3)	Actual cement content (Kg/m^3)	Tempe-rature °C	Adm. (N°)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm^2) 1 d	7 d		28 d		90 d		Specific gravity (Kg/m^3)
						Compr.	Flex	Compr.	Flex	Compr.	Flex	Compr.	
400	426	20	-	0,47	100	231	50	560	47	752	53	767	2475
	426	70	-	0,47	100	407	48	483	56	633	60	717	2475
	423	20	1	0,31	210	414	61	897	62	1024	78	1255	2575
	423	70	1	0,31	210	762	60	830	60	945	64	1167	2575
	413	20	2	0,33	220	444	58	766	63	982	67	1052	2525
	413	70	2	0,33	220	673	53	789	60	895	66	1030	2525
500	469	20	-	0,43	110	292	47	702	49	840	-	879	2450
	469	70	-	0,43	110	453	58	591	56	682	-	825	2450
	498	20	1	0,31	230	400	62	905	75	1037	-	1320	2537
	498	70	1	0,31	230	755	72	870	89	941	-	1185	2537
	498	20	2	0,26	220	528	68	844	70	1005	74	1145	2512
	498	70	2	0,26	220	722	64	894	65	960	72	1117	2512

(•) = ratio does not include the water of admixture

TABLE 5

Lightweight Concretes (1800 Kg/m^3) Prepared with Type I Cement

Nominal cement content (Kg/m^3)	Actual cement content (Kg/m^3)	Tempe-rature °C	Adm. (N°)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm^2) 1 d	7 d		28 d		90 d		Specific Gravity (Kg/m^3)
						Compr.	Flex	Compr.	Flex.	Compr.	Flex.	Compr.	
400	432	20	-	0,52	80	171	28	450	30	509	-	-	1835
	432	70	-	0,52	80	373	-	450	-	525	-	-	1835
	401	20	2	0,45	210	199	29	482	34	537	-	-	1750
	401	70	2	0,45	210	402	-	475	-	520	-	-	1750
500	489	20	-	0,48	110	209	24	530	27	577	-	-	1750
	489	70	-	0,48	110	419	-	529	-	553	-	-	1750
	501	20	2	0,38	220	249	30	605	37	620	-	-	1820
	501	70	2	0,38	220	452	-	557	-	580	-	-	1820

(•) = w/c ratio does not include the water of admixture

TABLE 6

Lightweight Concretes (1800 Kg/m^3) Prepared with Type III Cement

Nominal cement content (Kg/m^3)	Actual cement content (Kg/m^3)	Temperature °C	Adm. (N.)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm^2) 1 d Compr.	7 d Flex.	7 d Compr.	28 d Flex.	28 d Compr.	90 d Flex.	90 d Compr.	Specific Gravity (Kg/m^3)
400	410	20	-	0,64	100	175	25	480	30	590	-	-	1780
	410	70	-	0,64	100	343	-	451	-	552	-	-	1780
	437	20	1	0,51	210	245	32	591	33	715	-	-	1830
	437	70	1	0,51	210	487	-	556	-	672	-	-	1830
	416	20	2	0,53	200	252	33	588	39	667	-	-	1850
	416	70	2	0,53	200	476	-	541	-	658	-	-	1850
500	524	20	-	0,50	100	260	16	539	19	666	-	-	1840
	524	70	-	0,50	100	473	-	571	-	630	-	-	1840
	514	20	1	0,40	215	374	42	667	43	758	-	-	1895
	514	70	1	0,40	215	588	-	662	-	712	-	-	1895
	514	20	2	0,41	210	394	36	658	41	768	-	-	1890
	514	70	2	0,41	210	545	-	660	-	684	-	-	1890

(•) = w/c ratio does not include the water of admixture.

TABLE 7

Lightweight Concretes (1600 Kg/m^3) Prepared with Type III Cement

Nominal cement content (Kg/m^3)	Actual cement content (Kg/m^3)	Temperature °C	Adm. (N.)	w/c ratio (•)	Slump (mm)	Strength (Kg/cm^2) 1 d Compr.	7 d Flex.	7 d Compr.	28 d Flex.	28 d Compr.	90 d Flex.	90 d Compr.	Specific Gravity (Kg/m^3)
400	386	20	-	0,66	110	105	12	208	14	293	-	-	1540
	386	70	-	0,66	110	198	-	190	-	216	-	-	1540
	394	20	1	0,55	210	140	28	283	27	305	-	-	1605
	394	70	1	0,55	210	231	-	272	-	311	-	-	1605
	397	20	2	0,56	200	145	26	260	31	335	-	-	1640
	397	70	2	0,56	200	241	-	287	-	292	-	-	1640
500	494	20	-	0,50	100	167	16	295	13	358	-	-	1590
	494	70	-	0,50	100	248	-	259	-	326	-	-	1590
	496	20	1	0,41	225	226	27	333	27	367	-	-	1670
	496	70	1	0,41	225	328	-	352	-	354	-	-	1670
	497	20	2	0,42	200	218	26	337	27	405	-	-	1675
	497	70	2	0,42	200	323	-	359	-	407	-	-	1675

(•) = w/c ratio does not include the water of admixture

TABLE 8

Characteristics of Concretes Subjected to Different Vibration

Cement Content (Kg/m³)*	w/c ratio	Adm.	Slump (mm)	Type of aggregate	Specific Gravity (Kg/m³)**
418	0,33	no	10	normal	2525
411	0,46	no	100	normal	2460
415	0,56	no	220	normal	2485
417	0,35	yes	220	normal	2520
405	0,48	no	10	lightweight	1780
432	0,52	no	80	lightweight	1835
415	0,65	no	220	lightweight	1730
401	0,48	yes	210	lightweight	1750

* Type I Cement was used

** Data given for fully compacted concrete

TABLE 9

Steel-Concrete Bond Strength

Caracteristics of concrete	Workability Slump (mm)	BOND STRENGTH (Kg/cm²) 7 d Smooth Bar	7 d Twisted Bar	28 d Smooth Bar	28 d Twisted Bar
400 Kg/m³ of cement N.1 without admixture	100	12	150	13	152
400 Kg/m³ of cement N.1 with admixture	220	35	275	40	285
500 Kg/m³ of cement N.2 without admixture, lightweight concrete (1800 Kg/m³)	100	4	66	6	92
500 Kg/m³ of cement N.2 with admixture, lightweight concrete (1800 Kg/m³)	210	9	142	21	210

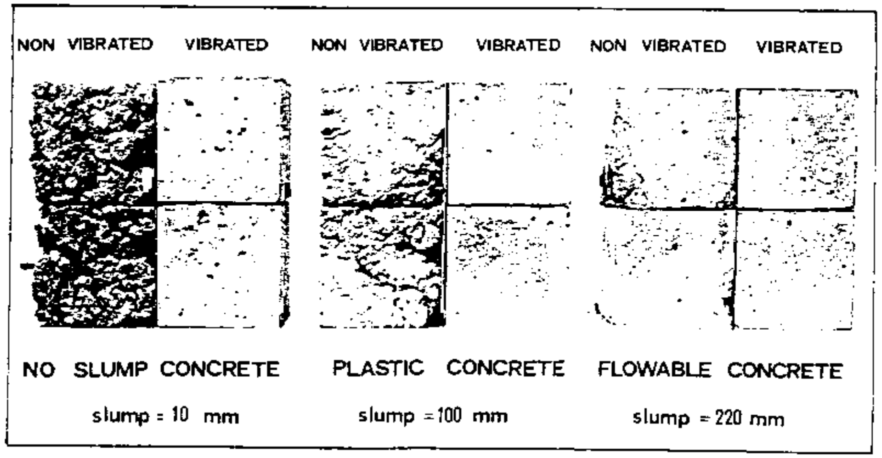

Fig. 1--Concrete aspect as a function of workability and vibration

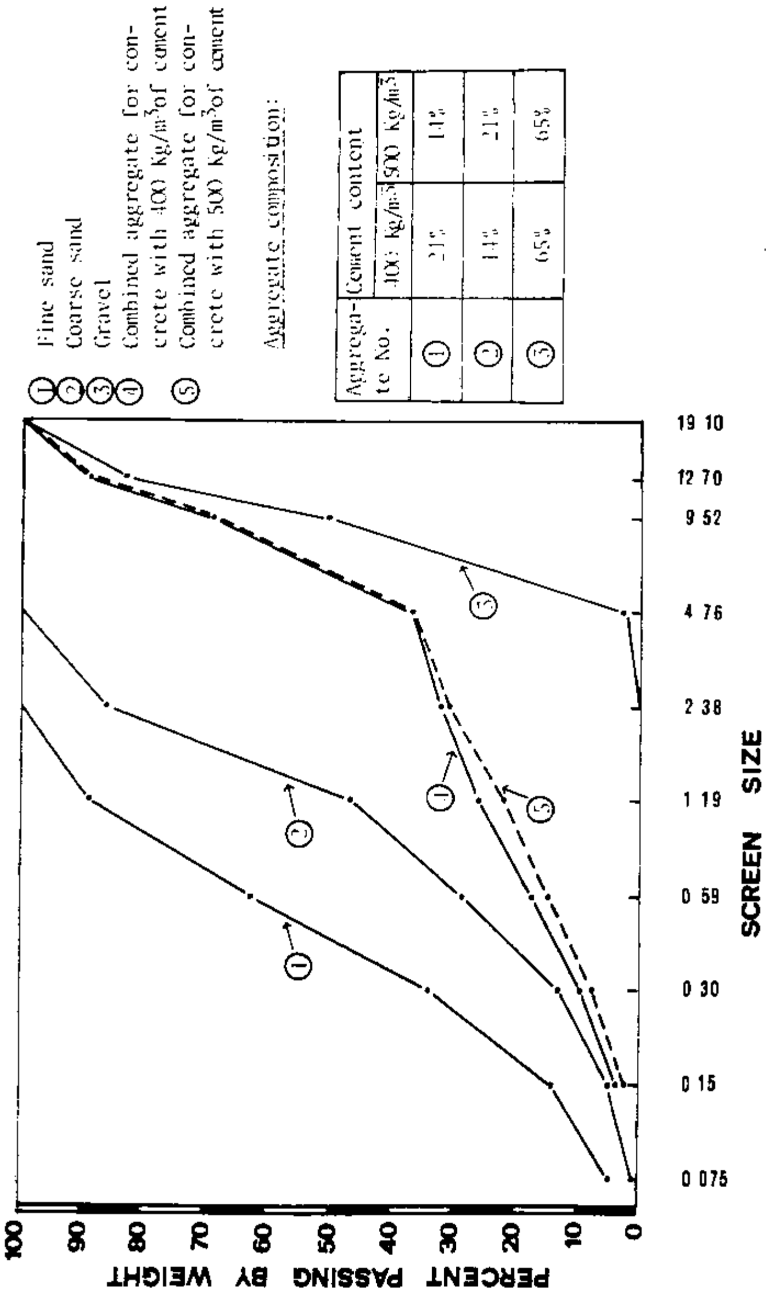

Fig. 2--Particle size distribution for normal concretes (sp.gr. = approximately 2500 Kg/m³)

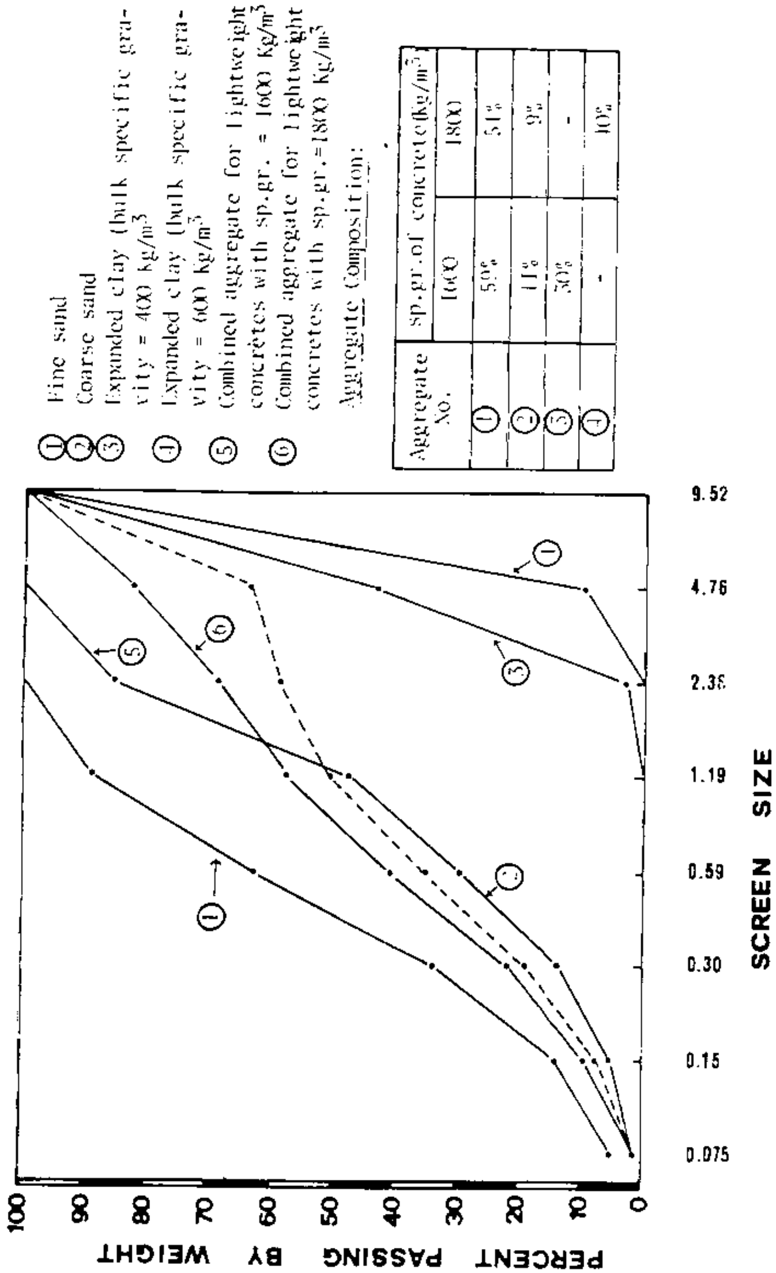

Fig. 3--Particle size distribution for lightweight concretes (sp.gr. = 1600-1800 Kg/m³)

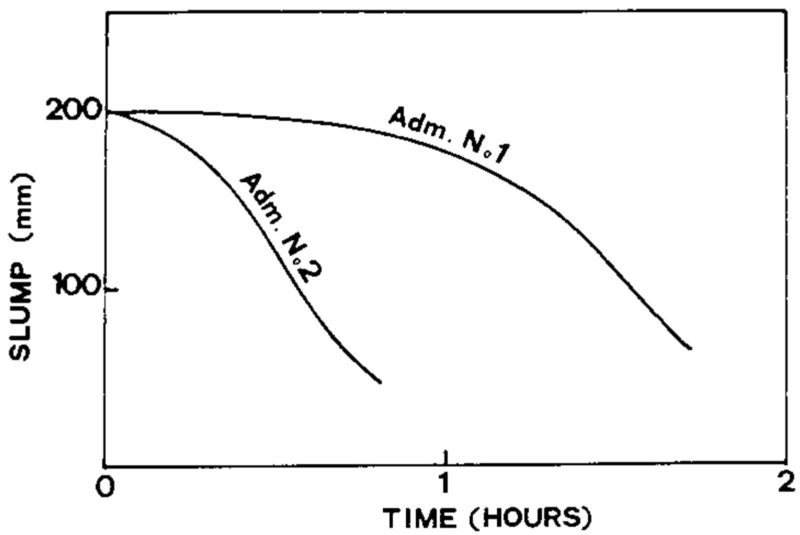

Fig. 4--Workability loss as a function of time

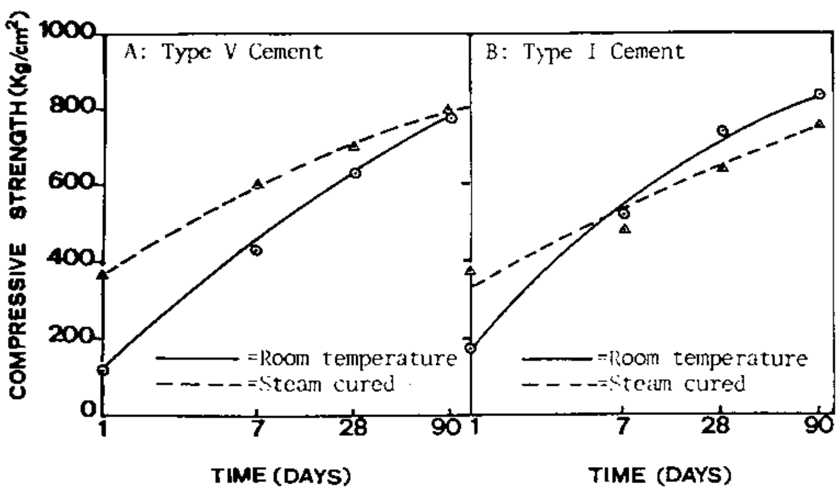

Fig. 5--Influence of type of cement on the compressive strength of concrete cured at room temperature and steam cured

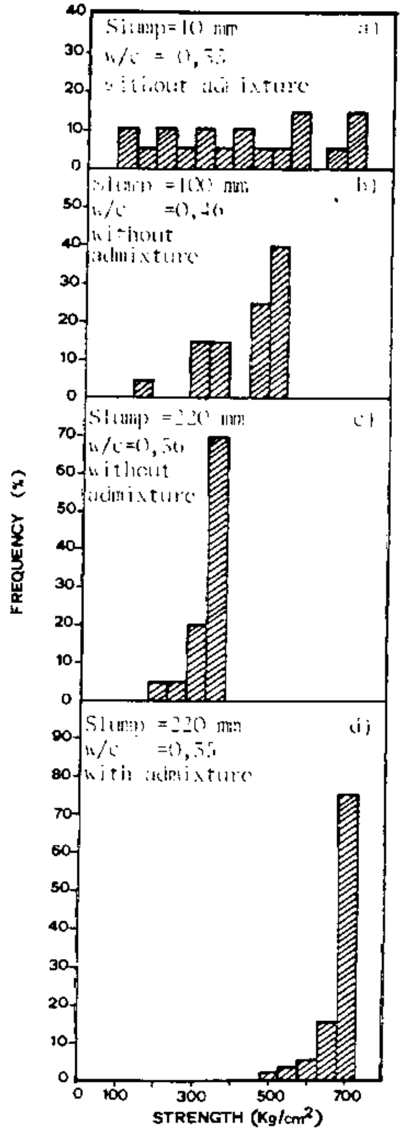

Fig. 6--Frequency as a function of strength for normal concrete with different workability and vibrated for different time (0-30 sec)

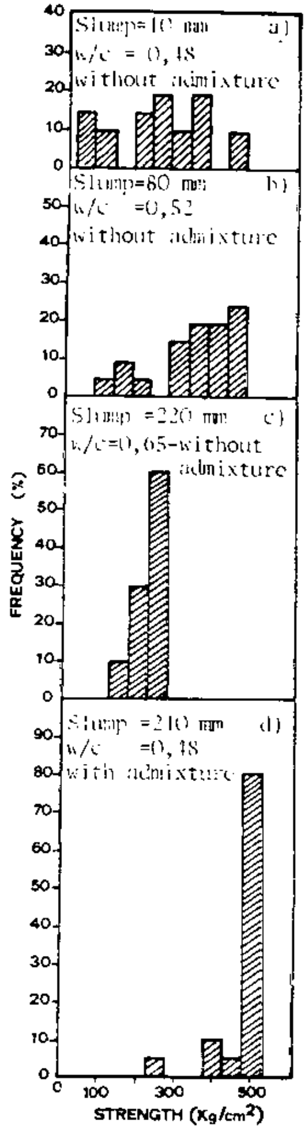

Fig. 7--Frequency as a function of strength for lightweight concretes with different workability and vibrated for different time (0-30 sec)